

Firm Technology Upgrading Through Emerging Work

Enghin Atalay (Federal Reserve Bank of Philadelphia)¹
Sarada (University of Wisconsin School of Business)

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¹Research results and conclusions expressed are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Philadelphia, the Federal Reserve System, or the Federal Reserve Board of Governors.

Background

- ▶ Key question in economic growth: Which firms adopt new technologies?
 - ▶ Important for understanding firm-level productivity, industry dynamics, aggregate growth.
 - ▶ Difficult to construct comprehensive, comparable firm-level measures
- ▶ Our hypothesis: Firms' job ads not only lead to employer-employee matches, but also signal their adoption of new technologies

Research Questions

1. How do hiring decisions reflect new technology adoption?
2. What are the sources of new technology adoption: entry/exit vs. incumbent tech updating?

This paper

How do hiring decisions reflect new technology adoption?

- ▶ Explore firms' job vintages, in their vacancy postings, over 1940-2000.
 - ▶ 5 million ads from the *New York Times*, *Boston Globe*, and *Wall Street Journal*
 - ▶ Vintage: When in the sample did each job title tend to appear
 - ▶ For example: "Comptometer Operator" tended to appear earlier on than "Figure Clerk", likely represents older technology.
- ▶ Job title vintages provide a new measure of firms' technology adoption
- ▶ There is substantial heterogeneity in the mix of job title vintages across firms.
 - ▶ Among publicly traded firms, newer job vintages correlated with R&D intensity, future sales growth.
 - ▶ Those posting for newer job vintages entered more recently, are more likely to survive

This paper

What are the sources of new technology adoption: entry/exit vs. incumbent technology updating?

- ▶ Estimate an industry equilibrium model with heterogeneous firms, with both sources of updating
 - ▶ Match correlations among firms' age, their distance to the frontier, and their marginal costs
- ▶ Each margin accounts for approximately half of industry tech. updating

Contribution

Measurement of innovation, technology adoption, or new work

- ▶ ... looks at adoption incentives within individual firms or industries (Griliches 1957, Henderson 1995, Arora and Gamberdella 1994)
- ▶ ... looks at aggregate technology adoption rates (Comin, Hobijn, and Rovito, 2008, Comin and Hobijn, 2010)
- ▶ ... or focuses on new work (Lin, 2011; Autor. Salomons, Seegmiller, 2021).

Our contribution: Present measurement of firm technology adoption across multiple industries, over a long time-period

Models of firm technology updating

- ▶ Costly R&D → product innovation (Klette and Kortum, 2004)
- ▶ Investment in vintage capital (Jovanovic and Yutsenko, 2012, Jovanovich and Rousseau, 2014)

Our contribution: New question

Outline

1. Data set and job vintage measures
2. Job title vintage is an indicator of innovative, high-skilled activity.
3. Job title is predictive of future firm performance
4. To what extent does vintage updating occur via entry and exit?

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Unprocessed page of ads from the 1960 New York Times

buyer

SENIOR

Leading Mid-Manhattan engineering company seeks Senior Buyer with minimum 3 years' purchasing experience in research and development field handling electronic components. Capable of reading blueprints.

SALARY TO \$7,000
Send Complete Resume to
ENR JOB TIMES

ACCOUNTANTS

Due to staff promotions, openings have developed in our Cost and Auditing Divisions of parent company. We are looking for men with 2 to 3 years of experience with a large public accounting firm. Good opportunities for growth. Excellent salary.

Send resume
to Personnel Department
Johnson & Johnson
New Brunswick, New Jersey

MECHANICAL ENGINEER

Seeking to position in aircraft engine, gas turbine and mechanical systems. 4 to 10 years exp. in design, testing, etc. in public utility, etc. Good salary. Send resume to: **United Aircraft Corp.**

METHODS ENGR

Large New England steel mill seeking plant manufacturing process and manufacturing methods engineer with progressive thinking and with experience in design of machine and layout. Excellent salary and growth opportunities.

RESUMES PRINTED

\$2.50 per set in color. Includes cover and 100 copies. Add 50¢ for each set. **DAY** City, N.Y. 10017. **DAY** City, N.Y. 10017. **DAY** City, N.Y. 10017. **DAY** City, N.Y. 10017.

Major Oil Company

Needs A

TRANSPORTATION ADVERTISING SUPERVISOR

With ...

Specific experience in creating advertising for truck-bus, aviation, marine or construction industries.

Understanding of advertising media, creative functions, agency relationships and organization procedures.

College degree with a background in advertising and sales promotion.

Versatility, initiative and a good personality.

Some knowledge of the petroleum requirements and their application to the transportation industry desirable.

OPPORTUNITY FOR ADVANCEMENT

Interview by letter only, submitting detailed resume of education, experience and salary requirements.

Socony Mobil Oil Company, Inc.
190 East 42 Street, N. Y. (at Lexington)

PERFORMANCE ENGINEERS

Aircraft & Space Vehicle
Systems Evaluation

Diversified projects include the evaluation of advanced propulsion concepts for subsonic, hypersonic and space vehicles in terms of system performance capabilities. Sustained program with excellent support from management—computer services from the nation's largest industrial computing facility—contributing efforts by experienced component specialists.

Minimum qualifications for these positions include a M.S. degree in aeronautical engineering plus 3 years' related experience.

Please write to
Mr. W. M. Walsh.

**RESEARCH LABORATORIES
UNITED AIRCRAFT CORPORATION**
400 Main Street • East Hartford, Conn.

TIMES ACCOUNTANTS Due to staff promotions, openings have developed in our Cost and Auditing Divisions of parent company. We are looking for men with 2 to 5 years of experience with a large public accounting firm. Good opportunities for growth. Excellent salary. Send resume to Personnel Department Johnson & Johnson. New Brunswick, New Jersey **MECHANICAL ENGINEER** Specialist In selection of pumps, compressors & general mechanical equipment. 4 to 6 yrs exp. with pump mfr.. engineering contractor. or public utility, etc. o . . Good starting salary o . Excellent conditions ark Area BOX 219, Large New England sheet metal fabricating plant manufacturing extensive line of Institutional furniture has good opportunity for Methods Engineer with comprehensive knowledge of operations and layout. Include resume and salary requirements. X7548 **TIMES** u RESUMES PRINTED \$3.50 1st5Goiviesfnciudiw type. Si ch - add. 100 copies. I Add 35c to mail ord (P1AE) Open DiSh td6 P.M. **DAY** The PRESS 42Wust 33 SI4E6Y.C. OX 5.3658 Major Oil Company Needs A **TRANSPORTATION ADVERTISING SUPERVISOR** With Specific experience in creating advertising for: truck-bus, aviation, marine or construction industries. Understanding of advertising media, creative functions, agency relationships and organization procedures. College degree with a background in advertising and sales promotion. Versatility, initiative and a good personality. Some knowledge of the, petroleum requirements and their application to the transportation industries desirable. **OPPORTUNITY FOR ADVANCEMENT** ? by letter only, submitting detailed resume of education, experience and salary requirements. Socony Mobil Oil Company, Inc. 150 East 42 Street, N. Y. (at Lexington) **PERFORMANCE ENGINEERS** Aircraft & Space Vehicle Systems Evaluation Diversified projects include the evaluation of advanced propulsion concepts for subsonic, hypersonic and space vehicles in terms of system performance capabilities. Sustained program with excellent support from services from the largest industrial computing efforts by experienced component specialists. Minimum qualifications for these positions include a M.S. degree in aeronautical engineering plus 3 related experience. **UNITED AIRCRAFT CORPORATION** 400 Main Street . East Hartford, Conn. Please write to Mr. W. M. Walsh **RESEARCH LABORATORIES**

Data Set

- ▶ In past work (Atalay, Phongtheingtham, Sotelo, Tannenbaum, 2020) we processed ads from the *New York Times*, *Boston Globe*, and *Wall Street Journal*
 - ▶ For each ad we identify the job title, educational requirements, sets of tasks workers perform, technologies they use.
- ▶ New, relative to earlier work, we identify the firm name and posted salary.
- ▶ For publicly-traded firms, we link firm names to Compustat
- ▶ For all firms we hand collect entry and exit dates.
- ▶ Link firm names to patent grantees.

Processed page of ads from the 1960 New York Times

TIMES ACCOUNTANT [[132011]] Due to staff promotions, openings have developed in our Cost and Auditing Divisions of parent company. We are looking for men with 2 to 5 years of experience with a large public accounting firm. Good opportunities for growth. Excellent salary. Send resume to Personnel Department Johnson & Johnson, New Brunswick, New Jersey

MECHANICAL ENGINEER [[172141]] Specialist In selection of pumps, compressors & general mechanical equipment. 4 to 6 yrs exp. with pump mfr., engineering contractor, or public utility, etc. . . . Good starting salary . . . Excellent conditions Ark Area BOX 219, Large New England sheet metal fabricating plant manufacturing extensive line of Institutional furniture has good opportunity for Methods Engineer with comprehensive knowledge of operations and layout. Include resume and salary requirements. X7548 TIMES u RESUMES PRINTED \$3.50 1st 50 copies free. Si ch - add. 100 copies. 1 Add 35c to mail order (P1AE) Open DiSh td6 P.M. DAY The PRESS 42 Wust 33 SI4E6Y.C. OX 5.3658 Major Oil Company Needs A

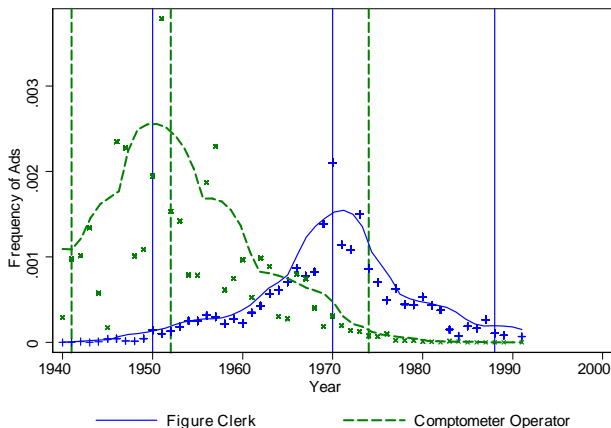
TRANSPORTATION ADVERTISING SUPERVISOR [[531031]] With Specific experience in creating advertising for: truck-bus, aviation, marine or construction industries. Understanding of advertising media, creative functions, agency relationships and organization procedures. College degree with a background in advertising and sales promotion. Versatility, initiative and a good personality. Some knowledge of the, petroleum requirements and their application to the transportation industries desirable. OPPORTUNITY FOR ADVANCEMENT ? by letter only, submitting detailed resume of education, experience and salary requirements. Socony Mobil Oil Company, Inc. 150 East 42 Street, N. Y. (at Lexington)

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PERFORMANCE ENGINEER [[173029]] Aircraft & Space Vehicle Systems Evaluation Diversified projects include the evaluation of advanced propulsion concepts for subsonic, hypersonic and space vehicles in terms of system performance capabilities. Sustained program with excellent support from services from the largest industrial computing efforts by experienced component specialists. Minimum qualifications for these positions include a M.S. degree in aeronautical engineering plus 3 related experience.

UNITED AIRCRAFT CORPORATION 400 Main Street. East Hartford, Conn. Please write to Mr. W. M. Walsh RESEARCH LABORATORIES

Defining Job Title Vintages



- ▶ Year of Emergence_{*j*}: 1st percentile of years in which *j* appeared
- ▶ Year of Disappearance_{*j*}: 99th percentile of years in which *j* appeared

Summary Statistics

- ▶ 5.2 million job ads for which we can identify the job title
 - ▶ 9 thousand unique job titles
 - ▶ 190 thousand ads for which identify the posted salary
 - ▶ 252 thousand ads for which identify the posting firm
 - ▶ Among these, 82 thousand ads correspond firms that are publicly traded
- ▶ How much dispersion is job title vintages?
 - ▶ For each year of ads, compute average job title vintage.
Relative to this average
 - ▶ Std. Dev.(Yr. of Emergence_j) \approx 6.7 years;
 - ▶ Std. Dev.(Yr. of Disappearance_j) \approx 6.5 years

Emerging Job Titles

| Yr. of Emergence; $\in 1950-1959$ | | Yr. of Emergence; $\in 1960-1969$ | |
|-----------------------------------|--------------------------|-----------------------------------|--------------------|
| 1 | administrative assistant | 1 | programmer analyst |
| 2 | programmer | 2 | computer operator |
| 3 | legal secretary | 3 | marketing manager |
| 4 | management trainee | 4 | product manager |
| Yr. of Emergence; $\in 1970-1979$ | | Yr. of Emergence; $\in 1980-1989$ | |
| 1 | paralegal | 1 | telemarketer |
| 2 | typesetter | 2 | hiv aid |
| 3 | word processing | 3 | line cook |
| 4 | word processor | 4 | broker trainee |
| Yr. of Emergence; $\in 1990-2000$ | | | |
| 1 | power builder | | |
| 2 | client server | | |
| 3 | web developer | | |
| 4 | web master | | |

Disappearing Job Titles

| Yr. of Disappearance; ∈1940-49 | Yr. of Disappearance; ∈1950-1959 |
|----------------------------------|------------------------------------|
| 1 lens grinder | 1 soda dispenser |
| 2 radio instructor | 2 millinery designer |
| 3 christmas card salesperson | 3 buyer wants contd |
| 4 fluorescent salesperson | 4 long distance telephone operator |
| Yr. of Disappearance; ∈1960-1969 | Yr. of Disappearance; ∈1970-1979 |
| 1 house worker | 1 stenographer |
| 2 bookkeeper stenographer | 2 stenographer typist |
| 3 dental mechanic | 3 secretary stenographer |
| 4 alteration hand | 4 office boy |
| Yr. of Disappearance; ∈1980-1989 | |
| 1 clerk typist | |
| 2 draftsman | |
| 3 statistical typist | |
| 4 biller typist | |

Outline

1. Data set and job vintage measures
2. **Job title vintage is an indicator of innovative, high-skilled activity.**
3. Job title vintage is predictive of future firm performance
4. To what extent does vintage updating occur via entry and exit?

Relating job vintages and other ad characteristics

$$y_{at} = \beta_t + \beta_o + \beta_1 \cdot v_{j(a)}^{0.01} + \beta_2 \cdot v_{j(a)}^{0.99} + \epsilon_a \quad (1)$$

- ▶ y_a : Characteristics of ad a :
 - ▶ posted salary
 - ▶ mentions of an undergraduate or graduate degree requirement
 - ▶ mentions of an ICT (EDP, Unix, Lotus 123, FORTRAN, 44 others)
- ▶ $v_{j(a)}^{0.01}, v_{j(a)}^{0.99}$: Year of Emergence and Disappearance of the job title.
- ▶ β_t, β_o : year and occupation fixed effects

Newer work is associated with human capital and technology usage

| Dep. Variable | Log Salary | Undergrad Degree | Graduate Degree | Technology |
|---------------------------|--------------------|--------------------|---------------------|------------------|
| Year of Emergence j | 0.0015 (0.0002) | 0.0063 (0.0003) | -0.0075 (0.0005) | 0.040 (0.001) |
| Year of Disappearance j | 0.0004 (0.0002) | 0.0033 (0.0003) | 0.0100 (0.0004) | 0.049 (0.001) |
| Sample | | —— 1940-2000 —— | | 1970-2000 |

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| Sample | —— 1940-2000 —— | | —— 1970-2000 —— | |

A decade increase in job vintage is associated with... :

- ▶ a 1.9 log point ($\approx (0.0015 + 0.0004) \cdot 10$) increase in salaries;
- ▶ a 0.02 standard deviation increase in the frequency of undergraduate degree mentions;
- ▶ a 0.11 standard deviation increase in the frequency of technology mentions.

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Job Vintage and Firm Characteristics

Compute the average job vintage of the ads that firm i places in year t :

$$\text{Year of Emergence}_{it} = \frac{1}{|A_{it}|} \times \sum_{a \in A_{it}} \text{Year of Emergence}_j$$

$$\text{Year of Disappearance}_{it} = \frac{1}{|A_{it}|} \times \sum_{a \in A_{it}} \text{Year of Disappearance}_j$$

$$\text{Median Vintage}_{it} = \frac{1}{|A_{it}|} \times \sum_{a \in A_{it}} v_{j(a)}^{0.50}$$

- A_{it} set of ads posted by firm i in year t

Empirical Setup

$$\begin{aligned}x_{it} = & \beta_t + \beta_1 \text{Year of Emergence}_{it} + \beta_2 \text{Median Vintage}_{it} \\& + \beta_3 \text{Year of Disappearance}_{it} + \beta_n \\& + \beta_4 \log k_{it} + \beta_5 \log l_{it} + \beta_6 \log_t y_{it} + \sum_o \beta_o S_{ito} + \epsilon_{it}\end{aligned}$$

- ▶ x_{it} : Firm-level characteristic
- ▶ β_t year fixed effects, β_n industry fixed effects
- ▶ k_{it} , l_{it} , y_{it} : capital, labor, revenues,
- ▶ S_{ito} : share of firm i 's ads in (2-digit) occupation o .

Newer work is not correlated with contemporaneous productivity

| Dep. Variable | $\log(y_{it}/l_{it})$ | | |
|----------------------------------|-----------------------|----|---------------------|
| Year of Emergence $_{it}$ | -0.0002 (0.0020) | | |
| Median Vintage $_{it}$ | 0.0011 (0.0017) | | -0.0021 (0.0020) |
| Year of Disappearance $_{it}$ | 0.0123 (0.0043) | | |
| Include occup. shares? | No | No | Yes |

- No significant difference between contemporaneous productivity and job vintages

Newer work is not correlated with contemporaneous productivity... but is associated with R&D intensity

| Dep. Variable | $\log(y_{it}/l_{it})$ | | $\log(R\&D_{it}/y_{it})$ | | |
|----------------------------------|-----------------------|---------------------|--------------------------|------------------|------------------|
| Year of Emergence $_{it}$ | | -0.0002 (0.0020) | | 0.033 (0.007) | |
| Median Vintage $_{it}$ | 0.0011 (0.0017) | | 0.030 (0.006) | | 0.031 (0.006) |
| Year of Disappearance $_{it}$ | | 0.0123 (0.0043) | | 0.004 (0.011) | |
| Include occup. shares? | No | No | No | No | Yes |

- ▶ A decade difference in job vintage is associated with a 30 log point difference in R&D intensity

Newer work is also predictive of future growth

| Dep. Variable | $\log(y_{i,t+5}/y_{it})$ | | | $\log(y_{i,t+10}/y_{it})$ | | |
|----------------------------------|--------------------------|---------|---------|---------------------------|---------|---------|
| Avg. Median | 0.010 | 0.009 | 0.008 | 0.016 | 0.014 | 0.013 |
| Year _{it} | (0.002) | (0.002) | (0.002) | (0.003) | (0.003) | (0.003) |
| $\log(\text{patents}_{i,t} + 1)$ | | -0.012 | -0.013 | | -0.017 | -0.020 |
| | | (0.007) | (0.008) | | (0.010) | (0.011) |
| $\log(R\&D_{it}/y_{it})$ | | 0.007 | 0.007 | | 0.010 | 0.011 |
| | | (0.002) | (0.002) | | (0.003) | (0.003) |
| Include occup. shares? | No | No | Yes | No | No | Yes |

- ▶ A decade difference in job vintage is associated with **10** log points faster growth over 5 years, **16** log points over 10 years

New work is associated with young firms, firms that survive longer

| Dep. Variable | | Entry Year | | | Exit Year | |
|-------------------------------|------------------|------------------|------------------|------------------|-------------------|-------------------|
| Year of Emergence $_{it}$ | | 0.521 (0.153) | | | 0.279 (0.183) | |
| Median Vintage $_{it}$ | 0.694 (0.124) | | 0.621 (0.112) | 0.178 (0.109) | | -0.027 (0.125) |
| Year of Disappearance $_{it}$ | | 0.401 (0.179) | | | -0.068 (0.143) | |
| Include occup. shares? | No | No | Yes | No | No | Yes |

- Similar results (stronger for the exit margin, less so for the entry margin) when considering entry/exit from publicly traded status.

Summary so far

New work:

- ▶ is correlated with other innovative activities,
- ▶ predictive of survival and future growth,
- ▶ occurs in young firms
 - ▶ Contrary to patenting and having high R&D intensity: occurs in old firms

Other exercises

- ▶ Among all firms, new work is associated with being publicly traded, patenting more frequently, having more highly cited patents.
- ▶ Among privately held firms, firms posting ads for new work are more likely to go public in the future

Outline

1. Data set and job vintage measures
2. Job title vintage is an indicator of innovative, high-skilled activity.
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4. **To what extent does vintage updating occur via entry and exit?**

Model: Environment

- ▶ Use t to refer to time
- ▶ **New assumption:** Firms with vintage $(v) \leq t$ exit the industry
- ▶ Heterogeneous firms differ according to their vintage (v) & marginal cost shifter (z)
 - ▶ Potential entrants: Enter after paying sunk cost to draw v and z ; $v \in [t, t + 1]$

Model: Environment

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- ▶ Main trade-offs:

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 - ▶ Potential Entrants: Sunk cost = Expected value of profits over the lifetime of the firm.

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 - ▶ Incumbents: Earn variable profits (increasing in z), decide whether to pay to (probabilistically) update their vintage to the frontier $(t + 1)$
- ▶ Main trade-offs:
 - ▶ Potential Entrants: Sunk cost = Expected value of profits over the lifetime of the firm.
 - ▶ Incumbents: MC of vintage upgrading = Expected increase in firm value of moving from current to frontier vintage

Model: Estimation and Main Result

- ▶ How large is marginal cost of incumbent upgrading to sunk entry cost?
 - ▶ Can be identified from corr. between age and job title vintage
 - ▶ If marginal cost of updating is high (or sunk cost is low) \rightarrow incumbents update their vintage infrequently \rightarrow firms' ages and distance to the frontier are highly correlated
- ▶ Other parameters
 - ▶ Heterogeneity in $z \iff$ heterogeneity in firm revenues
 - ▶ 1 model period = ? years \iff Dispersion in firm job title vintage
- ▶ Estimate these parameters via simulated method of moments:
 - ▶ dispersions of revenues, ages, job title vintages
 - ▶ correlations among revenues, ages, job title vintages
- ▶ Estimated model: 55 percent of updating occurs through entry margin

Conclusion

This paper provides a new measure of adoption to new technologies

Our measure correlates with innovativeness and firm success

- ▶ Public firms which place ads for new work
 - ▶ are more R&D intensive
 - ▶ have faster future sales growth
- ▶ Among all firms, new work occurs in younger firms, firms likely to survive in the future.

We estimate a model of vintage updating through updating by incumbents or through entry

- ▶ Slightly greater than half of updating occurs through entry and exit

Model: Overview

- ▶ Goal: Decompose sources of new vintage job titles.
- ▶ Summary: Firms enter with new vintage technologies, can upgrade at a cost
 - ▶ Benefit of updating depends on competitive environment, marginal cost of producing
- ▶ Consistent with documented patterns
 - ▶ Little correlation between productivity and vintage
 - ▶ More recent entrants have newer vintage technologies
 - ▶ Firms with older vintage job titles are more likely to exit

Model: Consumers

Time $t \geq 0$

Consumers have CES preferences over the output of the active firms (indexed by j)

$$Y_t = \left[\int_{j: v(j) \in [t, t+1]} y_t(j)^{(\eta-1)/\eta} dj \right]^{\eta/(\eta-1)}$$

- ▶ Only willing to purchase from firms with vintages between t and $t + 1$.
- ▶ t : "obsolete vintage"
- ▶ $t + 1$: "frontier vintage"

Model: Firms

Monopolistic competition among heterogeneous firms:

- ▶ z : inverse marginal cost of production (permanent)
 - ▶ revenues, y , proportional to $z^{\eta-1}$
- ▶ v : vintage of the firm's technology (subject to change)
 - ▶ firms entering at time τ enter with $v \in [\tau, \tau + 1]$
 - ▶ endogenously exit when their vintage is obsolete: $v < t$;
exogenous exit (at rate δ)
 - ▶ incur $\frac{\kappa}{2}\lambda^2$ costs to update vintage (probabilistically) with rate λ .

Flow profits when in the industry

$$\alpha z^{\eta-1} - \frac{\kappa}{2}\lambda^2$$

- ▶ α is a constant
 - ▶ independent of z and v
 - ▶ pinned down by free entry condition (next slide)

Model: Free Entry and Stationary Equilibrium

- ▶ Let $V(k, z) \equiv$ "value of having a vintage k units behind frontier" and productivity z .
- ▶ Free entry condition: firms pay sunk cost f to draw z and initial k

$$f = \int_0^\infty \left[\int_0^1 V(k, z) h(k) dk \right] g(z) dz$$

- ▶ $h(k)$: distribution of entrants' distance to frontier:
 $h(k) = \beta \cdot (1 - k)^{\beta-1}$ for $\beta \geq 1$ and $k \in [0, 1]$
 - ▶ $\beta \rightarrow 1$: uniform between $k = 0$ and 1
 - ▶ $\beta \rightarrow \infty$: all mass at $k = 0$
 - ▶ $\mathbb{E}[k] = (1 + \beta)^{-1}$
- ▶ $g(z)$: distribution of entrants' productivity: Log Normal $(-\frac{1}{2}\sigma^2, \sigma^2)$

Model: Free Entry and Stationary Equilibrium

- ▶ Let $V(k, z) \equiv$ "value of having a vintage k units behind frontier" and productivity z .
- ▶ Free entry condition: firms pay sunk cost f to draw z and initial k

$$f = \int_0^{\infty} \left[\int_0^1 V(k, z) h(k) dk \right] g(z) dz$$

- ▶ Stationary equilibrium: Set of prices, consumption choices, entry decisions:
 - ▶ Consumers' relative demand of each firm's product maximizes utility
 - ▶ Firms choose prices to maximize (static) flow profits
 - ▶ Firms choose innovation rates to maximize V
 - ▶ Distribution of (k, z) is constant over time
 - ▶ Free entry condition is satisfied

Model: Characterization

- ▶ Continuous time Bellman Equation:

$$(r + \delta) \cdot V(k, z) = \max_{\lambda} \alpha \cdot z^{\eta-1} - \frac{\kappa}{2} \lambda^2 + \lambda \cdot [V(0, z) - V(k, z)] + V'(k, z)$$

- ▶ FOC

$$\underbrace{\kappa \cdot \lambda}_{\text{marginal cost}} = \underbrace{V(0, z) - V(k, z)}_{\text{benefit from updating vintage}}$$

- ▶ Right-hand side increasing in z , increasing in $k \Rightarrow$ More innovation by high z firms, firms further behind the frontier.

Model: Characterization

- ▶ Continuous time Bellman Equation:

$$(r + \delta) \cdot V(k, z) = \max_{\alpha} \alpha \cdot z^{\eta-1} - \frac{\kappa}{2} \lambda^2 + \lambda \cdot [V(0, z) - V(k, z)] + V'(k, z)$$

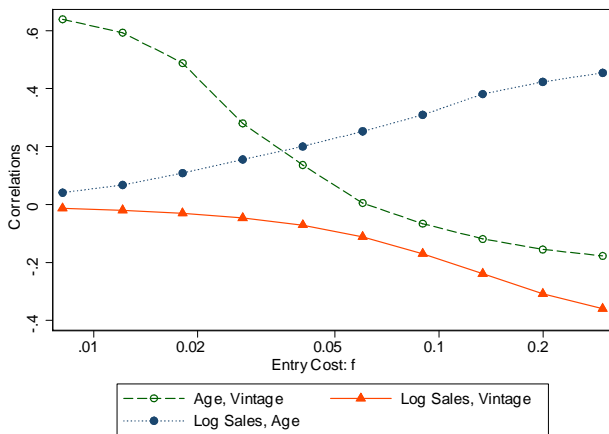
- ▶ FOC

$$\underbrace{\kappa \cdot \lambda}_{\text{marginal cost}} = \underbrace{V(0, z) - V(k, z)}_{\text{benefit from updating vintage}}$$

- ▶ Right-hand side increasing in z , increasing in $k \Rightarrow$ More innovation by high z firms, firms further behind the frontier.
- ▶ Plug FOC into Bellman Equation

$$(r + \delta) V(k, z) = \alpha z^{\eta-1} + \frac{1}{2\kappa} [V(0, z) - V(k, z)]^2 + V'(k, z)$$

Correlations among vintage, age, and productivity help identify $\frac{f}{\kappa}$



- When f is high \Rightarrow incumbents face less competition from entry \Rightarrow more vintage updating (especially by high z firms)

Calibration and Estimation

- ▶ Set σ (elasticity of substitution in preferences) equal to 3; normalize $\kappa = 1$
- ▶ Relate model discount rate so that $(1 + r) = (1 + r^A)^T$
 - ▶ T : number of years per model period; r^A annual discount rate: 0.02
- ▶ σ, β, f, T are estimated via SMM:
 - ▶ Correlations among firm age, distance to the frontier, log sales
 - ▶ Standard deviation of log sales, age, distance to the frontier
 - ▶ Difference in distance to the frontier for entrants relative to all firms

Calibration and Estimation

| Panel A: Moments | Model | Data |
|---|-------|-------|
| St. Dev. ($T \cdot a$) | | 35.45 |
| St. Dev. $\log(c)$ | | 1.66 |
| St. Dev. ($T \cdot k$) | | 3.83 |
| Corr($\log(c)$, $T \cdot a$) | | 0.33 |
| Corr($\log(c)$, $T \cdot k$) | | -0.04 |
| Corr($T \cdot a$, $T \cdot k$) | | 0.07 |
| Incumbents' $T \cdot k$ – Entrants' $T \cdot k$ | | 1.53 |
| Panel B: Parameter Estimates | | |
| f : sunk cost of entry | | |
| β : entrant dist. to frontier | | |
| σ : entrant productivity sd | | |
| T : years per model period | | |

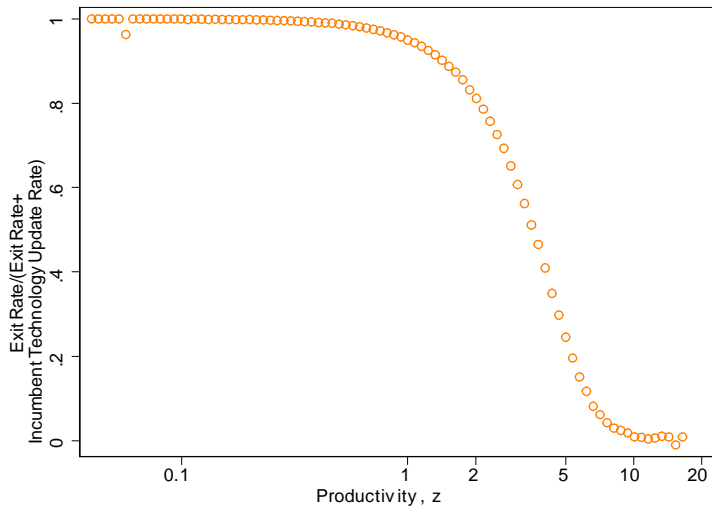
- ▶ k : distance to frontier; c : sales; a : age; T years per model period.

Calibration and Estimation

| Panel A: Moments | Model | Data |
|---|-------|-------|
| St. Dev. ($T \cdot a$) | 34.44 | 35.45 |
| St. Dev. $\log(c)$ | 1.34 | 1.66 |
| St. Dev. ($T \cdot k$) | 3.82 | 3.83 |
| Corr($\log(c)$, $T \cdot a$) | 0.25 | 0.33 |
| Corr($\log(c)$, $T \cdot k$) | -0.11 | -0.04 |
| Corr($T \cdot a$, $T \cdot k$) | 0.01 | 0.07 |
| Incumbents' $T \cdot k$ – Entrants' $T \cdot k$ | 4.12 | 1.53 |
| Panel B: Parameter Estimates | | |
| f : sunk cost of entry | 0.060 | |
| β : entrant dist. to frontier | 2.06 | |
| σ : entrant productivity sd | 0.605 | |
| T : years per model period | 15.10 | |

- ▶ k : distance to frontier; c : sales; a : age; T years per model period.

Sources of Vintage updating



Sources of Vintage updating: Summing Up Across Firms

- ▶ Integrate share of updating, summing over the (endogenous) productivity distribution:
 - ▶ Approximately 91 percent of vintage updating occurs through entry and exit
 - ▶ Approximately 56 percent when weighting by firm sales.

Conclusion

This paper provides a new measure of adoption to new technologies

Our measure correlates with innovativeness and firm success

- ▶ Public firms which place ads for new work
 - ▶ are more R&D intensive
 - ▶ have faster future sales growth
- ▶ Among all firms, new work occurs in younger firms, firms likely to survive in the future.

We estimate a model of vintage updating through updating by incumbents or through entry

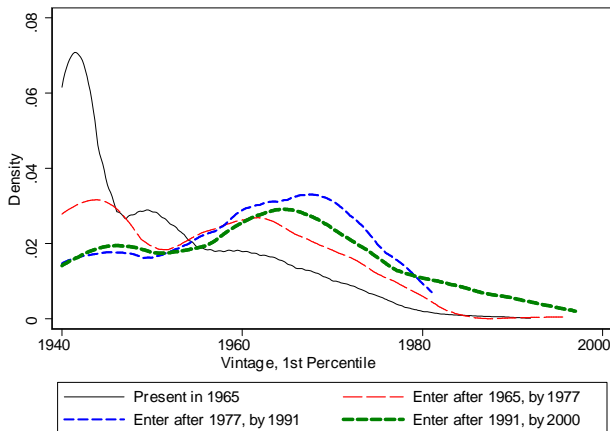
- ▶ Slightly greater than half of updating occurs through entry and exit

Comparison to Lin (2011)'s measure of new work

- ▶ Lin (2011) compares successive vintages of the Dictionary of Occupational Titles.
⇒ Four categories of job titles based on when they appeared (≤ 1965 , by 1977, by 1991, by 2000)
- ▶ For these four categories, plot the density of Yr. of Emergence;

Comparison to Lin (2011)'s measure of new work

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Productivity Distribution

