The making of high-tech clusters: Evidence from early-mover corporate labs in the US microchip breakthrough

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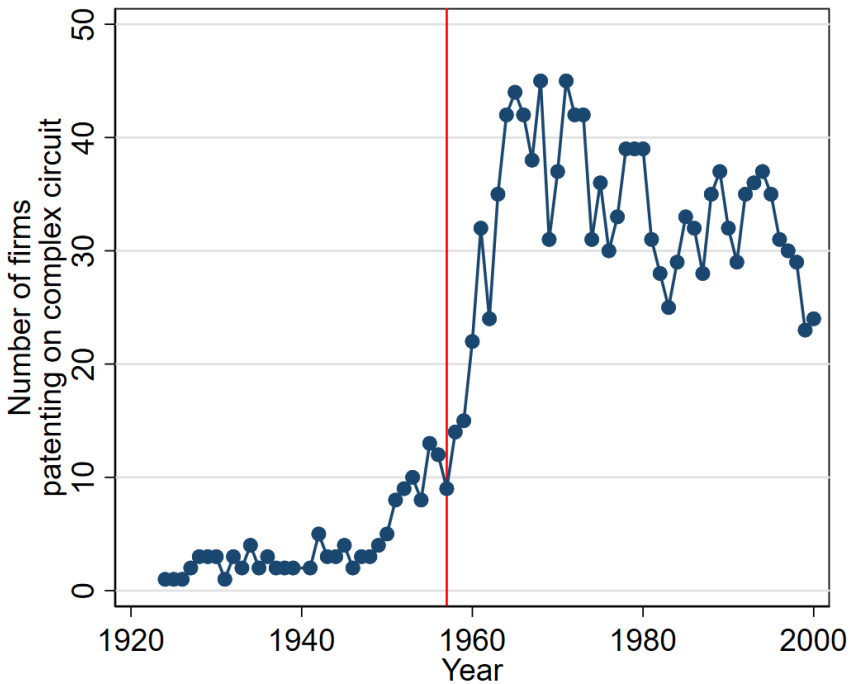
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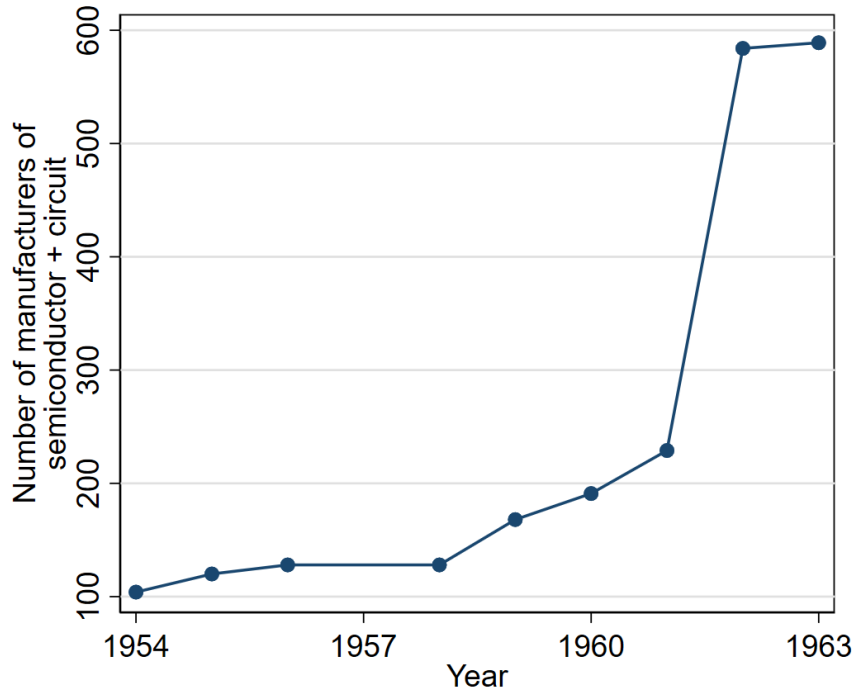
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- Why focus on early technology leaders? High-tech first-mover firms $\rightarrow$ oligopolies after industrial shake-out (market selection) (Klepper, 1996, 2002; Buenstorf and Klepper, 2009, 2010)
- Leverage a plausibly **unintended head start** during the 1950s American microchip breakthrough, and estimate how it impacts:
  - Innovation;
  - Diffusion;
  - Production;
  - Agglomeration

The 1950s' American microchip breakthrough

- In Oct. 1957, a group of "rebellious" engineers formed the Fairchild Semiconductor Div, and within 2 months $\rightarrow$ the first idea of planar (microchip) (Hoerni's lab notebook record, Dec. 1957).
- Product market expanded in an unprecedented speed; commercial-use microchip market size $>$ state-led military market within just 8 years (Berlin, 2005; Miller, *Chip War*, 2022).
- A dynamic economy: massive innovation diffusion, endless start-ups, persistent follow-on breakthroughs, etc. (Saxenian, 1994, Klepper, 2010).
- **Good old days have gone:** market concentration$\uparrow$ (Autor et al., 2020, Akcigit and Ates, 2021); knowledge diffusion$\downarrow$ from leader to follower (Akcigit and Ates, 2023).



(a) # of corporate innovators.



(b) # of semicon. circuit manufacturers

Figure: The takeoff of early American microchip industry.

Research design

- Ideally, a firm-level random head start in tech breakthrough;
- However, technology leadership is **research field specific** (Fairchild led IC circuits, but not mainframes; IBM led mainframes but not memory device, Intel led memory device but not amplifiers/insulators, etc.); **huge firm-level selection bias** NASA/DoD contracts/other contemporaneous shocks;

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- **A unique natural experiment:** pre-Fairchild semiconductor choice $\rightarrow$ quasi-exogenous, downstream lab$\times$field specific head start in applying microchip (the breakthrough innovation) to downstream research fields.
- With none-negative treatment spillover, lab$\times$field parameter $\rightarrow$ lower-bound estimate of firm level parameter.

Microchip, Silicon and Germanium

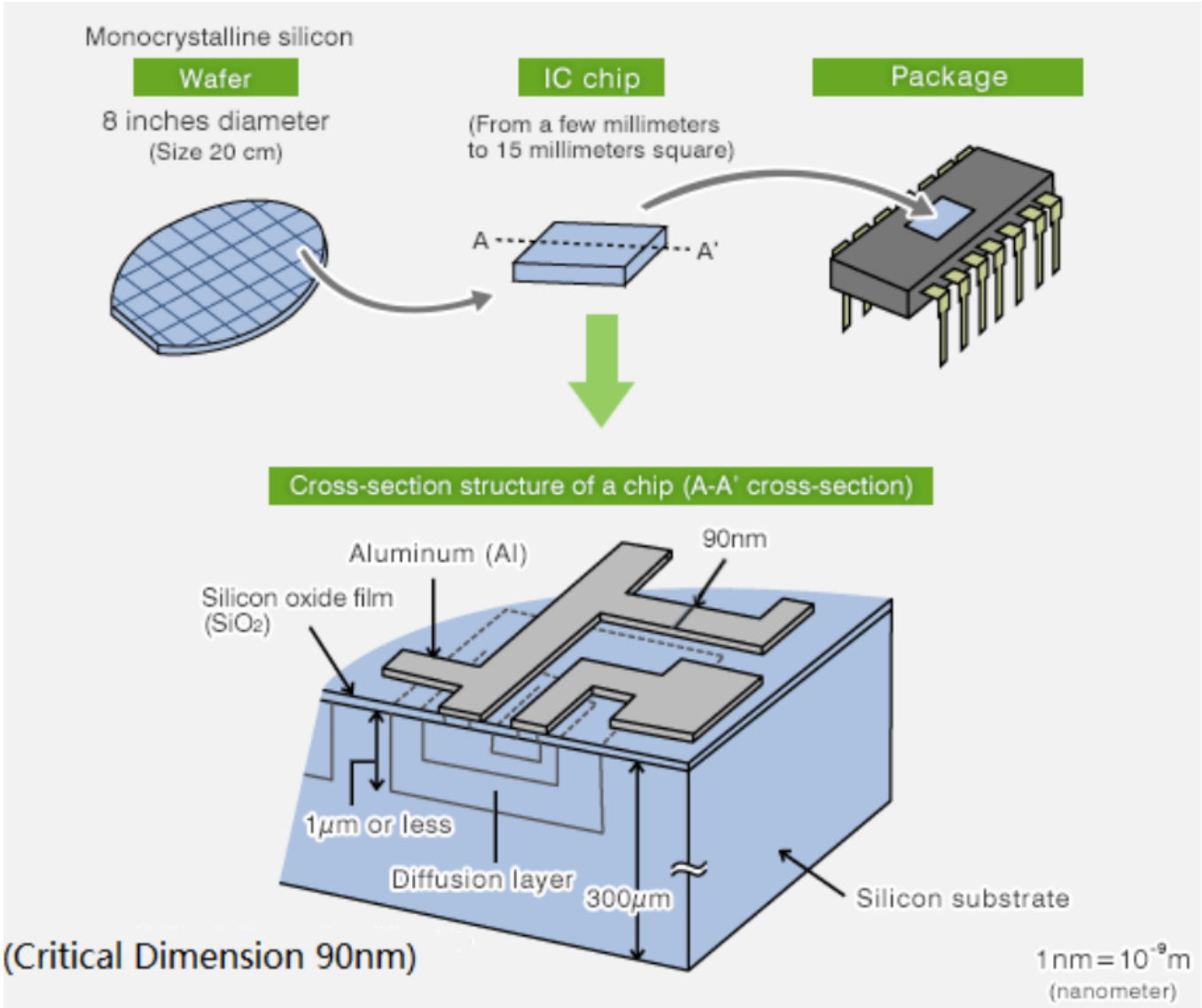


Figure: Microchip and Silicon's unique oxide layer properties (Image source: internet)

Identification setting

- **Pre-Fairchild:** Silicon vs Germanium $\rightarrow$ similar and good enough substitutes;
- **Post-Fairchild:** Microchip breakthrough $\rightarrow$ only Silicon was suitable for Fairchild's planar microchip;
- **Quasi-exogenous delay:** Germanium-based labs had to switch to Silicon to leverage the microchip technology (prob. of using microchip -15.6% ($p < 0.01$) within first 8 years).

Key events in 1957:

- Shockley breakaway (Sept. 1957)
- Fairchild Semiconductor Div emerged
- Fairchild's early discovery of planar technique (key basis of microchip) (Dec. 1957)

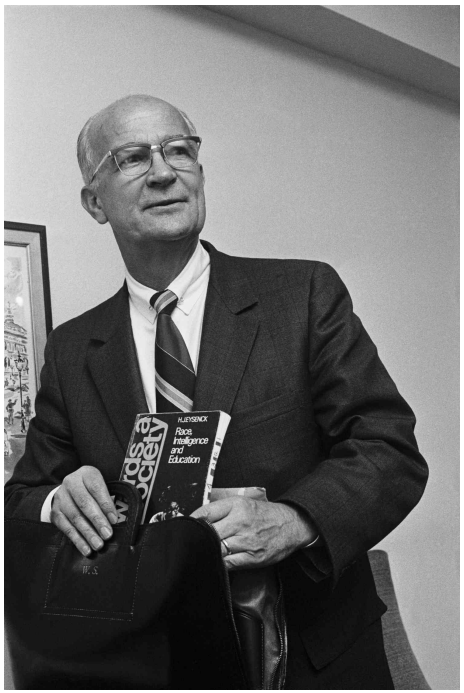
Labs	Research fields	1954-1957	1958-
		Pre breakthrough era	**Post breakthrough, microchip era**
1	A	Patents had NOT used Silicon	Delay → Start using microchip
2	B	Patents had NOT used Silicon	Delay → Start using microchip
2	C	Patents had used Silicon	Start using microchip
3	A	Patents had used Silicon	Start using microchip

Key event in 1954:
Both Silicon and Germanium entered mass use and production

Figure: Timeline

The 1957 Fairchild-Shockley breakaway

- The rise of Fairchild Semiconductor (Oct. 1957) and the initial planar (microchip) idea (Dec. 1957) was driven by an unanticipated breakaway across a group of ambitious (genius) engineers;



(a) William Shockley (Nobel prize laureate)



(b) Founders of Fairchild semiconductor division (the traitorous eight)

Figure: The Fairchild-Shockley breakaway happened in 1957 due to personal resentment with Shockley (nonanticipatory by other labs).

Treatment: a quasi-random head start

- **Unit of analysis:** Corporate R&D lab×research field (6-digit CPC code) pairs (170 Corporate R&D labs are corporation-county pairs collected from *Corporate Author Headings, 1958 & 1970*.)
- **Germanium group** (counterfactual head start): 428 lab×patent class pairs.
- **Silicon group** (actual head start): 643 lab×patent class pairs;
- **Observations:** Total lab×field×year obs: 13793.

Corporate lab	Research field (Patent CPC code)	Semiconductor choice (Pre-Fairchild, 1953-1957)	Treatment group (head start in microchip research)
Bell Telephone Laboratory (lab of Morris, New Jersey)	Solid state device	Had used Silicon	Actual head start
	Bipolar integrated circuit	Had only used Germanium	Counterfactual head start
	Substation equipment, e.g. for use by subscribers	Had used Silicon	Actual head start
...	...	...	...

Figure: Workflow to define head start pairs (treated, Silicon) and counterfactual head start pairs (control, Germanium)

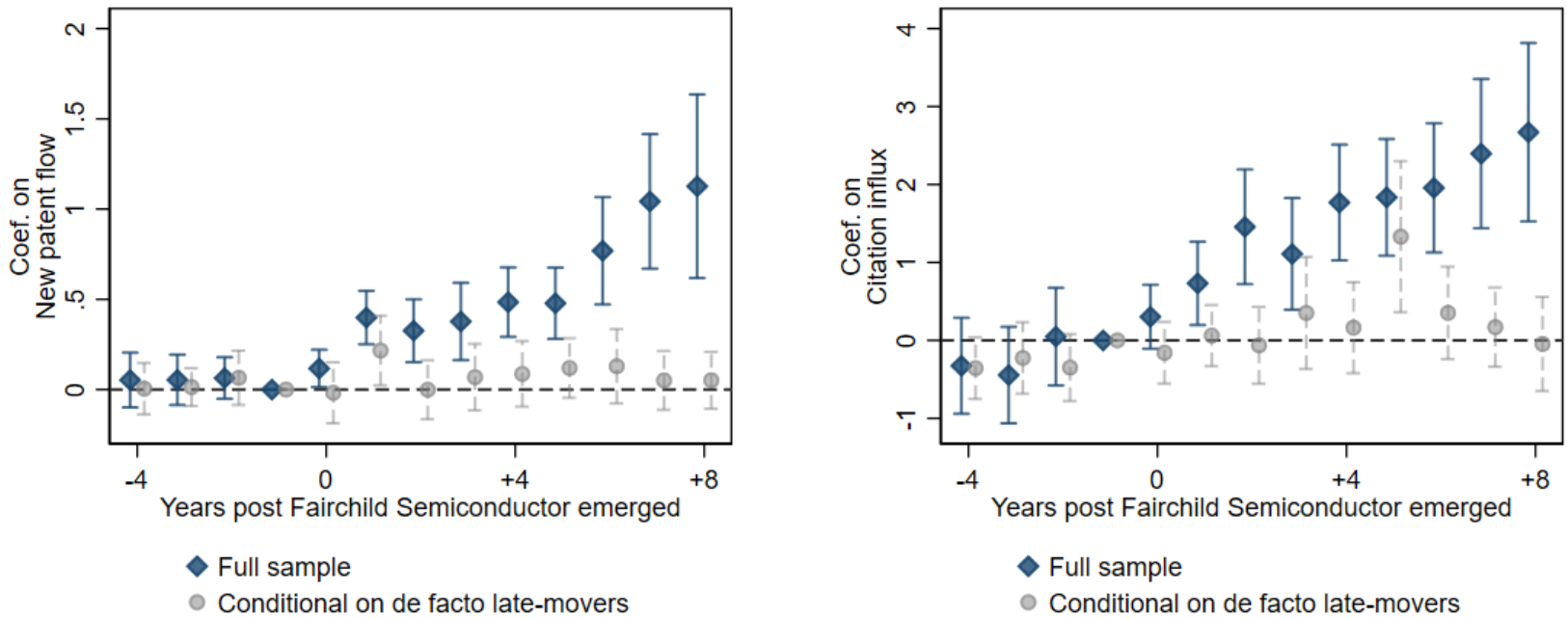
Baseline model

$$Y_{vft} = \alpha + \beta \mathbf{1}\{t \geq 1957\} \times \mathbf{1}\{vf \in Silicon\} + \mu_{vf} + \lambda_{ut} + X_{vt} + \varepsilon_{vft} \quad (1)$$

- v: corporate labs; f: research fields (patent classes); u: the parent firm of lab v; c: the county of lab v, t: years; μ_{vf} lab×research field FE; λ_{ut} firm×year FE.
- $\mathbf{1}\{vf \in Silicon\}$ is a treatment dummy: $= 1$ when lab v had patented with Silicon on research field f during 1954-1957, and 0 if it had only used Germanium.
- X_{vt} is a set of controls: 1) interaction of year dummies (γ_t) with a NASA county dummy, 2) interaction of γ_t with a pre-1957 top physics research institute county dummy, and 3) an advanced physics publications control (lab×field×year level).

I. Innovation: head start → persistent tech leadership

- Static ATT on each lab×research field: +0.526/+23.1% new patent flow per year; +1.761/+32.4% forward citation influx per year.



(a) New patent flow

(b) Influx of citations each year

Figure: Patent outcomes.

Note: Citation events inherit the priority dates of the citers. Self citations are excluded. t=0 is year 1957; t=-1 is omitted. Standard error clustered at the research field level.

II. Diffusion: a proxy for vonluntary knowledge disclosure

- During 1960s, corporate labs frequently released technical details as public knowledge via conference/working papers;
- More applied than basic research + weak intellectual property;
- Among which IEEE (Institute of Electrical and Electronics Engineers) is the largest platform.

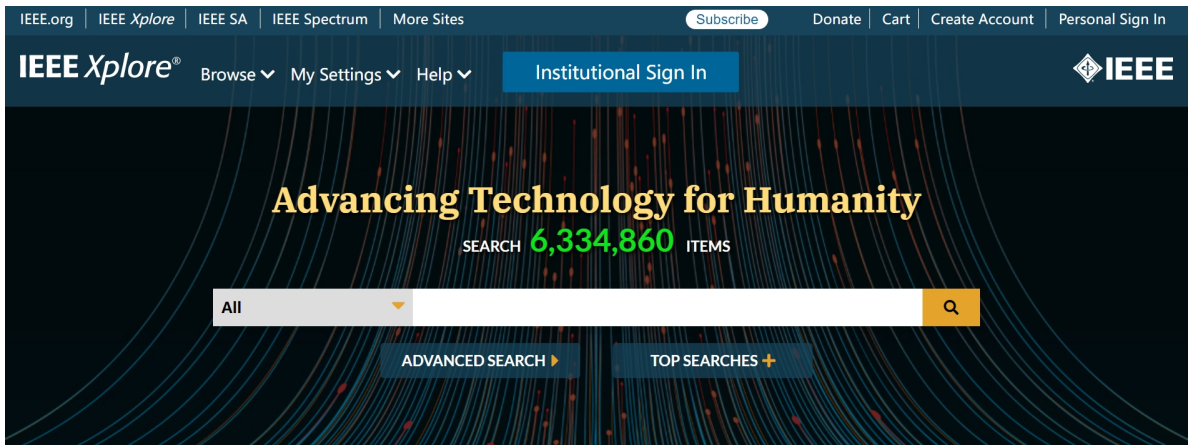
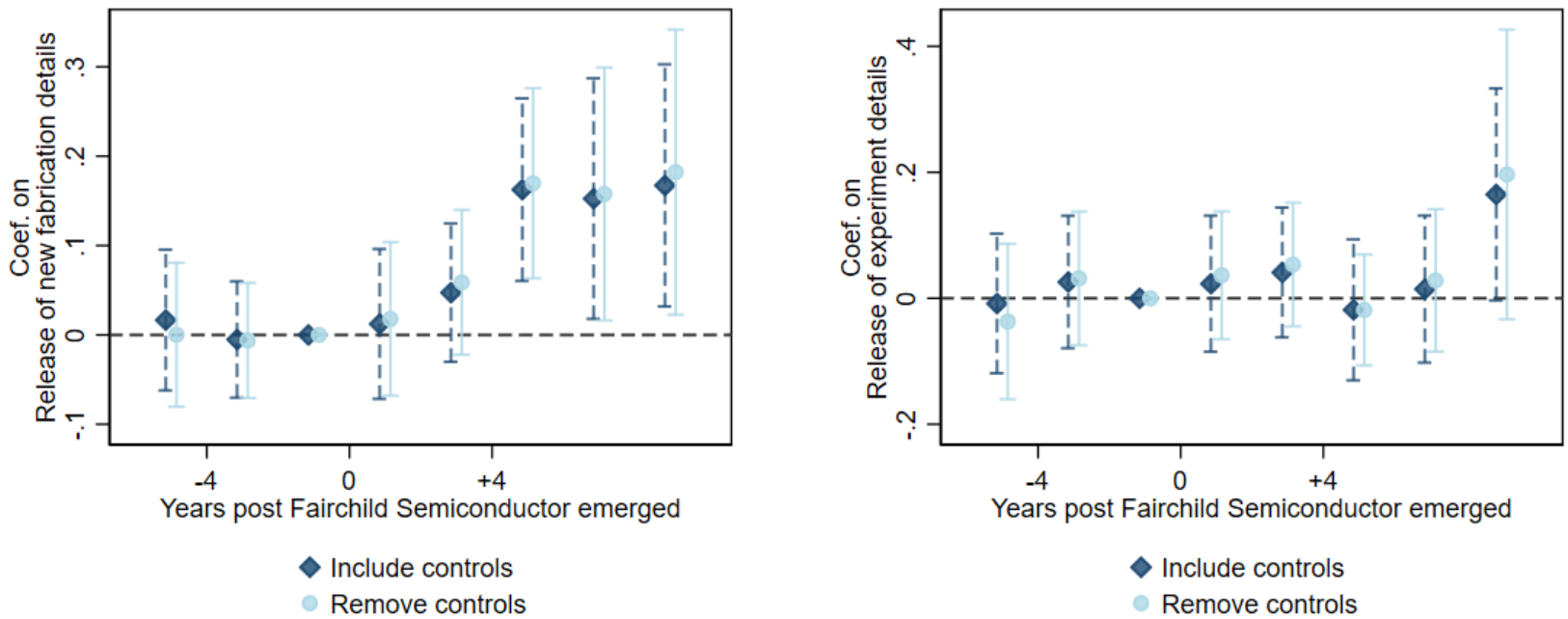


Figure: IEEE Xplore compiles rich historical records of corporate publications since 1890s.

II. Diffusion: the disclosure is likely strategic

- Since year 4 after corporate breakthrough, corporate head start → +0.157/+9.1% release of **fabrication details** per 2 years; negligible effect on the release of **experiment details**.



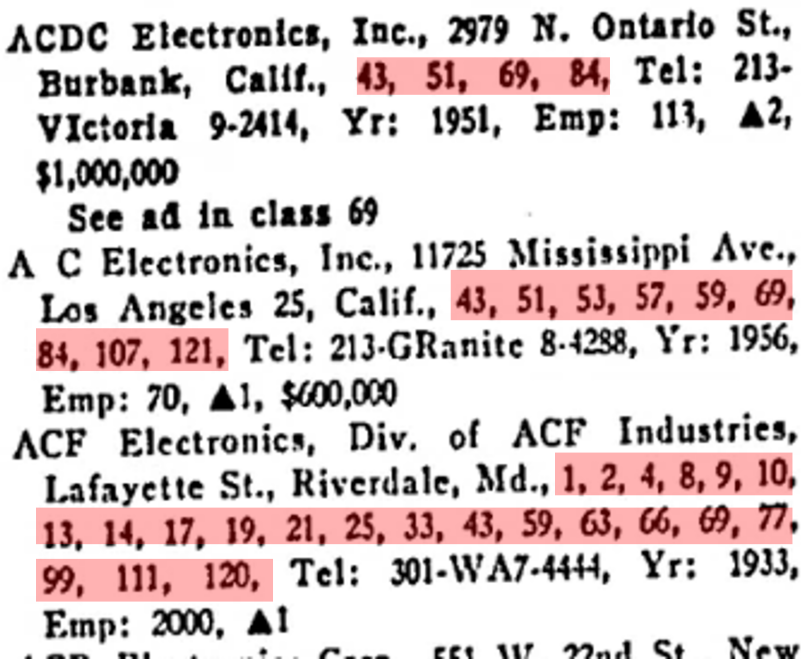
(a) Release of fabrication details (b) Release of experiment details

Figure: Meeting/conference publications outcomes.

Note: t=0 is year 1957; t=-1 is omitted; Germanium group set as the reference. Standard error clustered at the patent class level.

III. Production: Do leaders commercialize their patents?

- Product data from (a) IRE Membership Directory; (b) Electronic Industries trade journal.

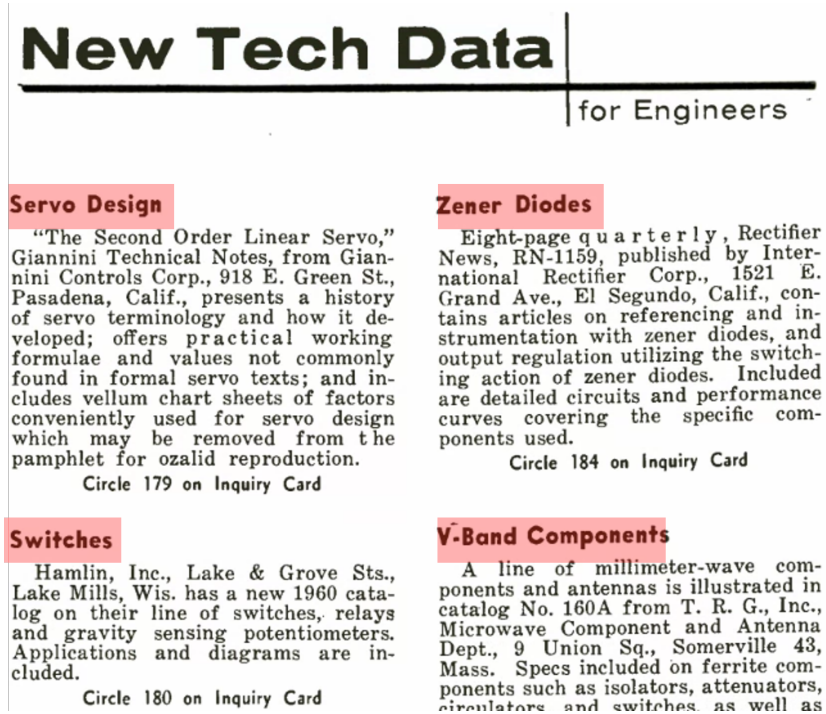


ACDC Electronics, Inc., 2979 N. Ontario St., Burbank, Calif., 43, 51, 69, 84, Tel: 213-VIctoria 9-2414, Yr: 1951, Emp: 113, ▲2, $1,000,000
See ad in class 69

A C Electronics, Inc., 11725 Mississippi Ave., Los Angeles 25, Calif., 43, 51, 53, 57, 59, 69, 84, 107, 121, Tel: 213-GRanite 8-4288, Yr: 1956, Emp: 70, ▲1, $600,000

ACF Electronics, Div. of ACF Industries, Lafayette St., Riverdale, Md., 1, 2, 4, 8, 9, 10, 13, 14, 17, 19, 21, 25, 33, 43, 59, 63, 66, 69, 77, 99, 111, 120, Tel: 301-WA7-4444, Yr: 1933, Emp: 2000, ▲1

(a) Digitized product lines.



New Tech Data for Engineers

Servo Design

"The Second Order Linear Servo," Giannini Technical Notes, from Giannini Controls Corp., 918 E. Green St., Pasadena, Calif., presents a history of servo terminology and how it developed; offers practical working formulae and values not commonly found in formal servo texts; and includes vellum chart sheets of factors conveniently used for servo design which may be removed from the pamphlet for ozalid reproduction.

Circle 179 on Inquiry Card

Zener Diodes

Eight-page quarterly, Rectifier News, RN-1159, published by International Rectifier Corp., 1521 E. Grand Ave., El Segundo, Calif., contains articles on referencing and instrumentation with zener diodes, and output regulation utilizing the switching action of zener diodes. Included are detailed circuits and performance curves covering the specific components used.

Circle 184 on Inquiry Card

Switches

Hamlin, Inc., Lake & Grove Sts., Lake Mills, Wis. has a new 1960 catalog on their line of switches, relays and gravity sensing potentiometers. Applications and diagrams are included.

Circle 180 on Inquiry Card

V-Band Components

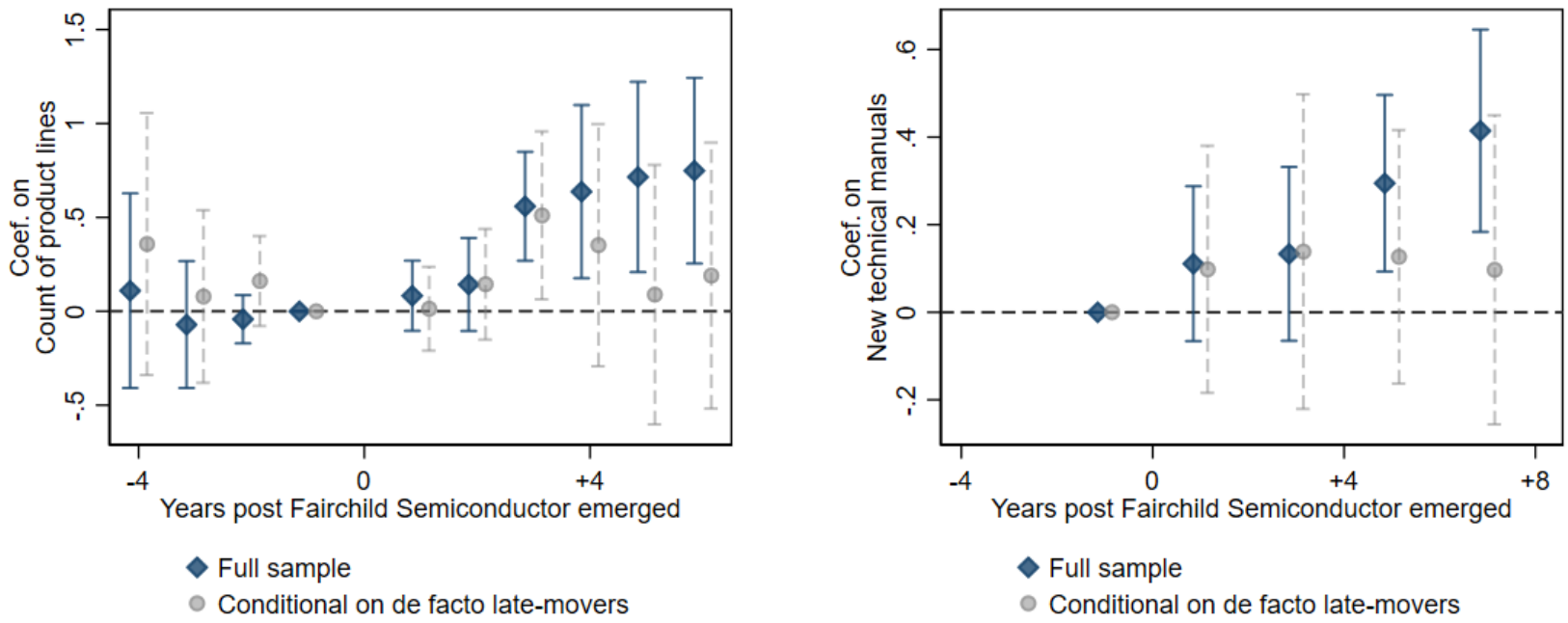
A line of millimeter-wave components and antennas is illustrated in catalog No. 160A from T. R. G., Inc., Microwave Component and Antenna Dept., 9 Union Sq., Somerville 43, Mass. Specs included on ferrite components such as isolators, attenuators, circulators, and switches, as well as

(b) Digitized new product manuals.

Figure: Newly digitized product-level datasets.

III. Production: head start → swift production

- Static ATT on each lab×research field: +0.482/+13.7% more product lines per year; +0.238/+8.3% more new product manuals per 2 years.



(a) Count of product lines

(b) New product manuals

Figure: Product outcomes.

Note: t=0 is year 1957; t=-1 is omitted. Standard error clustered at the research field level.

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- **Likely unintendedness of head start:** conditional on labs with pre-Fairchild microchip similar patents $\rightarrow$ sizable innovation, negligible knowledge disclosure, negligible production;

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- **Likely unintendedness of head start:** conditional on labs with pre-Fairchild microchip similar patents $\rightarrow$ sizable innovation, negligible knowledge disclosure, negligible production;
- **Agglomeration:**
  - Most of the observed leader disclosure comes from **face-to-face** conferences/symposiums arranged by Institute of Radio Engineer (IRE);
  - The IRE's "regional section" policy $\rightarrow$ Marshallian externalities in leader lab locations.

Thank you!

Any comments are hugely appreciated: j.zeng15@lse.ac.uk

Appendix: Ruling out alternative explanations

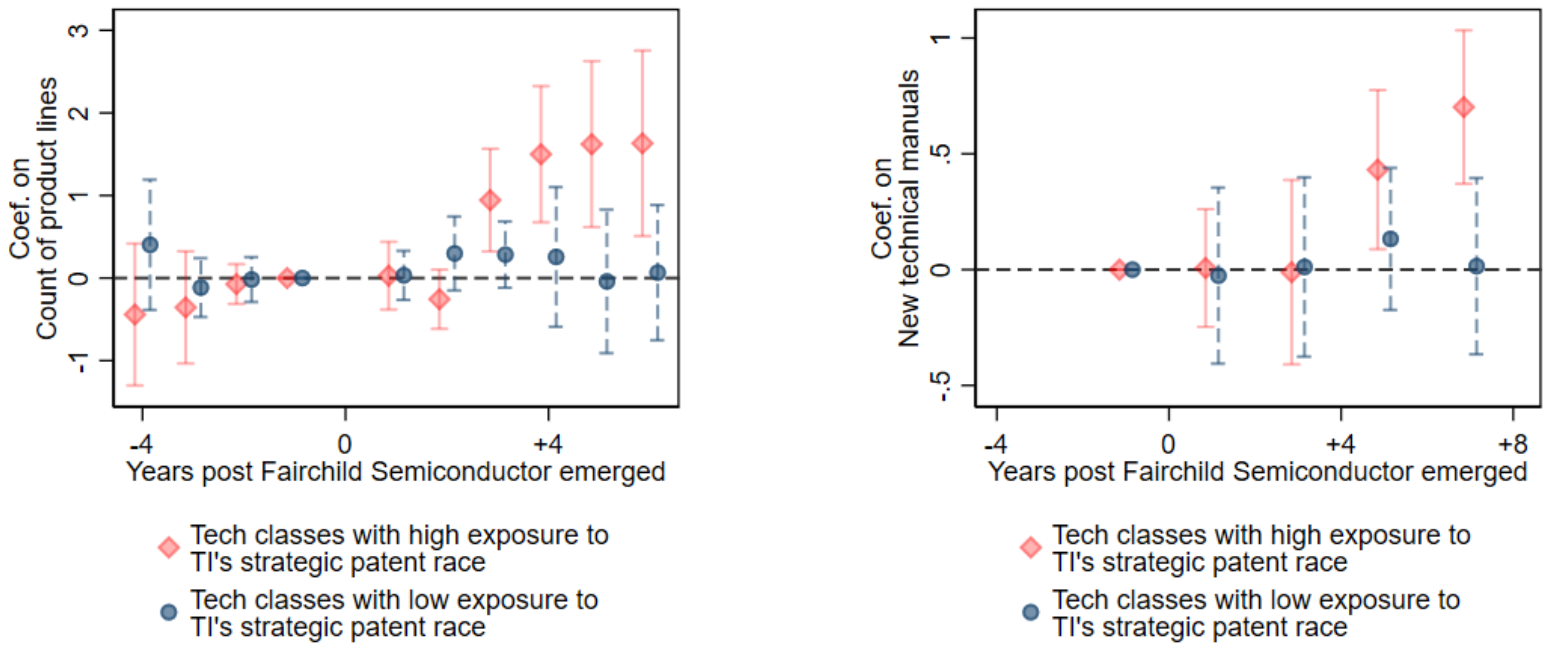
- Limited evidence found for:
  - Exclusivity to the valley/California/west coast.
  - Prior semiconductor choice impacts innovation outcomes beyond pathways of microchip (exclusion restriction);
  - The 1958 NASA Space Act favor Silicon (head start) labs over Germanium labs (see a more in depth discussion on the context in paper).
  - "Winner-takes-all": The effect is exclusive to the first assignees that applied microchip into each technology class.
  - Scouting via conferences.
  - Close research fields are strategic substitutes or between-lab R&D reallocation/negative treatment spillover.
  - Sensitivity to non-linear estimation methods on key outcomes.

The 1960s patent war

- In 1958, along with the discovery of the planar-based microchip idea by Fairchild, a parallel, non-planar-based microchip was invented by Texas Instruments (TI) (Berlin, 2005; Reid, 2001).
- The unanticipated parallel patent grant triggered a 5-year long litigation from TI (1962-1966) on all other actual/imaginary infringement (Lojek, 2007).
- **Did it deter other competing leader labs from new markets?** I sub-divide the sample:
  - Research fields with high exposure to TI's patent war;
  - Research fields with low exposure to TI's patent war.

Backfired patent race

- The other non-TI leader labs respond to TI's strategic patents with faster product development and more unconventional product designs.



(a) Count of product lines

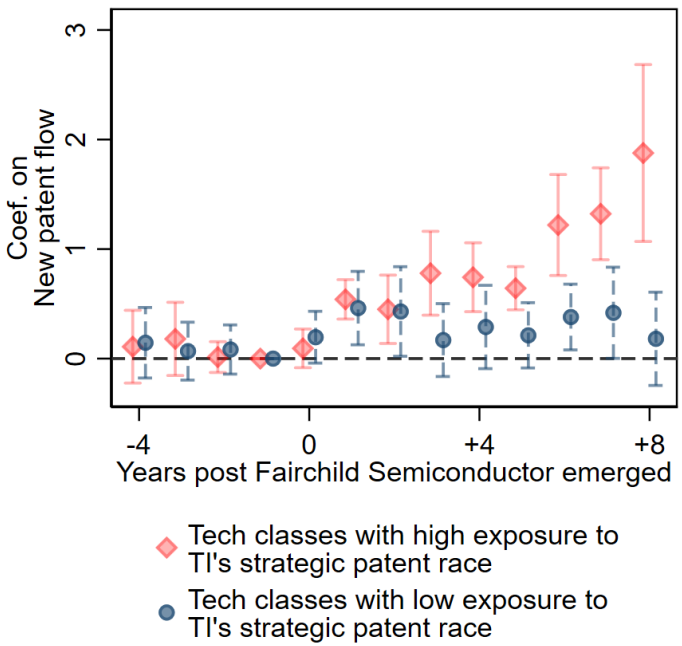
(b) New product manuals

Figure: Heterogeneity check: Product outcomes.

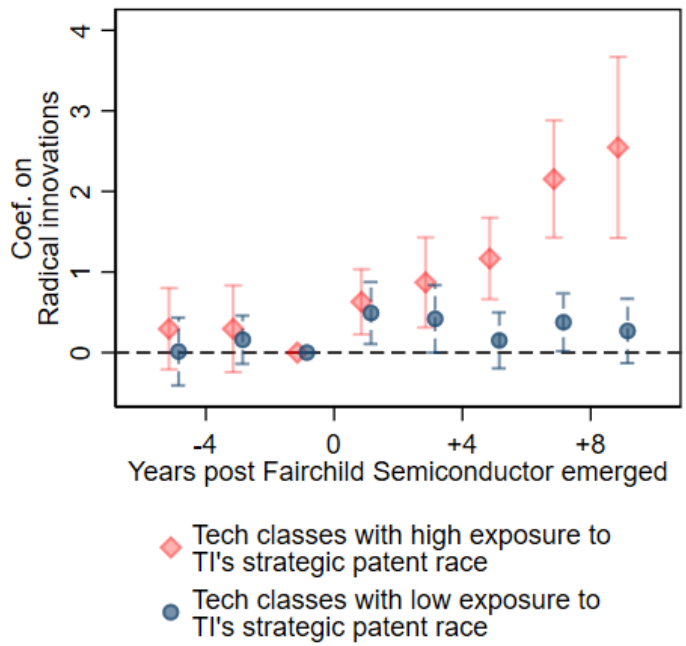
Note: t=0 is year 1957; t=-1 is omitted; Germanium group set as the reference. Standard error clustered at the patent class level.

Backfired patent race

- The TI's strategic exclusion backfired in more intense innovation from other leader rivals.



(a) New patent flow



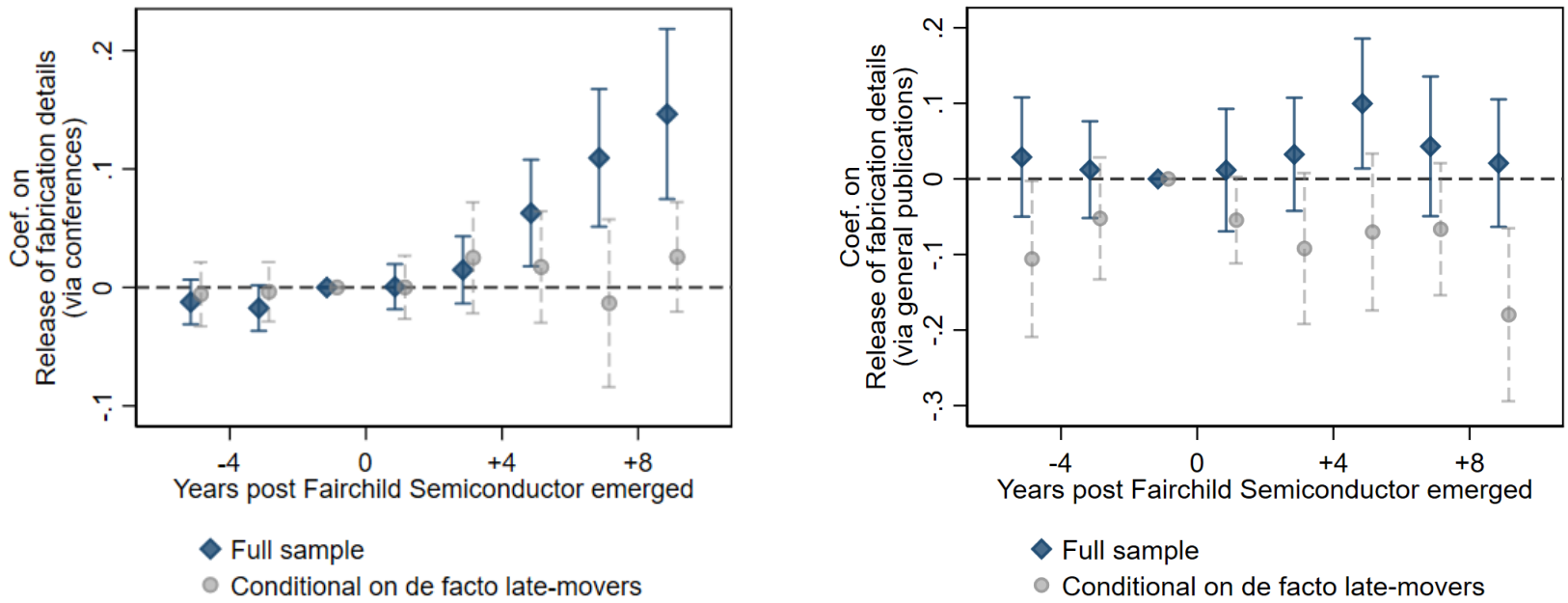
(b) Radical innovations

Figure: Heterogeneity check: patent outcomes.

Note: t=0 is year 1957; t=-1 is omitted; Germanium group set as the reference. Standard error clustered at the patent class level.

Demand for face-to-face contacts **20s**

- Most of the above knowledge diffusion comes via in-person conferences.



(a) via face-to-face conferences (b) via general publications

Figure: Meeting/conference publications outcomes.

Note: t=0 is year 1957; t=-1 is omitted. Standard error clustered at the research field level.

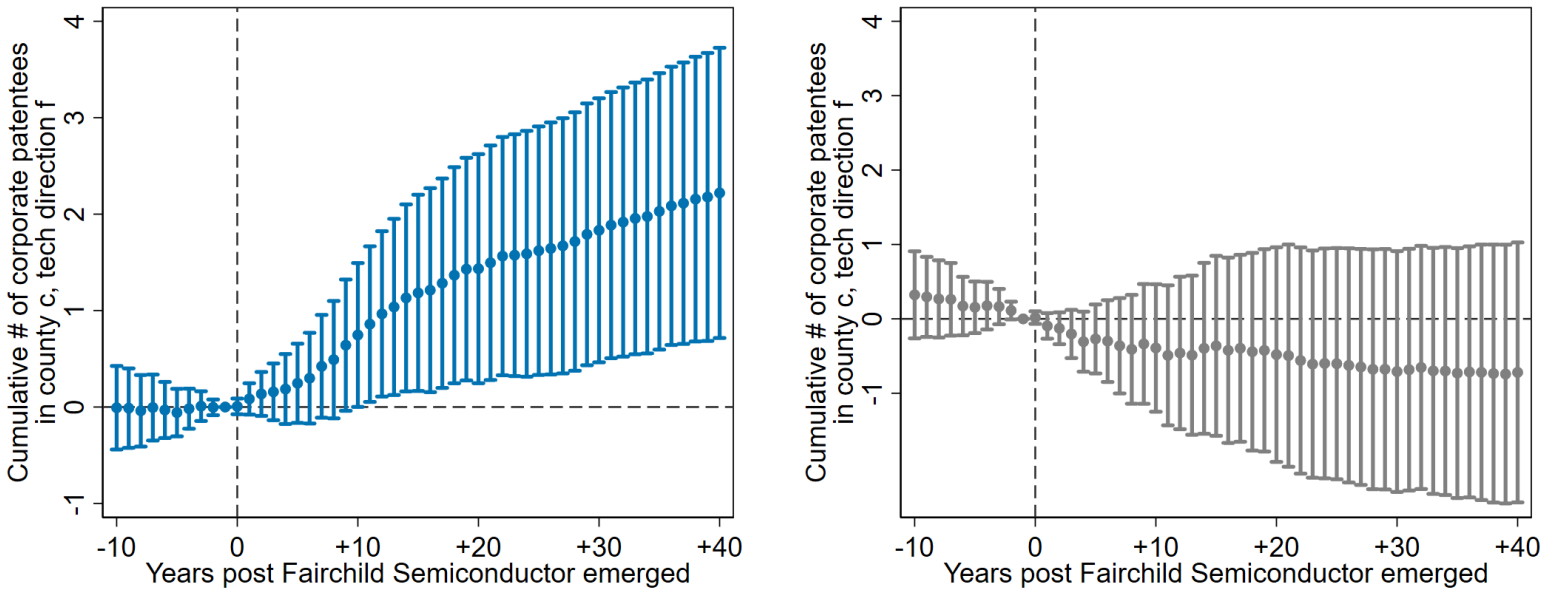
The local impact of corporate breakthrough

- **Institutional setting:** early IRE conventions and symposiums are grouped into regional sections, with at least 5 annual meetings required among section members $\rightarrow$ **localized strategic diffusion**:

$$Y_{cft} = \alpha + \delta \mathbf{1}\{t \geq 1958\} \times \mathbf{1}\{cf \in Silicon\} + \lambda_t + \mu_{cf} + \varepsilon_{cft} \quad (2)$$

- c: counties; f: 6-digit technology classes; t: years;
- $\mathbf{1}\{cf \in Silicon\}$ is a treatment dummy: $\mathbf{1}\{cf \in Silicon\} = 1$ when the county$\times$technology class {c,f} is in Silicon group and 0 in Germanium group.
- Y_{cft}: cumulative count of corporate patentees in research field f, county c.

The take-off of local innovation hubs



(a) Cumulative count of corporate patentees

(b) Placebo.

Figure: The take-off of local innovation hubs where leader labs located.

Note: t=0 is year 1957.

Supportive evidence for quasi-random selection assumption

- Pre-1957 covariates should be balanced between Silicon and Germanium groups.

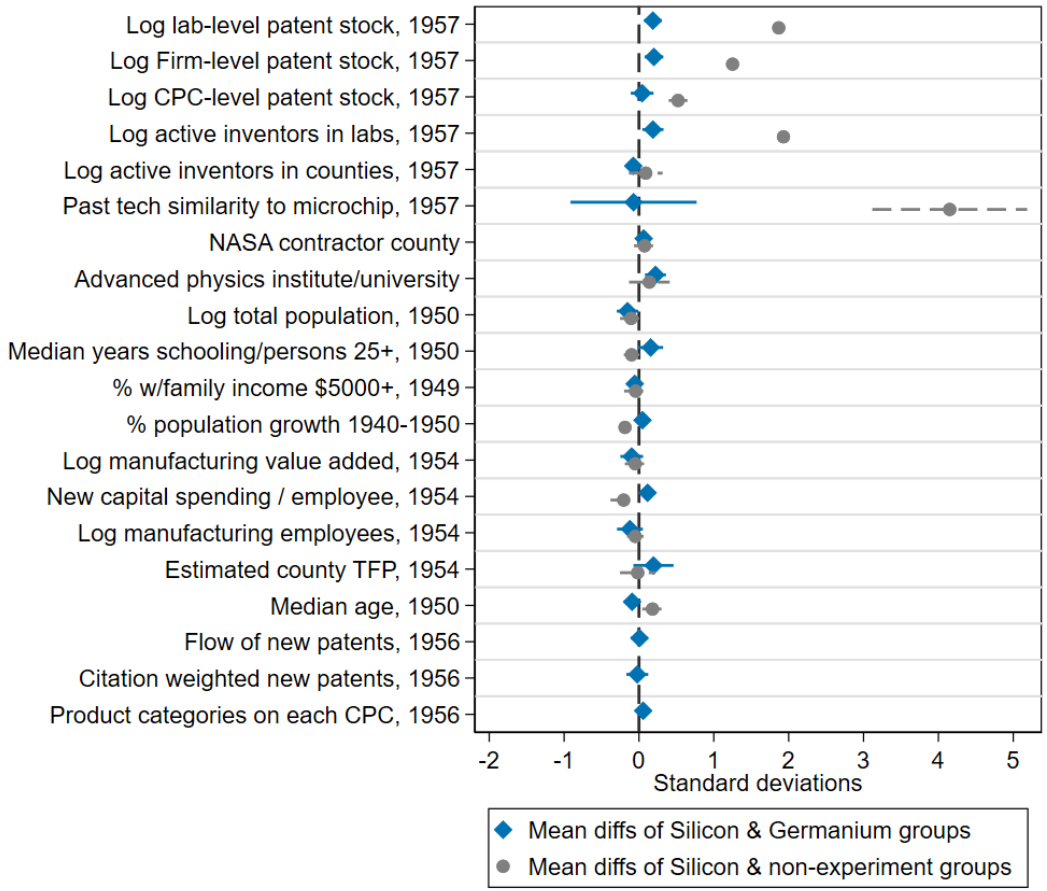
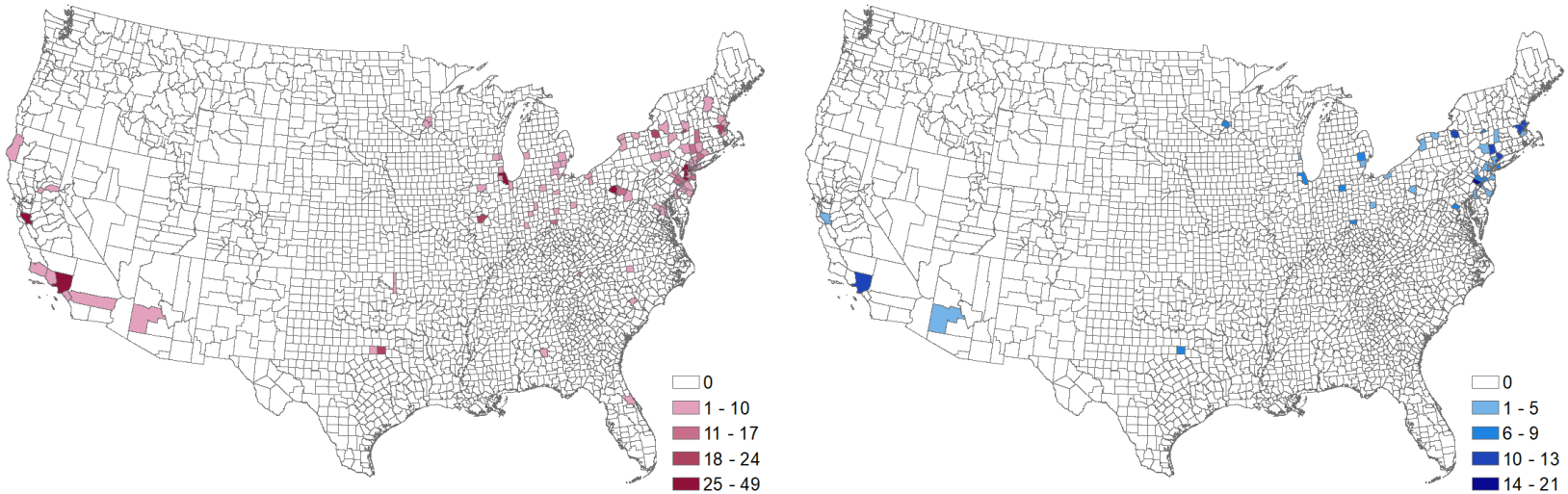


Figure: Covariate balancing tests.

Distribution of sample



(a) Silicon group

(b) Germanium group

Figure: Number of observations in each sample group.