Online Appendix for: Industry Shakeouts after an Innovation Breakthrough

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April 13, 2026

Appendix A. Breakthrough Industries and Years

Appendix A reports breakthrough industries and breakthrough years using publicly available 4-digit NAICS data from the Business Dynamics Statistics of the U.S. Census Bureau. Although the breakthrough detection procedure is conducted at the NAICS 6-digit level, 4-digit results are reported here to comply with Census disclosure requirements. This allows readers to assess the method's alignment with prominent anecdotal industry breakthroughs while preserving confidentiality.

To assess robustness, the appendix reports breakthrough timing calibrated at the 95th percentile (top 5%) of the adjusted net entry rate distribution, as detailed in the paper – as well as under a less stringent 10% threshold. Note that the industries selected at the 5% threshold form a strict subset of those selected at the 10% threshold. In Table A.1 below, "Year (5%)" reports the baseline breakthrough year, while "Year (10%)" reports the corresponding year under the looser threshold; entries are blank for industries not selected at 5%. Where breakthrough timing differs across thresholds, the table reports distinct breakthrough descriptions and entrants for each threshold.

A disclosure-approved version of the 6-digit results may be made available in the future upon request to qualified researchers. Due to Census confidentiality requirements, any such version must aggregate breakthrough timing into broader multi-year windows (e.g., 5 or 10 year periods) to avoid disclosing industry-year estimates based on too few firms.

Table A.1: NAICS-4 Breakthrough Table

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
2131	Support Activities for Mining	1978	1979	Mud-pulse telemetry	Teleco Oilfield Services (1978), Gearhart Industries*, Schlumberger (SLB)*	
3341	Computer and Peripheral Equipment Manufacturing	1978	1978	Personal computer: Apple II, TRS-80	Compaq (1982), Apple (1976), Epson America Inc (1975)	
4532	Office Supplies, Stationery, and Gift Stores	1978		Computerized POS systems	Paper Source, Inc. (1983), local stationery and gift chains	
5112	Software Publishers	1978	1978	Software packages separate from hardware	Microsoft (1975), Oracle (1977), Adobe (1982), Lotus (1982), Symantec (1982), VisiCorp (1976)	
5122	Sound Recording Industries	1978	1978	Compact Disc (Red Book CD-DA; commercial launch 1982)	Rykodisc (1984), DCC Compact Classics (1986), Metal Blade Records (1982)	
5324	Commercial and Industrial Machinery and Equipment Rental and Leasing	1978	1980	DIY ("Do-It-Yourself") movement	Home Depot (1978), Sunbelt Rentals (1983)	
5414	Specialized Design Services	1978		Postmodern and graphic design	Hovey-Kelley Design (1978, later IDEO), Pentagram* (US expansion)	
5415	Computer Systems Design and Related Services	1978	1978	Local-area network (LAN)	Network Solutions (1979); Systems Research and Applications Corp. (1978); BTG Inc. (1982), Local LAN integrators	
5615	Travel Arrangement and Reservation Services	1978		Computerized reservation systems	Apollo reservation system* (1971, developed by United)	
5616	Investigation and Security Services	1978	1978	Electronic surveillance and alarm systems	Brinks Home Security*, local alarm dealers	
5619	Other Support Services	1978	1978	Automated packaging	Uline (1980), Visual Pak Company (1982), Econo-Pak, Inc. (1981)	
6216	Home Health Care Services	1978	1979	Telehealth (STARPAHC + CT scanner)	Option Care, Inc. (1979), Home Health Care of America (1979, later Caremark International)	

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
6232	Residential Intellectual and Developmental Disability, Mental Health, and Substance Abuse Facilities	1978	1978	Community care (Ira Burnim)	Local Intermediate Care Facilities	
7115	Independent Artists, Writers, and Performers	1978	1978	Home recording and independent media production	Miramax Films (1979), SST Records (1978), Sub Pop (1982, originally Subterranean Pop)	
2111	Oil and Gas Extraction	1979		Modern deepwater drilling technology (first DP semi-submersible)	Diamond Offshore (1978), Oceaneering International*	
4812	Nonscheduled Air Transportation	1979		Charter flights (Airline Deregulation Act implementing open-entry/contestability logic)	Trans-Exec Air Service, Inc. (1979); Sun Country Airlines, Inc. (1982)	
5174	Satellite Telecommunications	1979	1994	Domestic C-band satellites (RCA Satcom 1, 1975); Direct Broadcast Satellite (DirecTV 1994)	Spacenet Inc. (1981), Orion Network Systems (1983), PanAmSat Corporation (1984); DirecTV (1994), DISH Network (1996)	
5323	General Rental Centers	1979	1979	DIY ("Do-It-Yourself") big box movement	Local rental entrants	
6219	Other Ambulatory Health Care Services	1979	1979	Helicopter EMS (HEMS)	Air Methods Corporation (1980), CareFlite (1979), PHI Air Medical (1981)*	
8129	Other Personal Services	1979		One-hour photo minilab (retail photofinishing)	Moto Photo, Inc. (1982), Fromex One Hour Photo Systems, Inc. (1980), Technicolor Photo Centers* (1981)	
3311	Iron and Steel Mills and Ferroalloy Manufacturing	1980**	1998	Continuous casting**; Thin-slab casting	Birmingham Steel Corporation (1983), Elkem Metals U.S. (1981)*; Trico Steel (1997), International Steel Group (2002)	The continuous casting adoption wave in 1980 likely reflects rapid diffusion from bundled process improvements rather than a single breakthrough. Thin-slab casting was a breakthrough in 1998.

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
3344	Semiconductor and Other Electronic Component Manufacturing	1980		VLSI design revolution (Mead-Conway + MOSIS)	LSI Logic Corporation (1981), Altera Corporation (1983), Xilinx, Inc. (1984)	Mead and Conway wrote their pivotal textbook in 1978; it was published in 1979 and the design principles were first adopted in 1980 with the DARPA-funded VLSI Project.
4234	Professional and Commercial Equipment and Supplies Merchant Wholesalers	1980	1980	UPC barcodes	SYNNEX Corporation (1980), CDW Corporation (1984), PSS World Medical, Inc. (1983)	UPC barcodes was a key technology that made large-scale, multi-vendor distribution operationally feasible.
5231	Securities and Commodity Contracts Intermediation and Brokerage	1980		Discount brokerages	Scottsdale Securities, Inc. (1980; later Scottrade), TradePlus, Inc. (1982; later E*TRADE), Security Pacific Corporation - Discount Brokerage Unit (1982)*	
5239	Other Financial Investment Activities	1980		Modern venture market (ERISA "prudent man" reinterpretation using Modern Portfolio Theory)	Institutional Venture Partners (1980), Accel Partners (1983), Battery Ventures (1983), Bain Capital, LP (1984)*	
5322	Consumer Goods Rental	1980	1982	Home video-rental: 1st VCR (VHS standardization)	Blockbuster Video, Inc. (1985), West Coast Video (1983), Erol's Inc. (1980)*	
6213	Offices of Other Health Practitioners	1980		Modern medical optometry (Optometry TPA laws)	Local optometry practices	
6214	Outpatient Care Centers	1981		Urgent care clinics (retail outpatient care)	Patient First (1981), American Family Care (1982)	
4871	Scenic and Sightseeing Transportation, Land	1982		National Main Street Program Four-Point Approach: Heritage tourism	Local heritage railroads and trolleys	

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
4921	Couriers and Express Delivery Services	1982		Computerized package tracking and express courier networks	FedEx COSMOS (1979), Roadway Package System, Inc. (1985; later FedEx Ground), Eastern Connection Operating, Inc. (1983), LaserShip, Inc. (1986)	
4922	Local Messengers and Local Delivery	1982	1982	Urban same-day couriers (radio/pager dispatch)	Eastern Connection Operating, Inc. (1983), LaserShip, Inc. (1986)	
5223	Activities Related to Credit Intermediation	1982	1984	Bankcard electronic authorization and settlement networks	Total System Services, Inc. (1983), Chase Paymentech Solutions, LLC (1985; Paymentech)	
8131	Religious Organizations	1982	1982	Megachurch model (Church Growth Movement)	Association of Vineyard Churches (1982)	
2372	Land Subdivision	1983		Special-district infrastructure finance: master-planned land subdivision	Catellus Development Corporation (1984, Santa Fe Pacific Realty)	
4885	Freight Transportation Arrangement	1983		EDI load-matching: non-asset freight brokers/forwarders	Eagle USA Airfreight (1984; later EGL, Inc.), Airgroup Corporation (1987), Landstar System, Inc. (1988)*	
6222	Psychiatric and Substance Abuse Hospitals	1983	1985	DRG/IPPS classification: specialty psychiatric and addiction hospitals	Local speciality hospitals	
5612	Facilities Support Services	1984	1984	Computer-Aided Facility Management (CAFM) software	Pritchard Industries, Inc., Johnson Controls* (acquisition of Pan Am World Service)	
5617	Services to Buildings and Dwellings	1984		Market-design innovation: FTC Franchise standardized disclosure	Vanguard Cleaning Systems, Inc. (1984), Coverall North America, Inc. (1985), CleanNet USA, Inc. (1987)	
6114	Business Schools and Computer and Management Training	1984		Lotus 1-2-3: first "killer app"	New Horizons Computer Learning Centers (1982), ExecuTrain Corporation (1984)	
4889	Other Support Activities for Transportation	1985	1985	UPC barcode and EDI transaction standardization: cross-dock specialists	Craters & Freighters, Inc. (1990); Annex Brands, Inc. (1985, Postal Annex+, Inc.)	

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
5613	Employment Services	1985		Modern Co-employment (PEO) model (NAPEO founded in 1984)	Administaff, Inc. (1986; now Insperity), TriNet Group, Inc. (1988), ASGN Incorporated (1985)	
4882	Support Activities for Rail Transportation	1986		Double-stack intermodal (APL/UP "Stacktrain," 1984)	Road & Rail Services, Inc. (1987), Rail Terminal Services (SSA subsidiary, 1987)	
4884	Support Activities for Road Transportation	1988	1988	Electronic toll collection (first U.S. ETC was in 1989: NTTA TollTag)	Amtech Corporation*, Lockheed Information Management Services*, TransCore*	
6117	Educational Support Services	1988	1989	Computer-based testing	Prometric (1990)	
1142	Hunting and Trapping	1989		1st commercial handheld GPS receiver: Magellan NAV 1000	Local hunting and trapping outfitters, and game preserves	Consumer handheld GPS units gave guides reliable waypointing, boundary mapping, and repeatable access routes.
3133	Textile and Fabric Finishing and Fabric Coating Mills	1989	1990	Microfiber (microdenier) (DuPont, 1989)	Local dyeing/finishing & fabric-coating mills	
4431	Electronics and Appliance Stores	1989		Self-service superstores (Best Buy "Concept II" 1989)	Tandy Corporation* (1991, acquires Computer City)	
4872	Scenic and Sightseeing Transportation, Water	1989		High-speed catamaran passenger crafts	Jet Express Ferry (1989), local ferry and whale-watch operators	
5231	Securities and Commodity Contracts Intermediation and Brokerage	1989		Day trading broker dealers (Small Order Execution System (SOES))	Andover Brokerage LLC (1993), All-Tech Investment Group, Inc. (1994)	
5331	Lessors of Nonfinancial Intangible Assets (except Copyrighted Works)	1989		Trademark ITU/constructive priority	Rambus (1990), Intertrust Technologies (1990), Acacia Research (1993)	New rights architecture that converts ideas/brands into financeable lease assets
7132	Gambling Industries	1989	1990	Market-design mechanism: Compact-based geographically defined licenses	Foxwoods (1992), Mystic Lake (1992), President Casinos The President (1991, first riverboat casino)	The innovation is a standardized licensing mechanism that made casino rights contractible and contestable across jurisdictions.

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
4533	Used Merchandise Stores	1990		POS (item-level tagging and inventory)	Crossroads Trading (1991), Game X Change (1992)	
5112	Software Publishers	1990		Shareware and Graphical user interface (GUI) (Windows 3.0): PC gaming industry	id Software (1991), Take-Two Interactive (1993), Epic Games (1991)	
4242	Drugs and Druggists' Sundries Merchant Wholesalers	1991		Cold-chain biologics (biotech revolution)	Oncology Therapeutics Network, Inc. (1993), ASD Specialty Healthcare (1992), Priority Healthcare Corporation (1994), CuraScript (1994)	
4859	Other Transit and Ground Passenger Transportation	1991	1992	Brokered Non-Emergency Medical Transportation (NEMT)	LogistiCare* (1991 NEMT management); Medical Transportation Management (1995)	
5621	Waste Collection	1991		Curbside recycling	Republic Waste Services (1996)*; MBA Polymers (1994); Clean Earth (1990)	
6116	Other Schools and Instruction	1991		Storefront computer-based tutoring	Daekyo America* (1991), SCORE! Educational Centers (1992), Club Z! In-Home Tutoring (1995)	
1132	Forest Nurseries and Gathering of Forest Products	1992	1994	USDA National Agroforestry Center established: science-based agroforestry tools	Regional wild-harvest aggregators and contract gatherer co-ops	
5611	Office Administrative Services	1992		Client-server ERP	MedPartners (1993), PhyMatrix (1994), North American Medical Management (1993)	
6114	Business Schools and Computer and Management Training	1992		Computerized testing networks	Global Knowledge (1995), CompUSA Training Centers* (1993)	
5174	Satellite Telecommunications	1993	1994	1st DIRECTV DBS satellite: DirecTV 1	DirecTV (1994), DISH Network (1996)	
5179	Other Telecommunications	1993	1993	Centralized toll-free routing database enabled RespOrgs	ATL Communications (1993), International Telcom Ltd. (1993, now Kall8)	
4841	General Freight Trucking	1994		Satellite fleet telematics	Eliason Ranch Trucking (1995), Big G Express (1995), Munoz Trucking (1995)	

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
2372	Land Subdivision	1995		Land-secured bonds standardization	CDD/CFD subdividers	
5613	Employment Services	1995		Web job boards	CareerBuilder (1995), HotJobs (1996), Headhunter.net (1998)	
4889	Other Support Activities for Transportation	1996		Electronic export filing (AES)	Shipping Solutions (1996), Trade Technologies (1999)	
5416	Management, Scientific, and Technical Consulting Services	1996		Six Sigma deployments	Sigma Breakthrough Technologies (1997), Breakthrough Management Group (1999)	
1142	Hunting and Trapping	1997		Digital trail cameras enabled data-driven guiding	Local hunting guides and preserves	
4541	Electronic Shopping and Mail-Order Houses	1997	1997	Turnkey e-commerce	Zappos (1999), Drugstore.com (1999), Blue Nile (1999)	
4851	Urban Transit Systems	1997		CAD/AVL transit systems	First Transit (1999)	
5182	Data Processing, Hosting, and Related Services	1997	1999	Hosting control panels	DreamHost (1997), Rackspace (1998)	
3311	Iron and Steel Mills and Ferroalloy Manufacturing	1998	1998	Thin-slab casting enabled flat-rolled mini-mills	North Star BlueScope (1997), Trico Steel (1997), Acme Steel* (1997)	
5173	Wired and Wireless Telecommunications Carriers	1998		ADSL deployment interoperable at scale	DSL.net (1998), New Edge Networks (1999)	
5191	Other Information Services	1998		Link-analysis ranking	Google (1998), Teoma (2000)	
5239	Other Financial Investment Activities	1998		Online advice engines	Financial Engines* (1998), mPower* (1999)	
5259	Other Investment Pools and Funds	1998	1998	Sector ETFs	iShares (2000), PowerShares (2003)	
8129	Other Personal Services	1998		Online photofinishing	Shutterfly (1999), Ofoto (1999, later Kodak Gallery)	
4921	Couriers and Express Delivery Services	1999		Parcel Select workshare	Newgistics (1999), APC Postal Logistics (2001)	
4233	Lumber and Other Construction Materials Merchant Wholesalers	2000		B2B construction marketplaces	BuildPoint (1999), Citadon* (2000)	

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
4523	General Merchandise Stores, including Warehouse Clubs and Supercenters	2000		RFID/EPC	Five Below (2002), regional chains	
6117	Educational Support Services	2000		Computer-based testing networks	Pearson VUE (2000)*, Kryterion (2001)	
7223	Special Food Services	2000		Online corporate ordering	Local caterers	
3119	Other Food Manufacturing	2001	2012	USDA Organic standards; Plant-based meat	Bear Naked (2002), Justin's (2004); Beyond Meat (2012), Impossible Foods (2016)*	
3121	Beverage Manufacturing	2001	2002	Functional and energy drinks	Monster Beverage Corp. (2002), POM Wonderful (2002), Rockstar Energy (2001)	
4852	Interurban and Rural Bus Transportation	2001		Curbside e-ticketing	Lux Bus America (2003), Vamoose Bus (2004), Megabus US (2006)	
6116	Other Schools and Instruction	2001		NCLB Supplemental Educational Services	Local SES providers	The No Child Left Behind Act (2001) created a standardized tutoring market for Title I schools, which made this service contractible at scale.
2131	Support Activities for Mining	2002		Slickwater shale fracking	Frac Tech Services (2002), Calfrac (2002 US entry), ProPetro (2005)	
3279	Other Nonmetallic Mineral Product Manufacturing	2002	2002	Engineered quartz	Cambria Quartz (2000), DuPont Zodiaq (2000)	
6223	Specialty (except Psychiatric and Substance Abuse) Hospitals	2002	2002	Physician-Owned Specialty Facilities	Local speciality hospitals	
5611	Office Administrative Services	2003		SOX 404 internal-controls system	Genpact* (2005, spinoff of GE), small admin/BPO entrants	SOX 404 codified a testable workflow for providers to execute: an institutional innovation that created a contractible product.
6216	Home Health Care Services	2003		Web-based home-health EHRs	Amazing Care Home Health (2004), local home healthcare firms	

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
7225	Restaurants and Other Eating Places	2003		Open-kitchen, limited-service model	Five Guys* (2003), Shake Shack (2004), Smashburger (2007)	
2111	Oil and Gas Extraction	2006		Multi-stage horizontal fracking	Laredo Petroleum (2006), Northern Oil & Gas (2006), Oasis Petroleum (2007)	
2122	Metal Ore Mining**	2006**	2006**	HPGR commercialization in mining**	General Moly* (2007)	HPGR commercialization in mining was incumbent-led, and the most visible discrete shock that galvanized entrants was demand from China, not a discrete breakthrough. Kept for transparency.
4242	Drugs and Druggists' Sundries Merchant Wholesalers	2006		NABP VAWD accreditation	FFF Enterprises (2006)	NABP's VAWD was a market-design innovation that created a uniform audit, license verification, and inspection regime that pharmacies and PBMs could trust.
5191	Other Information Services	2006		In-browser Flash video	Crunchyroll (2006), Hulu (2007)	
3365	Railroad Rolling Stock Manufacturing	2007		Hybrid locomotive switchers	National Railway Equipment* (2006), Brookville* (2008, BL20GH)	
4879	Scenic and Sightseeing Transportation, Other	2007		Canopy tour systems	Hocking Hills Canopy Tours (2007), Navitat Canopy Adventures (2010)	
4882	Support Activities for Rail Transportation	2007		Web-based AEI tracking	ShipXpress (2007), smaller third-party providers	
3112	Grain and Oilseed Milling	2008		Gluten-free milling	Montana Gluten Free (2009), smaller mills (especially gluten free oat mills)	
3119	Other Food Manufacturing	2008	2012	High-purity sweeteners	Truvia* (2008), Purevia* (2008)	High-purity Rebiana was introduced, which offered a cleaner taste profile, helping to overcome aftertaste associated with less refined stevia.

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
3114	Fruit and Vegetable Preserving and Specialty Food Manufacturing	2009		Sterilized fruit pouches	GoGo squeeZ (2008), Peter Rabbit Organics (2009), Buddy Fruits (2009), Happy Family* (2009)	In 2008, the fruit food manufacturing industry began selling retail aseptic fruit puree pouches. Compared to traditional methods, aseptic pouches retain more nutrients and flavor; and allow the fruit to be stored at room temperature without preservatives.
3115	Dairy Product Manufacturing	2009		Ultrafiltration: strained high-protein yogurt	Noosa Yoghurt (2009)	
3122	Tobacco Manufacturing	2009	2009	E-cigarettes	VMR Products (2009)	
3254	Pharmaceutical and Medicine Manufacturing	2009		Single-use bioreactor (SUBs) manufacturing	Gallus BioPharmaceuticals (2010), Pfenex (2009)	
4861	Pipeline Transportation of Crude Oil	2009	2009	Shale crude gathering networks	Rangeland Energy (2009), Bridger Pipeline LLC (2010)	
3113	Sugar and Confectionery Product Manufacturing	2010		Stand-up pouch packaging for snacks	Unreal Brands (2010), barkTHINS (2013)	
3118	Bakeries and Tortilla Manufacturing	2010		Mobile point of sale	Cinnaholic (2010), Baked by Melissa* (2008)	
4523**	General Merchandise Stores, including Warehouse Clubs and Supercenters**	2010**		RFID/EPC	Local entrants	My method also selected RFID/EPC as a breakthrough in 2000. Since the technology had considerably matured by 2010, this selection likely reflects industry process innovation (inventory accuracy and shrink control) rather than a discrete shock. Kept for transparency.

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Table A.1 continued.

NAICS4	Industry	Year (10%)	Year (5%)	Breakthrough	Prominent Entrants (First 5 Years)	Comments
1131	Timber Tract Operations	2011		Compliance forest-carbon protocols	Carbon-oriented timber firms	This institutional innovation transformed the national business model for timber tracts by enabling verifiable revenue generation from carbon sequestration and conservation.
8129	Other Personal Services	2012		On-demand service apps	Rover.com (2011), Wag Labs (2015)	

Notes:
Year (5%) reports the baseline threshold used in the paper. Year (10%) reports breakthrough timing under a less stringent threshold; Year (5%) entries are blank for industries not selected at 5%. When breakthrough timing differs across thresholds and the underlying breakthrough also differs, the reported breakthrough descriptions and entrant lists are ordered as: 10%; 5%.
* Indicates firms founded prior to the breakthrough year but which entered the focal industry within the 5-year window, typically through product development or acquisition.
** Indicates a possible false positive.

Appendix B. Robustness Using Public NAICS-4 Data

The main results are robust to a wide range of minor adjustments to the breakthrough detection procedure. Reporting the full set of robustness exercises at the NAICS-6 level would substantially increase the volume of confidential output subject to Census disclosure review, imposing nontrivial administrative constraints without providing additional information about the stability of the results. Instead, this appendix documents robustness using publicly available NAICS-4 tabulations from the Business Dynamics Statistics. This approach both respects Census disclosure limits and provides an independent robustness check across a different level of industry aggregation. Since the NAICS-4 public data tabulates entry and exit at the industry level, the analysis in this appendix focuses on Facts 1-3, which do not depend on the firm-level data required for entrant-incumbent analysis.

B.1 Breakthrough Detection at the NAICS-4 Level

Before turning to robustness adjustments, I first re-establish the baseline facts using publicly available NAICS-4 tabulations from the Business Dynamics Statistics, applying the same breakthrough detection procedure as in the main paper. This step isolates the effect of industry aggregation by holding the detection strategy fixed while changing only the level at which industries are defined. As in the main analysis, the detection procedure is calibrated at the 95th percentile (top 5%) of the adjusted net entry rate distribution.

B.1.1 Timing and Frequency of Breakthrough Industry Detection

Figure B.1 reports the share of NAICS-4 industries classified as having experienced a breakthrough in each year. This figure is the NAICS-4 analogue of Figure 4 in Section 2.3: the detection procedure is identical and uses a chosen threshold of the top 5% of the adjusted net entry rate distribution.

The concentration of detected breakthroughs in the first sample year (1978) reflects a left-censoring effect inherent in the detection procedure. A breakthrough is defined as the first year of a sequence of five consecutive threshold exceedances. If an industry experienced a sustained entry surge prior to the beginning of the sample window (here, 1978-2019) and that surge remains elevated when the sample begins, the earliest observable year will satisfy the five-year condition and will be recorded as the breakthrough year. Pre-sample breakthrough episodes are therefore mechanically assigned to the first year of available data. This left-censoring affects the timing of detected breakthroughs but does not affect the subsequent dynamics that constitute the core empirical facts.

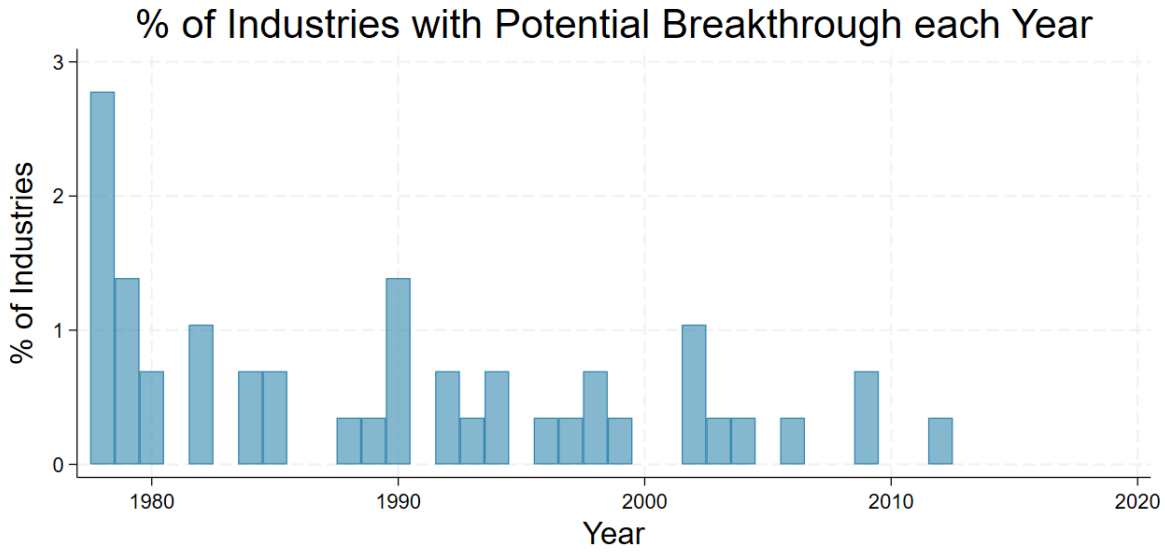

Figure B.1. The unit of observation is a NAICS-4 digit industry (39 industries and 46 breakthroughs are selected out of 288 industries). Figure shows the percentage of industries classified as a breakthrough industry each year, based on a 5% threshold. Note that given that the data spans 1978 to 2019 and the procedure employs five-year periods, the breakthrough industry selection years range from 1978 to 2014.

B.1.2 Variance of Net Entry Rate has been Decreasing

Similar to Figure 5 in Section 2.4, the cross-sectional variance of net entry rates across industries declines over time at the NAICS-4 level. Because the breakthrough detection procedure removes time fixed effects, this pattern does not reflect changes in the level of firm entry over time. Instead, it reflects a compression in the distribution of industry-specific deviations from the mean, indicating a decline in the prevalence of extreme outperforming industries.

Figure B.2 compares the annual cross-industry net entry rate variance at the NAICS-4 and NAICS-6 levels. The left panel reproduces the left panel of Figure 5 in Section 2.4, shown at annual frequency rather than in two-year bins. The right panel reports the corresponding series at the NAICS-6 level. In both cases, the standard deviation of net entry rates declines substantially over time, indicating that entry-driven breakthroughs have been decreasing.

Note that across aggregation levels the timing and shape of the decline in variance differs. At the NAICS-4 level, dispersion falls gradually over the sample period, whereas at the NAICS-6 level the decline is more abrupt after 1990, with the standard deviation falling from above 10% in the 1980s to around 5% thereafter. One interpretation is that finer industry classifications are more sensitive to reclassification, particularly in earlier periods, while aggregation at the NAICS-4 level smooths fluctuations across narrowly defined industries. Distinguishing measurement effects from economic mechanisms is beyond the scope of this paper, but the comparison highlights how aggregation affects the apparent evolution of entry rates.

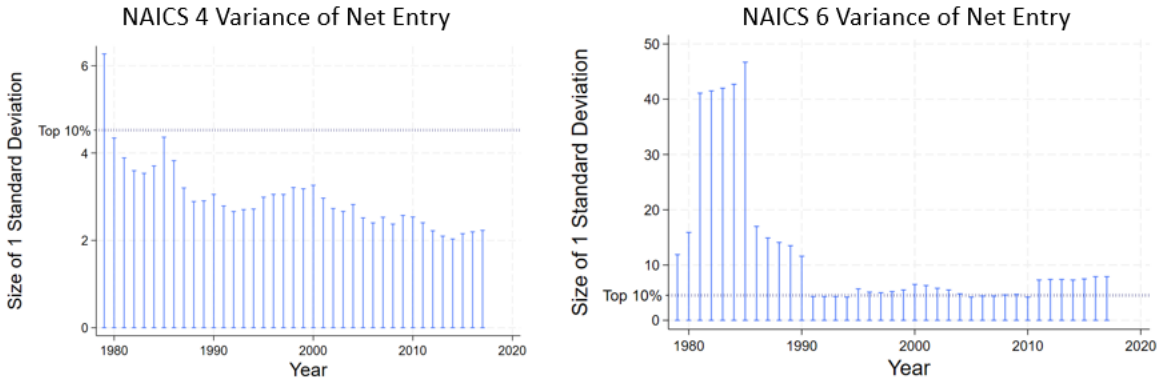

Figure B.2. The figure plots the cross-sectional standard deviation of raw net entry rates across industries by year. In the left panel, the unit of observation is a NAICS-4 industry using public BDS tabulations ($N = 288$). In the right panel, the unit of observation is a NAICS-6 industry ($N = 1{,}012$ industries). Both panels illustrate a pronounced decline in the dispersion of industry-level net entry rates between 1979-2017.

B.2 Facts 1–3 at the NAICS-4 Level

Having re-established breakthrough detection at the NAICS-4 level, I now show that the three core empirical facts documented in the main text continue to hold under this aggregation.

B.2.1 Fact 1: Heterogeneity in Post-Breakthrough Firm Dynamics

Figure B.3 shows that at the NAICS-4 level, breakthrough industries continue to exhibit substantial heterogeneity in net entry, which results in monotonic increases in the number of firms for some industries and shakeouts for others.

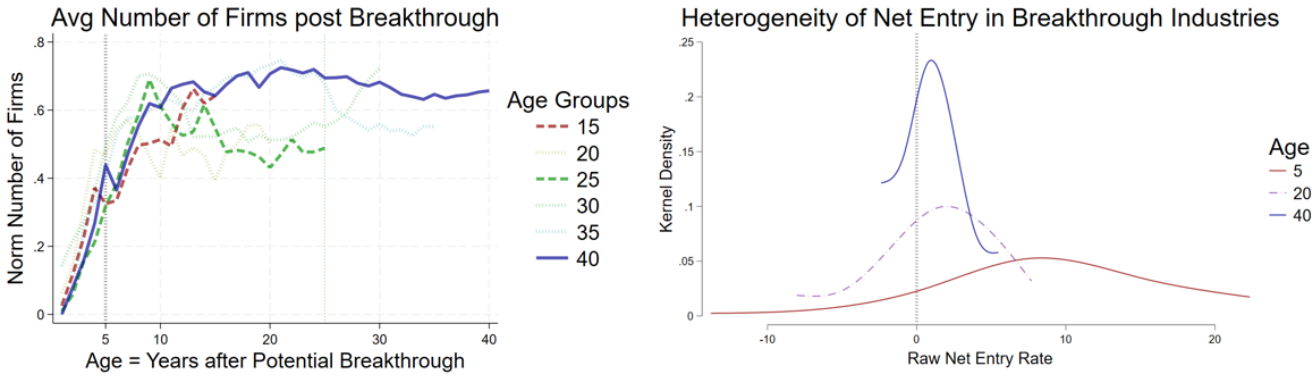

Figure B.3. The unit of observation is a NAICS 4-digit industry ($N = 46$). The left panel displays the normalized number of firms. The right panel displays the distribution of raw net entry rates across industries at ages 5, 20, and 40, with age defined as the number of years since each industry's selected breakthrough. The x-axis represents the raw net entry rate, or the rate calculated before any statistical adjustments.

B.2.2 Fact 2: Most of the breakthrough industries do not shake out

Figure B.4 shows that at the NAICS-4 level, most breakthrough industries do not experience shakeouts.

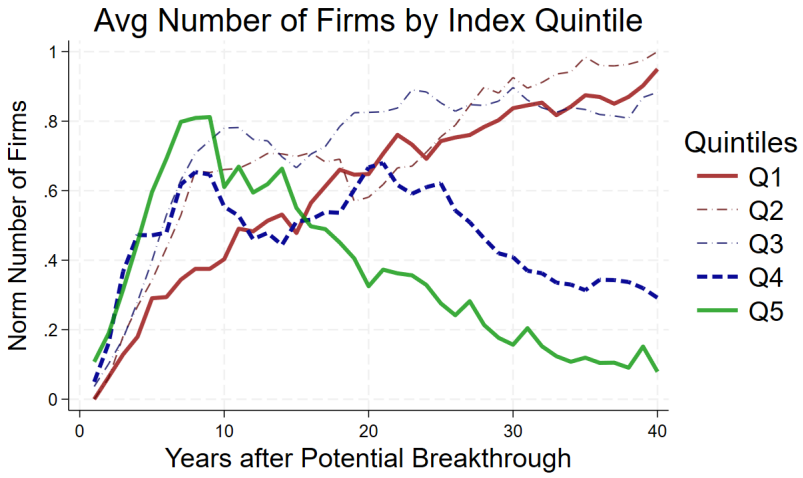

Figure B.4. The unit of observation is a 4-digit industry ($N = 46$). The figure displays the normalized number of firms, averaged across five panels of breakthrough industries based on their score on the Shakeout Index.

B.2.3 Fact 3: Labor reallocates toward breakthrough industries

Figure B.5 shows that employment reallocates toward breakthrough industries at the NAICS-4 level.

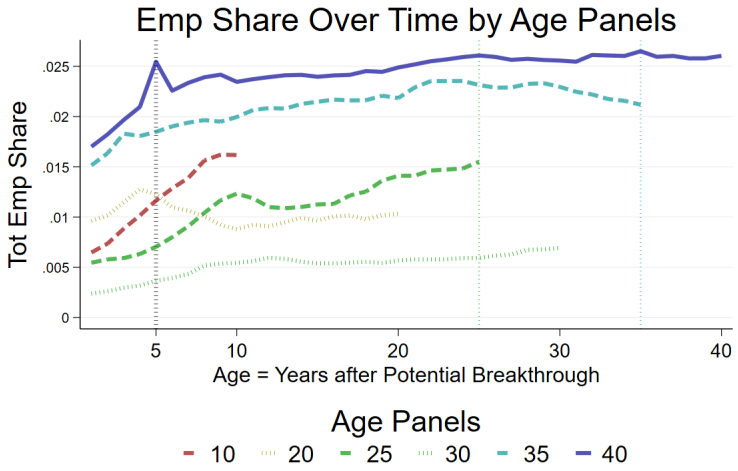

Figure B.5. The unit of observation is a 4-digit industry ($N = 46$) across the 1978-2019 observation window. The plot shows industry employment as a share of total national employment, averaged by age across seven panels of breakthrough industries.

B.3 NAICS-4 Sample Starting in 1990

As an additional robustness exercise, I repeat the NAICS-4 facts restricting the observation window to 1990–2019. This specification excludes the earliest years of the sample and assesses whether the main empirical patterns are sensitive to the initial decades of the data. Figure B.6 reports the share of industries classified as experiencing a breakthrough in each year under this restricted sample.

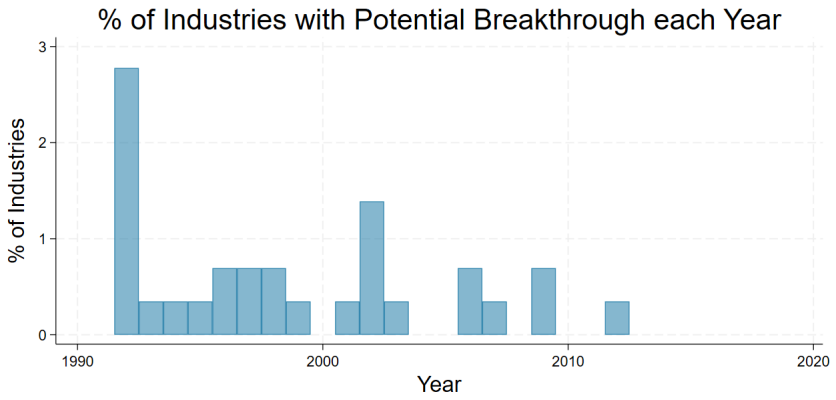

Figure B.6. The unit of observation is a NAICS-4 digit industry (29 industries and 30 breakthroughs are selected out of 288 industries). Figure shows the percentage of industries classified as a breakthrough industry each year, based on industries from the BDS tabulations. Note that given that the data spans 1990 to 2019 and the procedure employs five-year periods, the breakthrough industry selection years range from 1990 to 2014.

The three core empirical facts remain qualitatively unchanged under this restricted sample.

B.3.1 Fact 1: Breakthrough industries display enormous shakeout heterogeneity

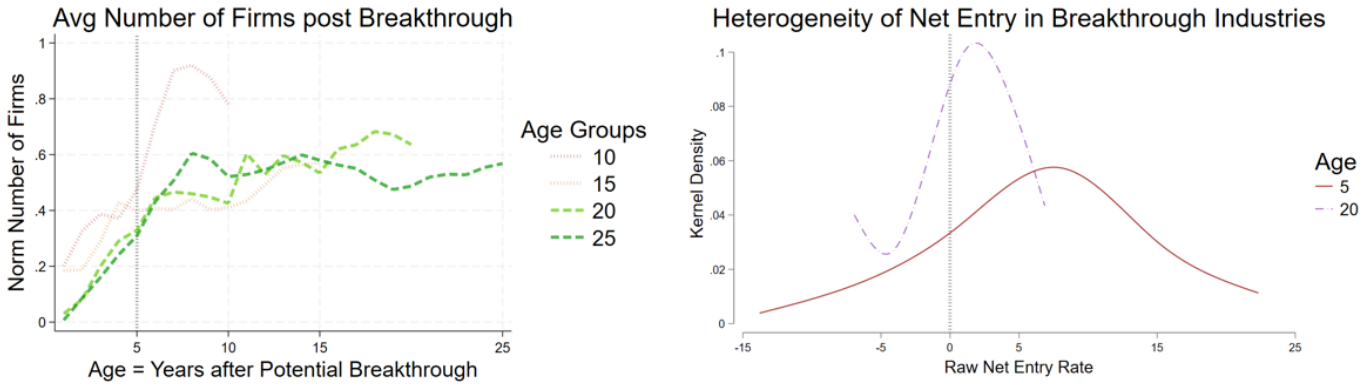

Figure B.7. The unit of observation is a NAICS 4-digit industry ($N = 30$) across the 1990-2019 observation window. The left panel displays the normalized number of firms. The right panel displays the distribution of raw net entry rates across industries at ages 5 and 20.

B.3.2 Fact 2: Most of the breakthrough industries do not shake out

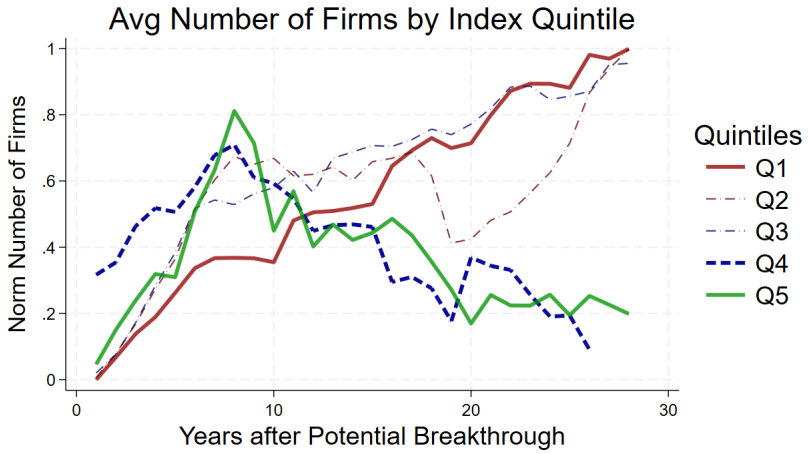

Figure B.8. The unit of observation is a NAICS 4-digit industry ($N = 30$). The figure displays the normalized number of firms, averaged across five panels of breakthrough industries based on their score on the Shakeout Index.

B.3.3 Fact 3: Labor reallocates toward breakthrough industries

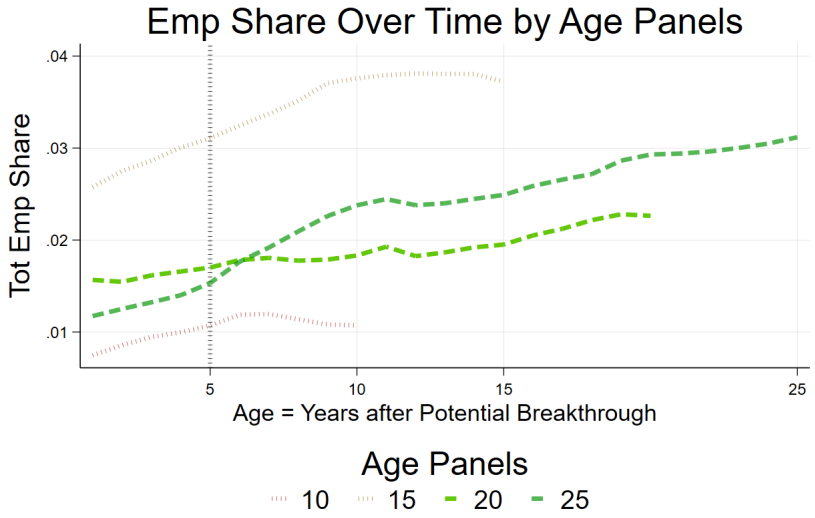

Figure B.9. The unit of observation is a NAICS 4-digit industry ($N = 30$). The plot shows industry employment as a share of total national employment, averaged by age across seven panels of breakthrough industries.

B.4 Selection Threshold: 10 Percent

As an additional robustness exercise, I relax the breakthrough selection threshold from the baseline top 5 percent to the top 10 percent. This specification assesses whether the main empirical patterns are sensitive to the exact percentile cutoff used to define periods of outlier entry. All other components of the detection procedure remain unchanged, including the removal of fixed effects, five-year smoothing, and the requirement of sustained threshold exceedance. Figure B.10 reports

the timing and frequency of detected breakthroughs under this alternative threshold.

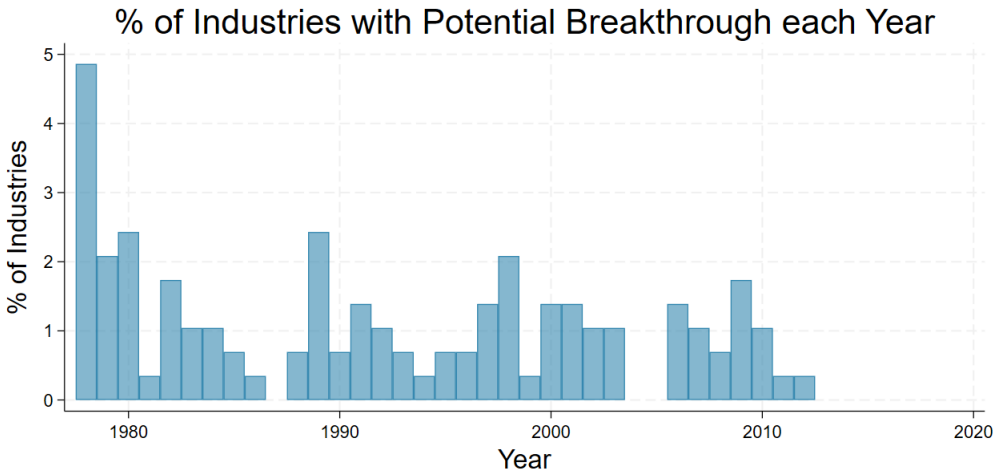

Figure B.10. The unit of observation is a NAICS-4 digit industry (87 industries and 111 breakthroughs are selected out of 288 industries). Figure shows the percentage of industries classified as a breakthrough industry each year, based on industries from the BDS tabulations.

The three core empirical facts remain qualitatively unchanged.

B.4.1 Fact 1: Breakthrough industries display enormous shakeout heterogeneity

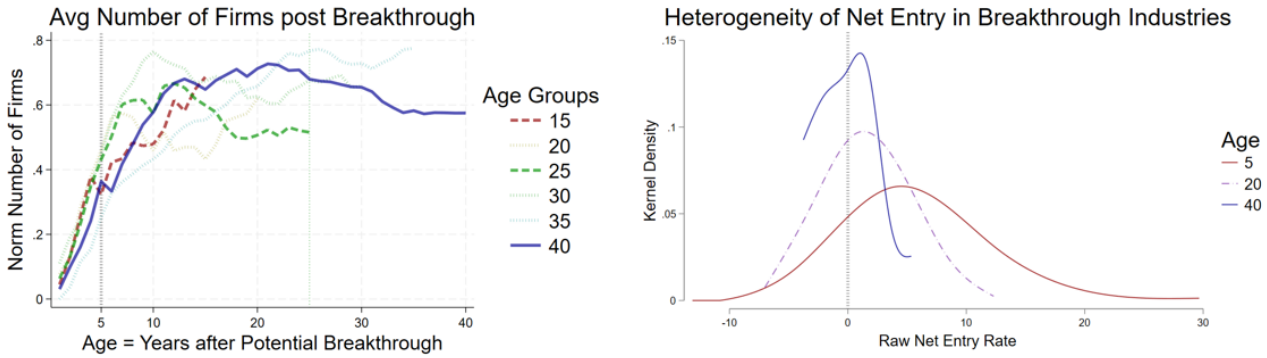

Figure B.11. The unit of observation is a NAICS 4-digit industry ($N = 111$). The left panel displays the normalized number of firms. The right panel displays the distribution of raw net entry rates across industries at ages 5, 20, and 40.

B.4.2 Fact 2: Most of the breakthrough industries do not shake out

Figure B.12 shows that at the NAICS-4 level, most breakthrough industries do not experience shakeouts.

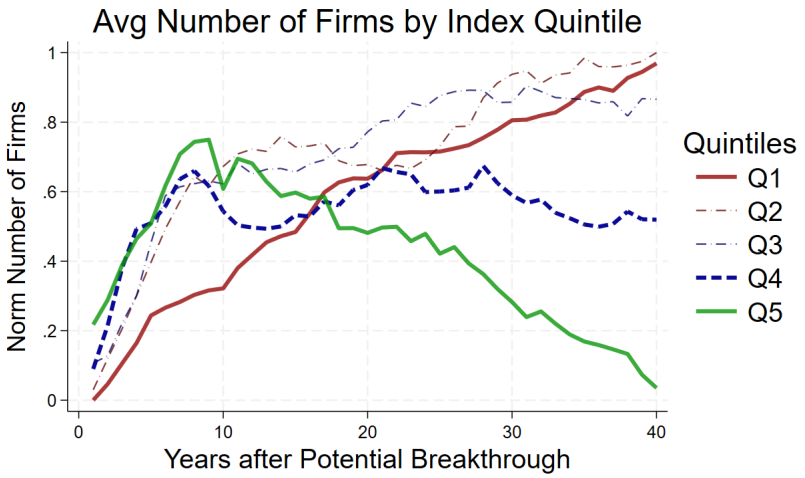

Figure B.12. The unit of observation is a 4-digit industry ($N = 111$). The figure displays the normalized number of firms, averaged across five panels of breakthrough industries based on their score on the Shakeout Index.

B.4.3 Fact 3: Labor reallocates toward breakthrough industries

Figure B.13 shows that employment reallocates toward breakthrough industries at the NAICS-4 level.

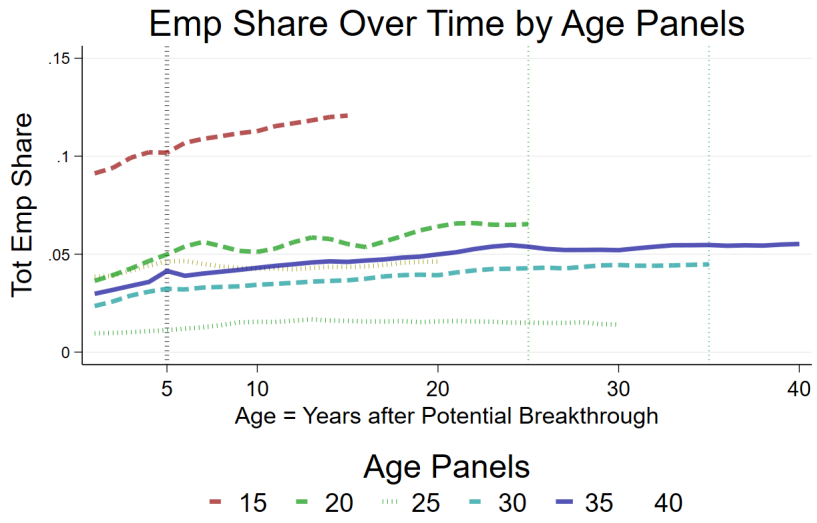

Figure B.13. The unit of observation is a 4-digit industry ($N = 111$) across the 1978-2019 observation window. The plot shows industry employment as a share of total national employment, averaged by age across seven panels of breakthrough industries.

B.5 Annual Cross-Section Threshold

I next redefine the outlier threshold relative to the cross-section of industries within each year rather than relative to the pooled distribution over the entire sample window. In the baseline

specification, industry-year observations are classified as outliers if their filtered net entry residual lies above a fixed percentile of the pooled 1978–2019 distribution. In this alternative specification, the percentile cutoff is computed separately within each calendar year. Formally, the set of outliers E is defined as the collection of industry-year pairs whose residual lies in the top γ percent of the contemporaneous cross-sectional distribution. All other elements of the detection rule remain unchanged. Figure B.14 reports the resulting breakthrough timing under this specification.

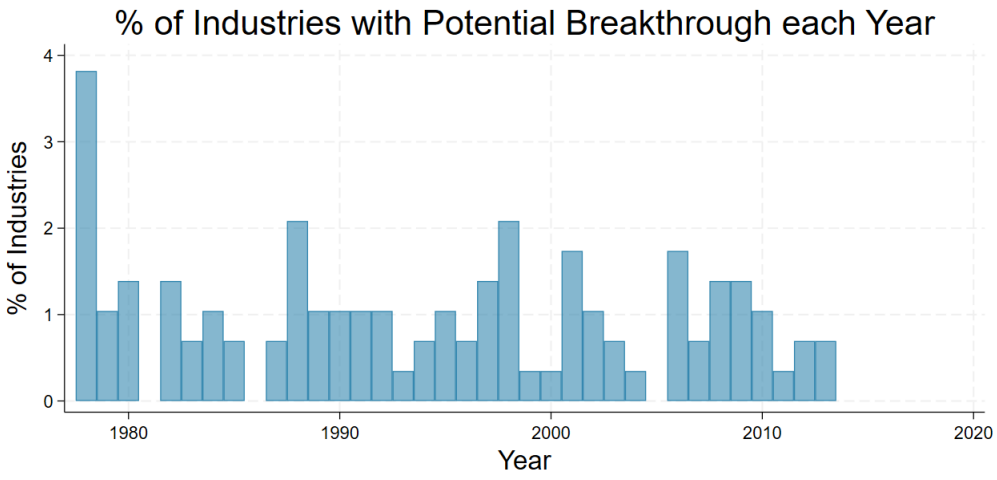

Figure B.14. The unit of observation is a NAICS-4 digit industry (84 industries and 103 breakthroughs are selected out of 288 industries). Figure shows the percentage of industries classified as a breakthrough industry each year, based on industries from the BDS tabulations.

The three core empirical facts remain qualitatively unchanged.

B.5.1 Fact 1: Breakthrough industries display enormous shakeout heterogeneity

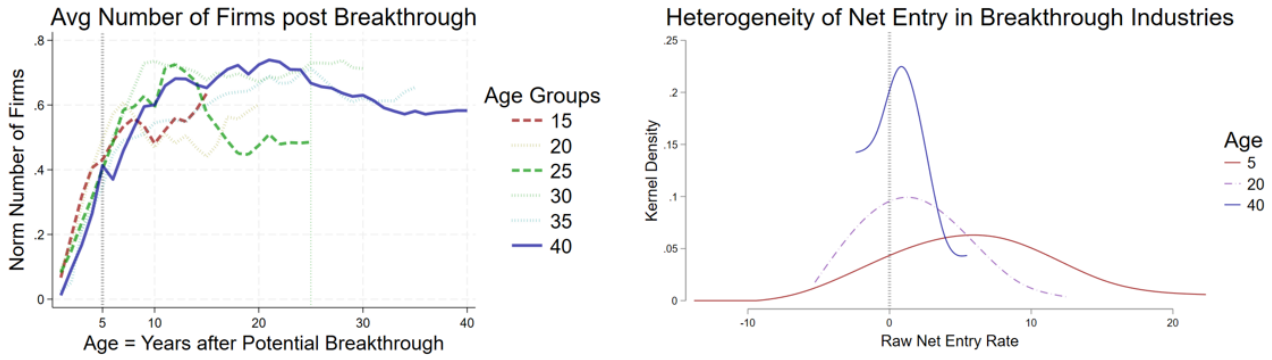

Figure B.15. The unit of observation is a NAICS 4-digit industry ($N = 103$). The left panel displays the normalized number of firms. The right panel displays the distribution of raw net entry rates across industries at ages 5, 20, and 40.

B.5.2 Fact 2: Most of the breakthrough industries do not shake out

Figure B.16 shows that at the NAICS-4 level, most breakthrough industries do not experience shakeouts.

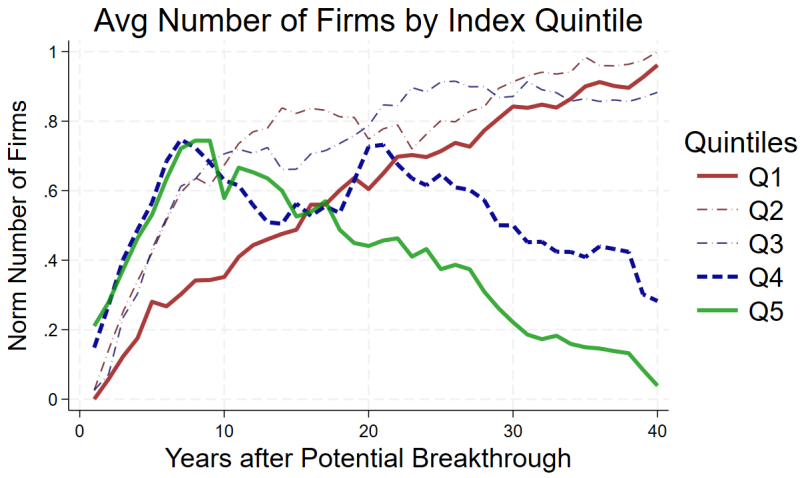

Figure B.16. The unit of observation is a 4-digit industry ($N = 103$). The figure displays the normalized number of firms, averaged across five panels of breakthrough industries based on their score on the Shakeout Index.

B.5.3 Fact 3: Labor reallocates toward breakthrough industries

Figure B.17 shows that employment reallocates toward breakthrough industries at the NAICS-4 level.

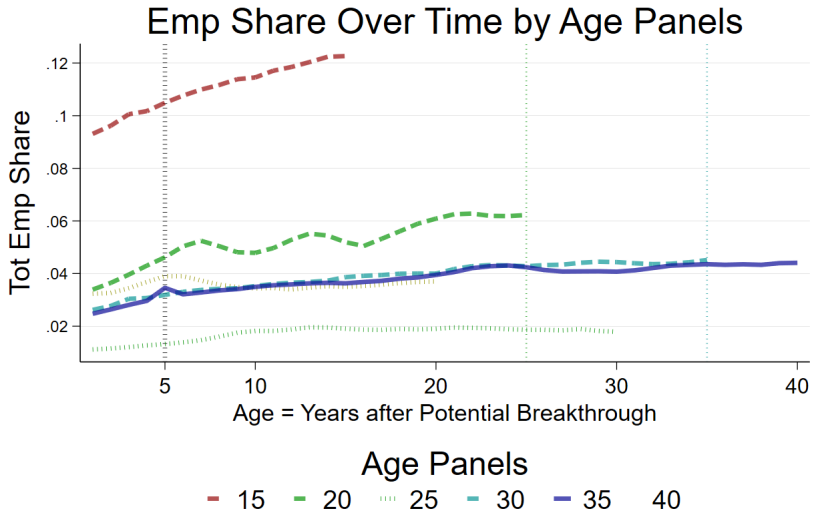

Figure B.17. The unit of observation is a 4-digit industry ($N = 103$) across the 1978-2019 observation window. The plot shows industry employment as a share of total national employment, averaged by age across seven panels of breakthrough industries.

B.6 Robustness to Smoothing Windows

The baseline detection procedure smooths fixed-effects-adjusted net entry residuals using a five-year moving average to reduce short-run fluctuations. As a robustness check, I select breakthroughs under alternative smoothing specifications: (i) no smoothing, and (ii) a two-year moving average. All other elements of the detection rule, including the percentile threshold (5%) and sustained exceedance requirement, remain unchanged.

Figure B.18 and Figure B.19 report the resulting breakthrough timing distributions under these alternative specifications. The pattern of selected breakthroughs are qualitatively similar to the baseline in Figure B.1, indicating that the main results are not driven by the choice of smoothing window.

B.6.1 No Smoothing

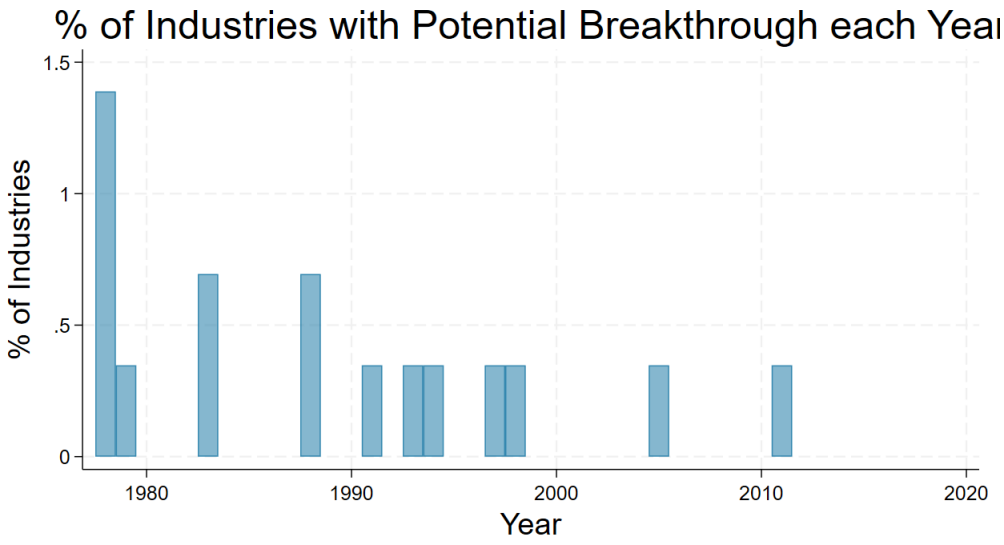

Figure B.18. The unit of observation is a NAICS-4 digit industry (14 industries and 16 breakthroughs are selected out of 288 industries). Figure shows the percentage of industries classified as a breakthrough industry each year, based on industries from the BDS tabulations.

B.6.2 Two-Year Smoothing Window

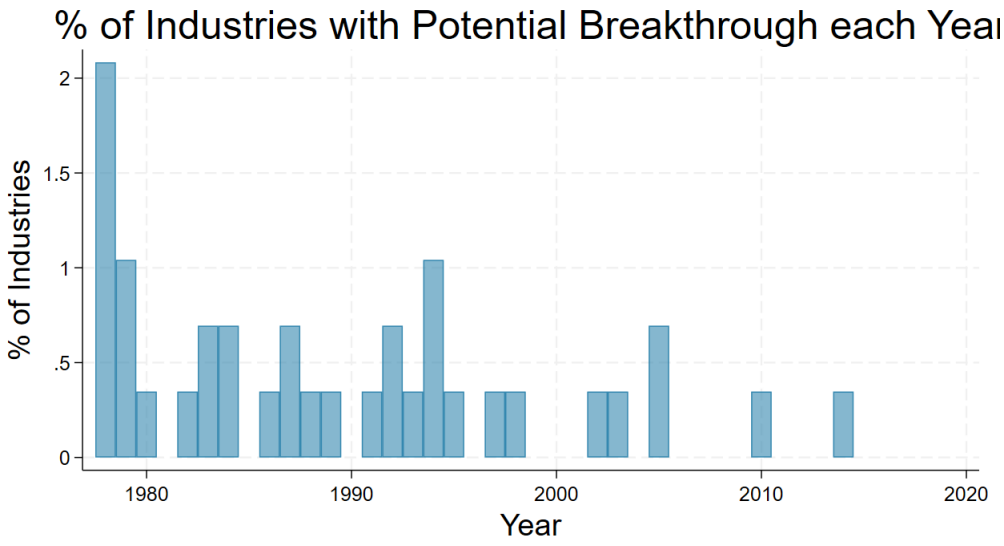

Figure B.19. The unit of observation is a NAICS-4 digit industry (30 industries and 36 breakthroughs are selected out of 288 industries). Figure shows the percentage of industries classified as a breakthrough industry each year, based on industries from the BDS tabulations.

Appendix C. Supplemental Material for the Detection Procedure and Empirical Facts

This appendix provides supplementary figures and methodological details accompanying the breakthrough detection procedure and the empirical facts presented in the main text. In particular, it documents the construction of key distributions and indices, clarifies disclosure-related constraints, and presents additional figures referenced in the Facts section.

C.1 Fact 1: Interpolation of net entry rate distributions

This subsection describes the disclosure constraints and interpolation procedure underlying the right panel of Fact 1, which presents the cross-industry distribution of raw net entry rates at ages 5, 20, and 40.

To comply with Census disclosure standards, each cross-industry distribution is released in discretized form. Net entry rates are grouped into a small number of bins (5-6), and for each bin only the midpoint and associated density are retained. All reported distributions are therefore constructed exclusively from these disclosed binned values.

To facilitate visual comparison across ages, a continuous curve is interpolated through the disclosed bin midpoints and densities using a cubic smoothing spline. For each age-specific distribution, the spline is estimated by minimizing the penalized least-squares criterion

$$\sum_i (y_i - f(x_i))^2 + \lambda \int (f''(x))^2 dx,$$

where x_i denotes the disclosed bin midpoints and y_i the corresponding densities. The smoothing parameter is chosen ex ante and held fixed across all distributions in the main text and appendices (corresponding to `spar = 0.25` in R's `smooth.spline` function). The fitted spline is evaluated on an evenly spaced grid of 300 points over the support of the disclosed data to obtain a continuous approximation of the underlying distribution. No information beyond the disclosed bin midpoints and densities is used in constructing these interpolated curves.

Figure C.1 displays the underlying disclosed bins for the distributions shown in the right panel of Fact 1.

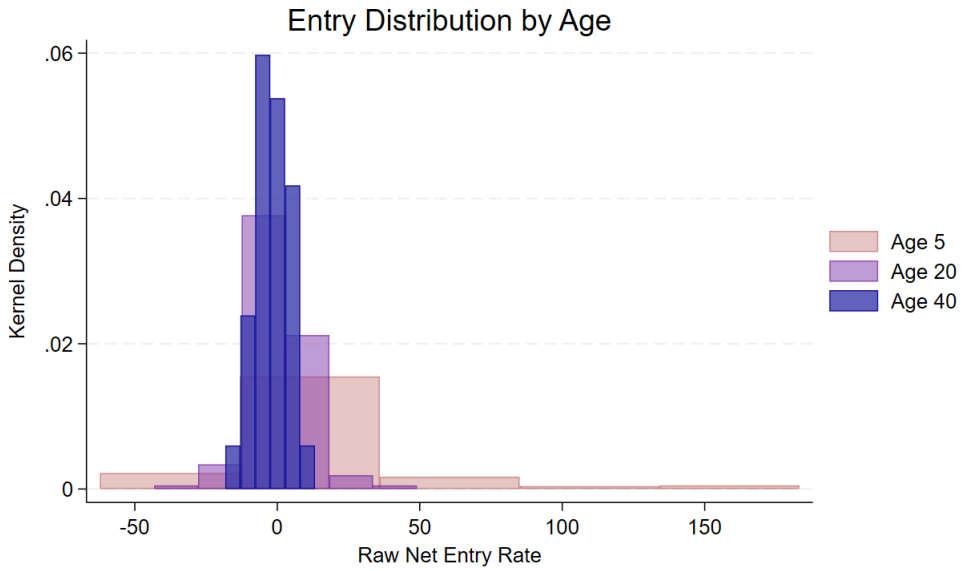

Figure C.1. The unit of observation is a NAICS 6-digit industry ($N = 191$). Overlay of Census-disclosed bins for the cross-industry distribution of raw net entry rates at ages 5, 20, and 40 NAICS-6 industries. Bar widths reflect disclosed bin widths and bar heights the corresponding densities.

C.1.1 Fact 2: Split by major sector, most of the breakthrough industries do not shake out

This subsection examines whether the absence of shakeouts documented in Fact 1 holds within major sectors. Figure C.2 plots the normalized number of firms for breakthrough industries, aggregated at the NAICS 4-digit level and grouped by major sector (NAICS 2-digit). Most sectors do not exhibit systematic shakeout dynamics on average. The primary exceptions are Manufacturing (NAICS 31-33) and Finance and Real estate (NAICS 52-53), which display patterns consistent with shakeouts. The presence of shakeouts in manufacturing aligns with the existing literature.

Due to sparsity concerns in sector-level analysis, breakthrough industries are defined using the 10% threshold rather than the baseline 5% threshold. At the 5% threshold, each sector contains only 3-9 breakthrough industries, leading to substantial cohort composition issues because industries

enter and exit the sample at different times. Expanding to the 10% threshold increases the number of breakthrough industries per sector to 10-28, which substantially mitigates these concerns. To further address cohort imbalance, I restrict the observation window to 35 years, rather than the full 1978-2019 span (42 years), as relatively few industries are observed over the full horizon.

To isolate within-sector dynamics, I normalize firm counts by total sector size. Specifically, for industry i in year t, I compute:

$$\text{Normalized Firms in Sector}_{it} = \frac{\text{Firms}_{it}}{\text{Firms in Sector}_{it}}$$

This adjustment removes variation driven by aggregate sectoral expansion or contraction, such as the long-run decline in manufacturing, ensuring that the reported dynamics reflect relative performance within sectors. The resulting series are then normalized to lie in [0,1] as described in Section **??**.

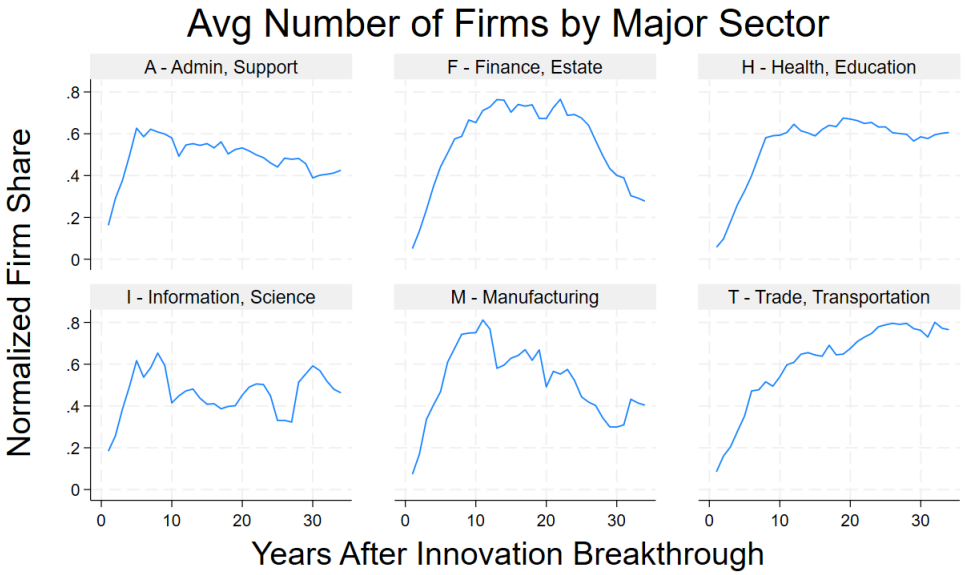

Figure C.2. The unit of observation is a NAICS 4-digit breakthrough industry. Panels correspond to major sectors (NAICS 2-digit: "Admin, Support" corresponds to NAICS 56; "Finance, Estate" corresponds to NAICS 52-53; "Health, Education" corresponds to NAICS 61-62; "Information, Science" corresponds to NAICS). Within each panel, firm counts are first adjusted by total sector size and then normalized as in Section **??**.

C.2 Fact 2: Mathematical formalization of the Shakeout Index

This subsection provides a formal definition of the Shakeout Index used to classify industries by shakeout intensity.

Let an industry's firm count trajectory be observed over its lifespan. The global maximum (peak) occurs either in the interior of the observation window or at its boundary. The construction of the index depends on this distinction.

Case 1: Interior Maximum. Suppose the global maximum occurs strictly within the observation period.

- Let T denote the final year of observation. Define three intermediate components:

$$\begin{aligned}
\widetilde{\text{RD}} &= 1 - \frac{\text{Firm count at trough}}{\text{Firm count at peak}}, \\
\widetilde{\text{DD}} &= \frac{\text{Year of trough} - \text{Year of peak}}{\text{Lifespan}}, \\
\widetilde{\text{CER}} &= \frac{\text{Firm count at } T}{\text{Firm count at Year 1}}.
\end{aligned}$$

- To limit the influence of extreme decline durations, I apply a logistic transformation to $\widetilde{\text{DD}}$

$$f(x) = \frac{1}{1 + e^{-x}}$$

  This transformation compresses large values while preserving ordinal rankings.

Case 2: Boundary Maximum. If the global maximum occurs at the right boundary (i.e., in the final year of observation), no post-peak decline is observed.

- In this case, I set $\widetilde{\text{RD}} = 0$ and $\widetilde{\text{DD}} = 0$. Here, variation in the Shakeout Index is driven solely by $\widetilde{\text{CER}}$.

Final Index Construction. In both cases, each component is shifted by 1 to ensure positive values. The final Shakeout Index components are:

$$\begin{aligned}
\%\ \text{Decline}_i &= \widetilde{\text{RD}} + 1, \\
\text{Decline Duration}_i &= f(\widetilde{\text{DD}}) + 1, \\
\text{Cumulative Entry Rate}_i &= \widetilde{\text{CER}} + 1.
\end{aligned}$$

The Shakeout Index is constructed from these components to provide a quantitative ranking of industries by shakeout intensity. Industries with large, sustained post-peak contractions are assigned higher index values and appear in the upper quintiles, while industries with little or no decline are concentrated in the lower quintiles.

C.2.1 Fact 3: Labor reallocates away from declining industries

Fact 3 documents that breakthrough industries absorb an increasing share of aggregate employment over time. While this pattern is mechanically mirrored by a decline in the employment share of non-breakthrough industries, it is useful to observe concrete examples where this decline reflects economically meaningful reallocation.

Figure C.3 presents employment shares for a set of prominent non-breakthrough industries that exhibit sustained decline over the sample period: printing, paper products, textiles, rubber products, and motor vehicle manufacturing. In each case, employment as a share of total U.S. employment decreases steadily over time, indicating a persistent reallocation of labor away from these sectors. The contrast between the industries below and the industries presented in Fact 3 highlights the economic significance of the reallocation documented in Fact 3 and supports the interpretation of breakthrough events as drivers of long-run structural change.

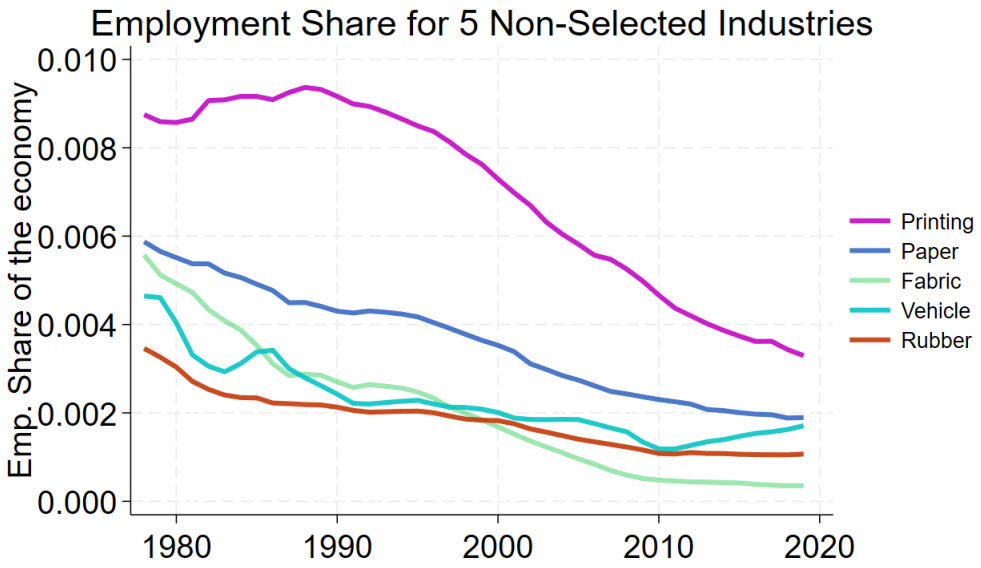

Figure C.3. Employment share trajectories for selected non-breakthrough industries. The unit of observation is a NAICS 4-digit industry. The figure plots industry employment as a share of total U.S. employment for five industries: NAICS 3132 (Fabric Mills), 3222 (Converted Paper Product Manufacturing), 3231 (Printing and Related Support Activities), 3262 (Rubber Product Manufacturing), and 3361 (Motor Vehicle Manufacturing).