Persistence of Growth Revisited - An Exploratory Analysis of US Data

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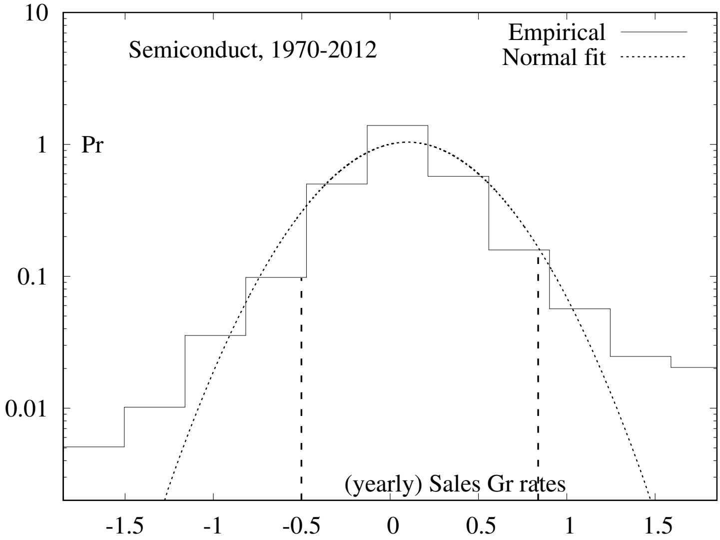
The Research Program: The Drivers of Firm Growth

- Why do some firms grow faster than others?
  - Innovation/ Productivity/ Organizational capabilities?
  - Strategy?
  - Industry?
  - Luck?
- Is growth persistent? Why?
  - How stable are the underlying drivers of growth?
  - What are the underlying dynamics?
- Why do some firms stop growing?

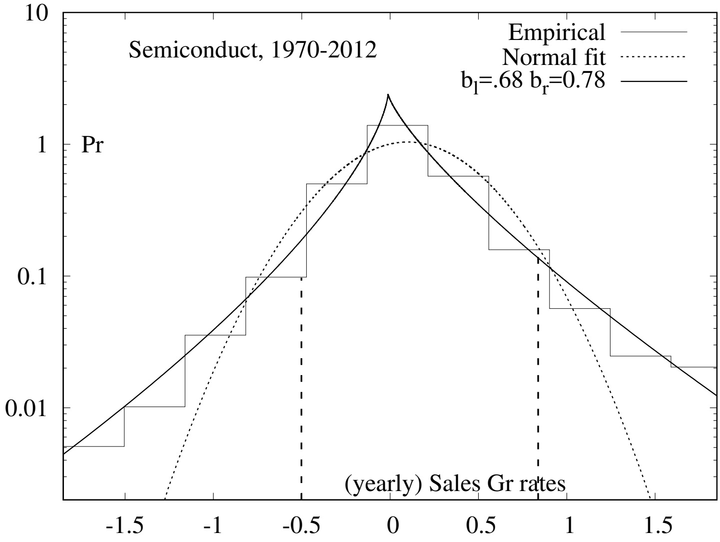
Why are these interesting questions?

- Growth is probably **the** single most important issue on the minds of practitioners - they all want their firms to grow
- The underlying issues cut across some of the most fundamentally important problems in organizational science and economics:
  - Innovation
  - Productivity
  - Organizational capabilities
  - Strategy and diversification
  - Organizational capabilities, learning and adaptability
- Heterogeneity in the growth process

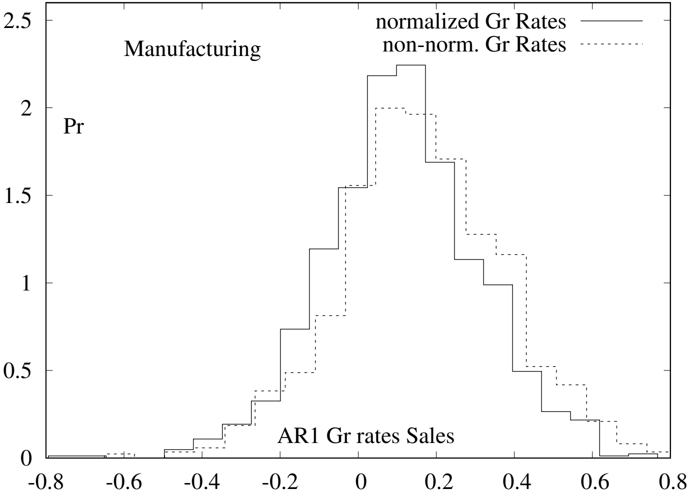
Growth rates distribution



Growth rates distribution - with tail index

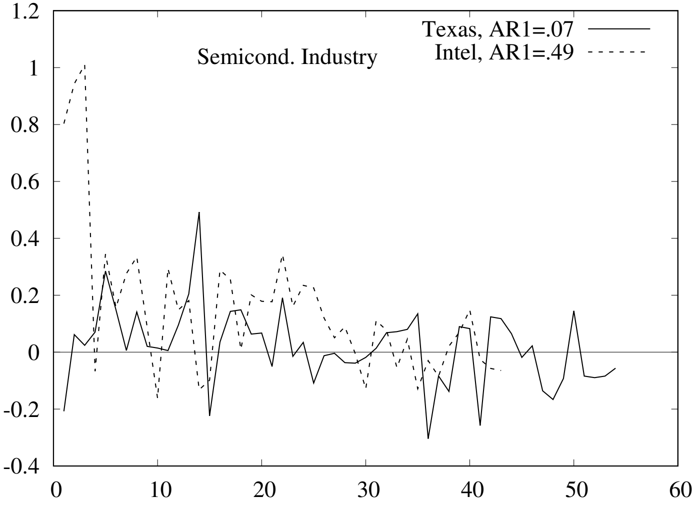


Persistence of firm growth



AR(1): $X_t = c + \varphi X_{t-1} + \varepsilon_t$

Profiles of firm sales growth (I)



Past Research: What We Know about Firm Growth

- Starting point is still Gibrat's Law, such as (in logs)

$$s_t - s_{t-1} = c + \lambda\, s_{t-1} + \epsilon_t \quad , \tag{1}$$

- The following stylised facts emerged (see review by Sutton, 1997 on JEL and Dosi 2007)
  - In general, $\lambda = 0$ (i.e. growth is random walk) is a good first approximation, especially for large firms
  - However, smaller firms tend to growth faster, on average, and $\lambda < 0$ especially among samples of small-micro firms
  - Smaller firms exhibit more volatile patterns: variance of growth rates decreases with size
  - The growth rates invariably fat-tailed (tent or Laplace) in different countries, sectors and periods of time
  - The generalized presence of fat tails in the distribution implies much more structure in the growth dynamics than generally assumed: 'lumpiness' and competition induces correlation

Past Research: What We Know about Firm Growth

- Variables that correlate with growth: Selection hp (Melitz, 2003); productivity growth more important than productivity levels (Dosi et al., 2015)
- basically no correlation with profitability (Coad, 2007; Bottazzi et al., 2010)
- Widespread recognition that financial constraints play a role in hampering growth (Bottazzi et al., 2014)
- Innovation proxies of various kind (R&D, patents, product and process innovation, ...) tend to have an effect especially for High-Growth firms in the top quantiles of the growth rates distribution (Coad and Rao, 2008; Bianchini et al., 2014)

A focus on the Productivity-growth nexus

The productivity-growth nexus is crucial, but how to measure multi-factor productivity with such intra-industry heterogeneity?

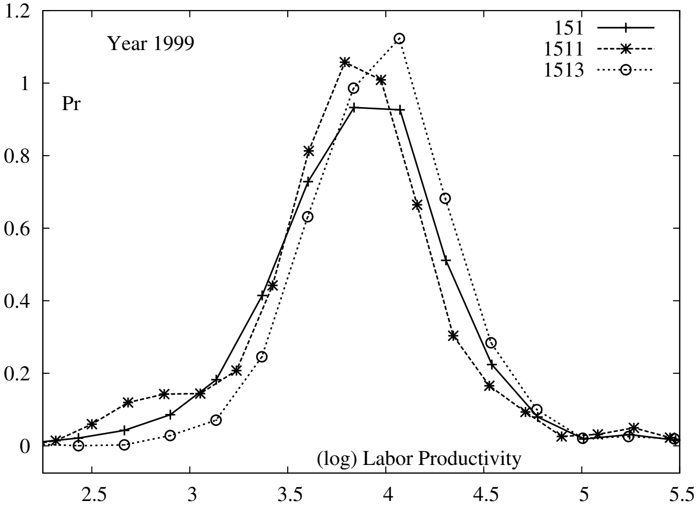
Robust evidence across many industries and countries (USA, Canada, UK, France, Italy, Netherlands, etc) consistently finds:

- wide asymmetries in productivity across firms
- equally wide heterogeneity in relative input intensities
- highly skewed distribution of efficiency, innovativeness and profitability indicators;
- **high intertemporal persistence in the above properties**
- **high persistence of heterogeneity also when increasing the level of disaggregation**

Disaggregation does not solve the problem

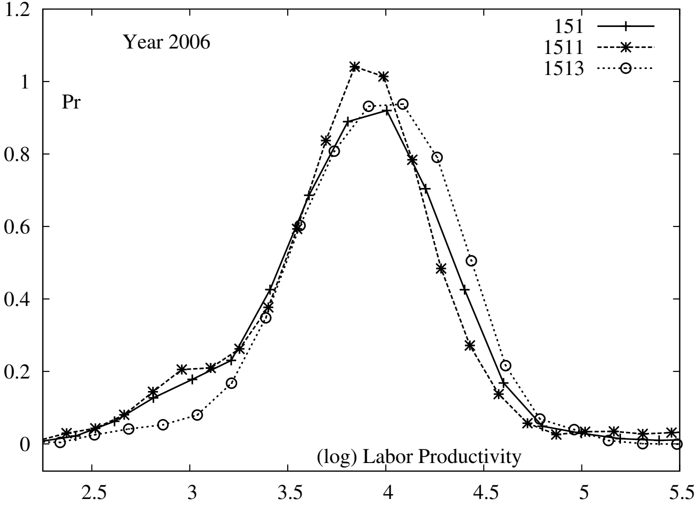
"*We [...] thought that one could reduce heterogeneity by going down from general mixtures as "total manufacturing" to something more coherent, such as "petroleum refining" or "the manufacture of cement." But something like Mandelbrot's fractal phenomenon seems to be at work here also: the observed variability-heterogeneity does not really decline as we cut our data finer and finer. There is a sense in which different bakeries are just as much different from each others as the steel industry is from the machinery industry.*" (Griliches and Mairesse, Production function: the search for identification, 1999)

Heterog. performances Meat Products (1999)



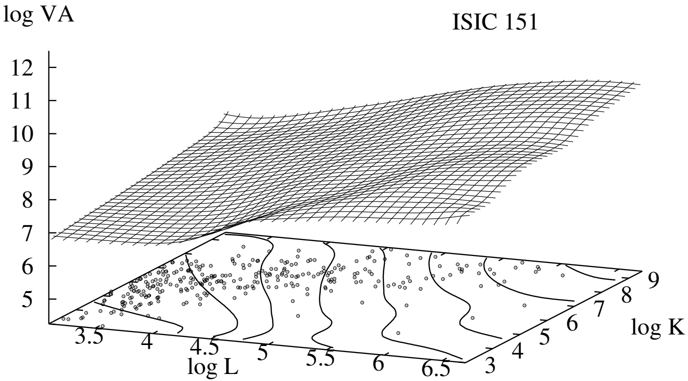
exp(3) ≈ 20 th. euro; exp(4.5) ≈ 90 th. euro

Heterog. in performances is persistent (year 2006)



$\exp(3) \approx 20$ th. euro; $\exp(4.5) \approx 90$ th. euro

Heterog. in adopted techniques



This is puzzling....

This evidence poses serious challenges to:

- Theories of competition and market selection
- Theoretical and/or empirical analyses which rely upon some notion of industries as aggregates of *similar/homogeneous* production units:
  - models based on industry production function
  - empirical exercises based on some notion of efficiency frontier
  - but also sectoral input-output coefficient à la Leontief are meaningless if computed as averages over such very dispersed and skewed distributions
  - indicators of technical change based on variations of such aggregates (isoquants or input-output coefficients) may be seriously misleading

Our goal

- Can we give a representation of the production technology(ies) of an industry without denying heterogeneity, but fully taking it into account?
- ... and without imposing any hypothesis on functional forms or input substitutions which do not have empirical ground?
- Can we produce empirical measures of the technological characteristics of an industry which explicitly take into account heterogeneity?
- we make an attempt building upon W. Hildenbrand "Short-run production functions based on microdata" *Econometrica*, 1981

Hildenbrand's analysis

- Represent firms in one sector as empirical input-output vectors of production at full capacity
- with some weak additional assumptions (divisibility) derives the empirical production possibility set for the industry (geometrically, a zonotope)
- and shows the following main properties of the derived efficiency frontier:
  - returns to scale are never constant
  - the elasticities of substitution are not constant

Our contribution

Building upon Hildenbrand (1981) we derive:

- indicators of industry heterogeneity
- rigorous measures of technical change at the industry level which do not assume any averaging out of heterogeneity
  - rate and direction of technical change
- Industry dynamics: how firm entry and exit affects heterogeneity and tech change
- We provide an application on Italian industrial census data
- Compare with existing measure of productivity
- Instructions for replication are available online

Production activities and Zonotopes

- The *ex post* technology of a production unit is a vector

$$a = (\alpha_1, \ldots, \alpha_l, \alpha_{l+1}) \in \mathbb{R}_+^{l+1},$$

  i.e. a **production activity** a that produces, during the current period, α_{l+1} units of output by means of $(\alpha_1, \ldots, \alpha_l)$ units of input.
  - Holds also for the multi-output case
- The **size** of the firm is the length of vector a, i.e. a multi-dimensional extension of the usual measure of firm size.
- The short run production possibilities of an industry with N units at a given time is a finite family of vectors $\{a_n\}_{1 \leq n \leq N}$ of production activities
- Hildenbrand defines the **short run total production set** associated to them as the Zonotope

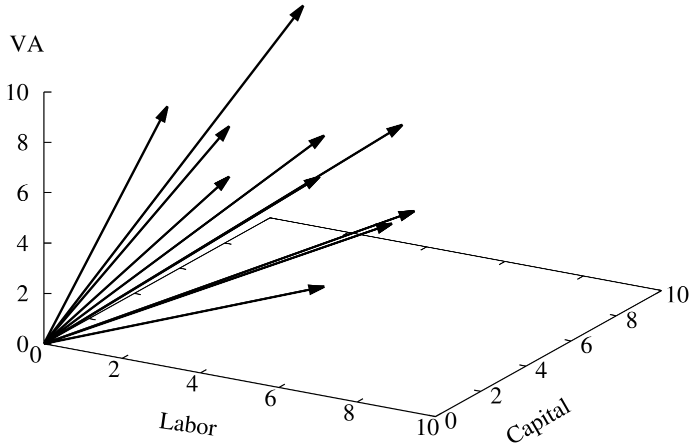
$$Y = \{y \in \mathbb{R}_+^{l+1} \mid y = \sum_{n=1}^{N} \phi_n a_n, 0 \leq \phi_n \leq 1\}.$$

A toy illustration

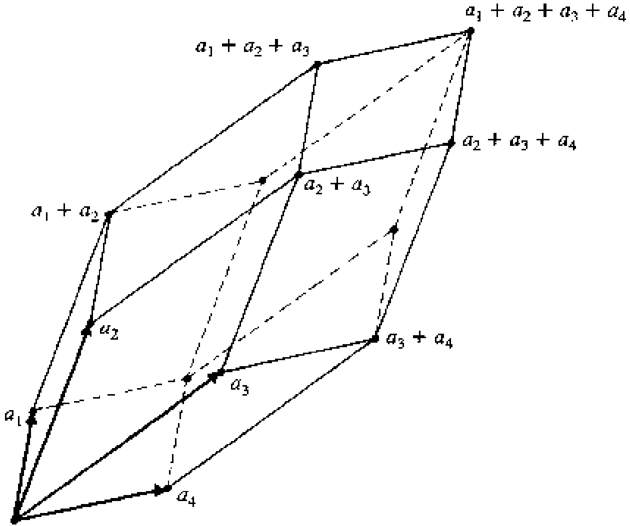
	Year 1			Year 2			Year 3			Year 4		
Firm	L	K	VA	L	K	VA	L	K	VA	L	K	VA
1	**8**	**2**	**10**	**8**	**2**	**10**	**8**	**2**	**10**	**8**	**2**	**10**
2	**2**	**8**	**10**	**2**	**8**	**10**	**2**	**8**	**10**	**2**	**8**	**10**
3	6	2	9	6	2	9	6	2	9	6	2	9
4	3	3	8	3	3	8	3	3	8			
5	3	3	6	3	3	6	3	3	6	3	3	6
6	**6**	**6**	**4**	**6**	**6**	**4**						
7	**2**	**2**	**9**	2	2	9	2	2	9	2	2	9
8	6	5	4	3	5	12	3	5	12	3	5	12
9	**6**	**2**	**3**	**2**	**2**	**11**	**2**	**2**	**11**	**2**	**2**	**11**
10	**3**	**7**	**4**	2	6	10	2	6	10	2	6	10
Total	45	40	67	37	39	89	31	33	85	28	30	77

Table: Production schedules in year 1 to 4 for an artificial industry, Number of employees (L), Capital (K) and Output (VA). External production activities in bold.

Production activities in a 3-dimensional space



The Zonotope



$$Y = \sum_{n=1}^{4} [0, a_n] \subset R^3$$

Volume of Zonotopes and Gini index

- Let $A_{i_1,\dots,i_{l+1}}$ be the matrix whose rows are vectors $\{a_{i_1},\dots,a_{i_{l+1}}\}$ and $\Delta_{i_1,\dots,i_{l+1}}$ its determinant.
- The **volume** of the zonotope Y in $\mathbb{R}^{l+1}$ is given by:

$$Vol(Y) = \sum_{1 \le i_1 < \ldots < i_{l+1} \le N} \mid \Delta_{i_1,\dots,i_{l+1}} \mid$$

where $\mid \Delta_{i_1,\dots,i_{l+1}} \mid$ is the module of the determinant $\Delta_{i_1,\dots,i_{l+1}}$.
- Interested in getting an **absolute** measure of heterogeneity in techniques; independent from the number of firms and from the unit of measure
- This absolute measure is the **Gini volume** of the Zonotope (a generalization of the well known Gini index):

$$Vol(Y)_G = \frac{Vol(Y)}{Vol(P_Y)} \quad , \tag{2}$$

where $Vol(P_Y)$ is the volume of the parallelotope P_Y of diagonal $d_Y = \sum_{n=1}^{N} a_n$, that is the maximal volume we can get when the industry production activity $\sum_{n=1}^{N} a_n$ is fixed.

Heterogeneity and Technical change in a toy example

	Year 1	Year 2	Year 3	Year 4
$Vol(Y^t)$	15217	12528	6020	4890
$G(Y^t)$	0.1262	0.0975	0.0692	0.0756
$G(\overline{Y}^t)$	0.1243	0.0940	0.0668	0.0749
$G(Y_e^t)$	0.1555	0.1407	0.0941	0.0941
Solid Angle	0.4487	0.3009	0.1238	0.1238
$G(Y^t)$ / $G(Y_e^t)$	0.81111	0.6931	0.7358	0.8036
$\text{tg}\theta_3^t$	1.1128	1.6555	1.8773	1.8764
$\text{tg}\varphi_1^t$	0.8889	1.0540	1.0645	1.0714

Table: Volumes and angles accounting for heterogeneity and productivity change, respectively, in the four years of the toy example.

(Back to main track) What we still don't know ?

- Persistence of growth: does growth replicate over time or is it a transitory phenomenon?
  - Analysis of AR structure of growth gives mixed results, generally hightligthing low correlation structure with some outliers (Bottazzi et al., 2007). With the exception of pharmaceuticals, where there is positive autocorrelation untill the 7^{th} lag, at product level (Bottazzi et al., 2001)
- What about autocorrelation in High-Growth patterns ? Do some firms exhibit superior growth over sustained periods of time, or is High-Growth just a transitory phenomenon ?
  - The few existing studies (see, for example, Hölzl, 2014; Daunfeldt and Halvarsson, 2015) suggest High-Growth firms are one-hit wonders, typically smaller and younger. Bianchini et al. (2014) find no difference in the characteristics of high growth versus persistently high-growth firms.

What we still don't know ?

- What about the long-run relationship between firm growth and industry growth?
- Lack deep theoretical understanding of the processes that drive growth and persistent growth
  - Since Penrose (1959), refinement of conjectures based on idiosyncratic capabilities (see discussions in Nelson and Winter, 1982; Dosi et al., 2008), but not much evidence

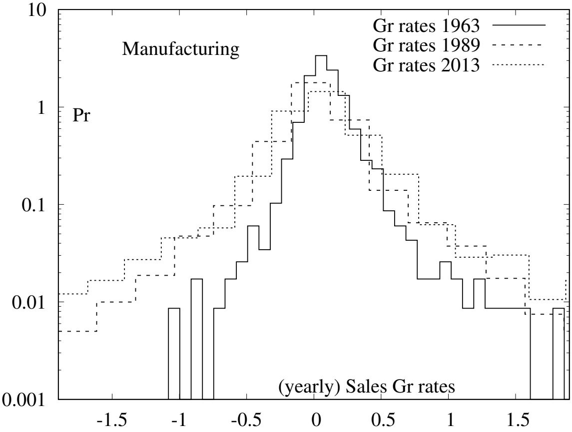
Our Research Program

- Large scale statistical analyses: Focus of today's session
  - Compustat data US firms 1960-2015 ($\Rightarrow$relatively long firm-level time-series)
    - In future research, we hope to go back to 1950
  - Patent data (NBER patent data project. US Patent data for 1976-2006 period, matched to Compustat.)
- Detailed industry growth case studies exploring dynamics within different industries
  - Semiconductors, computers, automobiles, textiles, pharmaceuticals, software
- Firm level case studies
  - Examination of statistical outliers to explore organizational factors not observable in large sample datasets
- Methodological contribution: new measure for "TFP" to account for industry heterogeneity.

Our Research Program (II)

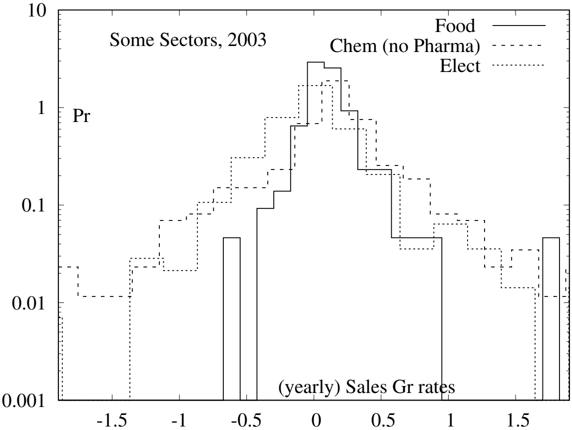
- Basic distributions of firm growth
  - Across time
  - Across industry
- Is growth persistent?
- Is there a link between firm growth dynamics and industry performance?
- Link between growth and organizational variables
  - Our Goals: exploration, characterize the phenomenon empirically, no hypothesis testing, no causal explanations, just the facts for now
- Exploiting the avalailable long time span: firms that have been in the dataset for at least 30 years
  - Characterization of the spikeness of growth process
  - AR1 coefficients estimated at the firm level: take into account heterogeneity
  - Industry and firms over the long-run

Distribution of Firm Sales Growth



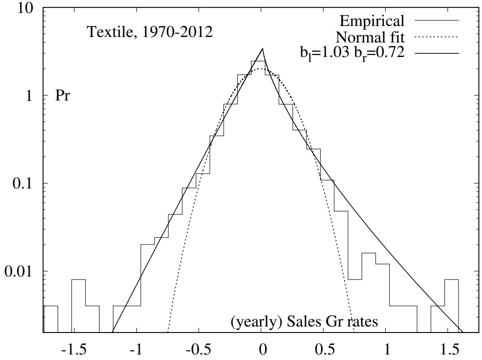
- Tent-shaped distributions
- Similar to what is found in other studies

Distributions Across Industries 2003



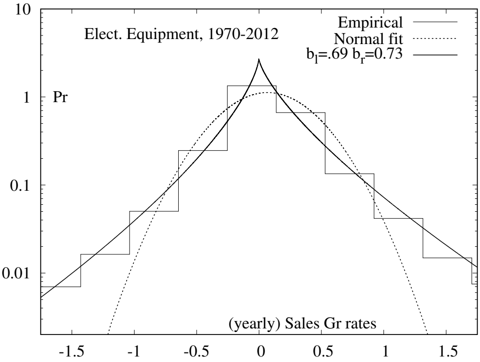
- Sectoral specificities

Textile - SIC 22 (years 1970-2012)



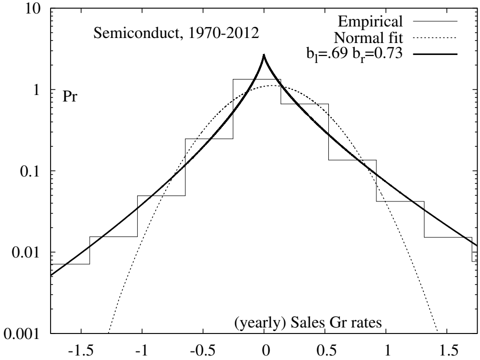
- We use a flexible family of distributions, the asymmetric exponential power (Bottazzi and Secchi, 2011)
- Relative high probability of extreme growth events, which disproportionately contribute to the evolution of industries

Electr Equipment - SIC 36 (years 1970-2012)

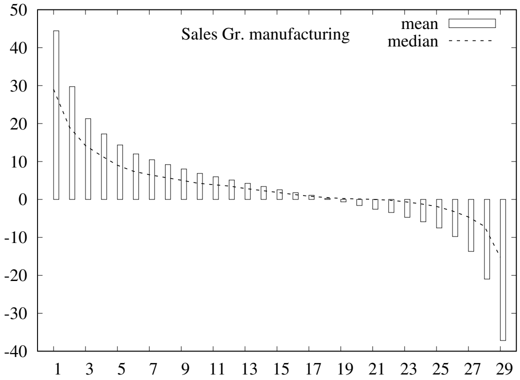


- Tent-shaped. Not an effect of aggregation, see next slide on Semicond 3674
- Fatter tail than low-tech sectors

Semiconductors - SIC 3674 (years 1970-2012)

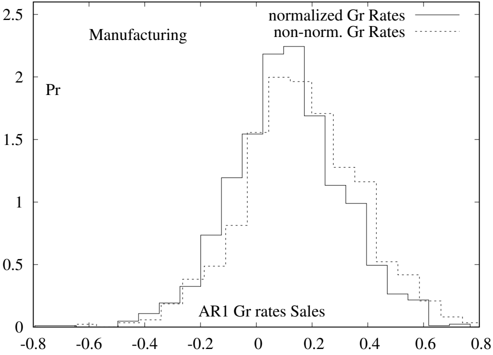


Spikeness of the growth process



- The growth process is spiky
- The largest expansion episode (median) accounts for around 40% of the cumulated growth over the reference period (30 years) (50% in the case of employment growth)

Persistence of Firm Growth - AR process



- Exploiting the avalailble long time span, we estimate, for each firm, AR1 Coefficients.
- Growth performance is not much persistent. Around 75% firms have an AR1 in the range $[-0.25, 0.25]$

Persistence of growth - TPM

- Transition Probabilities Matrix between time t and $t+1$ (wrt firm)

		t+1						*t+1*			
Aggr. Manuf.		1	2	3	4	Food & Bev.		1	2	3	4
t	1	**34.07**	24.51	20.42	21.00	*t*	1	**36.28**	25.49	19.49	18.74
	2	24.63	**30.11**	27.31	17.95		2	24.50	**32.56**	26.51	16.43
	3	20.72	27.01	**29.29**	22.98		3	19.82	24.51	**32.98**	22.69
	4	21.19	18.81	23.39	**36.61**		4	21.44	16.90	22.54	**39.12**

		t+1						*t+1*			
Chem. (no Pharma)		1	2	3	4	Pharma.		1	2	3	4
t	1	**38.72**	23.37	16.27	21.65	*t*	1	**40.30**	21.29	19.01	19.39
	2	24.45	**35.27**	26.89	13.39		2	26.23	**36.48**	24.59	12.70
	3	15.83	24.89	**37.27**	22.02		3	17.62	27.20	**36.02**	19.16
	4	22.83	15.93	21.08	**40.16**		4	19.57	14.04	23.83	**42.55**

		t+1						*t+1*			
Elect. Equip.		1	2	3	4	Semicond.		1	2	3	4
t	1	**35.19**	24.89	19.66	20.26	*t*	1	**34.29**	25.71	20.71	19.29
	2	24.76	**31.80**	25.11	18.33		2	28.36	**29.48**	27.99	14.18
	3	20.89	26.54	**32.71**	19.86		3	23.53	26.10	**27.57**	22.79
	4	21.01	17.44	23.45	**38.10**		4	19.38	17.83	25.58	**37.21**

Note. Quartiles of the yearly sales growth rates distribution, 1971-2011, ranging from the lowest (1) to the highest (4).

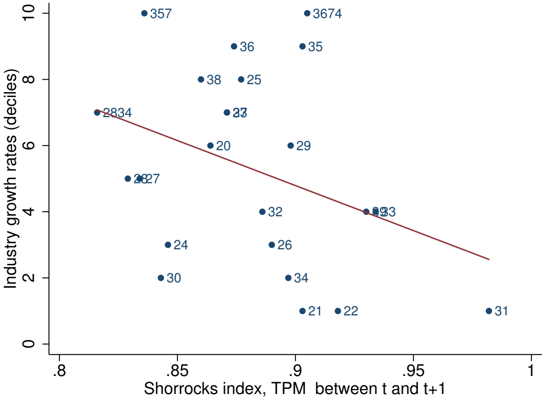
Persistence of growth - TPM

- Transition Probabilities Matrix between time t and $t+3$

Aggr Manuf.		$t+3$ 1	2	3	4	Food & Bev.		$t+3$ 1	2	3	4
t	1	**29.59**	23.18	22.43	24.81	t	1	**32.54**	23.13	21.69	22.65
	2	23.82	**29.24**	26.95	19.99		2	24.50	**29.30**	27.48	18.71
	3	22.99	27.05	**28.22**	21.74		3	21.61	25.48	**31.94**	20.97
	4	24.22	21.85	23.55	**30.39**		4	23.05	21.89	21.23	**33.83**
Chem. (no Pharma)		$t+3$ 1	2	3	4	Pharma		$t+3$ 1	2	3	4
t	1	**31.45**	23.46	21.87	23.22	t	1	**34.94**	22.49	22.49	20.08
	2	22.57	**29.93**	28.30	19.20		2	28.38	**28.82**	25.33	17.47
	3	19.42	29.67	**30.16**	20.75		3	15.16	29.92	**36.89**	18.03
	4	27.97	17.85	22.47	**31.71**		4	26.24	18.55	19.91	**35.29**
Elect. Equip.		$t+3$ 1	2	3	4	Semicond.		$t+3$ 1	2	3	4
t	1	**30.04**	23.63	21.98	24.36	t	1	**32.20**	23.86	23.11	20.83
	2	25.05	**29.98**	27.09	17.88		2	25.40	**27.78**	28.57	18.25
	3	22.49	28.61	**27.42**	21.48		3	23.14	26.67	**27.45**	22.75
	4	24.52	20.46	25.07	**29.95**		4	26.14	22.82	22.82	**28.22**

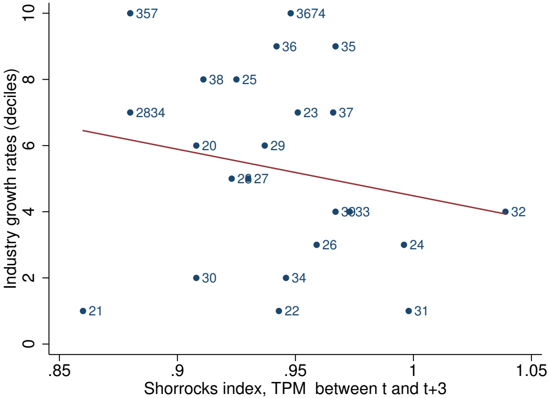
Note. Quartiles of the yearly sales growth rates distribution, 1971-2011, ranging from the lowest (1) to the highest (4).

Firm growth persistence and industry performance (1970-2011)



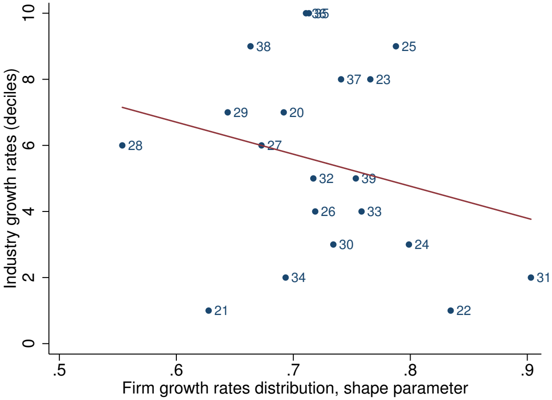
- Shorrocks index $= \frac{k - trace(M)}{k-1}$. High value means low persistence (high mobility)

Firm growth persistence and industry performance (1970-2011)



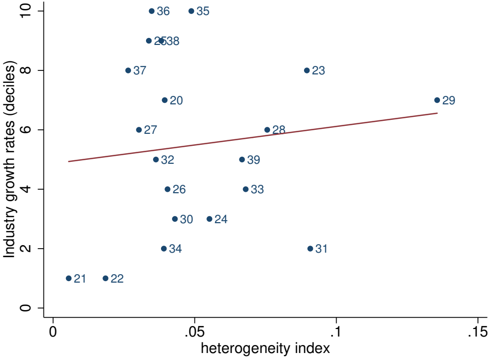
- Shorrocks index $= \frac{k - trace(M)}{k-1}$. High value means low persistence (high mobility)

Firm growth distribution and industry performance (1970-2011)



- Estimated shape parameters from AEP distribution, describing the tail behavior. Low value means fatter tails

Firm heterogeneity and industry performance (1970-2011)



- Mild evidence that heterogeneity is related to industry performance (reminding of Fisher fundamental law of selection)

Growth, Productivity, and Innovation

Table: Labour productivity$_{t-1}$-growth$_t$ relationship, OLS coefficients.

Relative productivity is positively correlated to relative firm growth in most sectors

Dep. variable: average sales growth over year windows	1-YEAR	3-YEARS	5-YEARS
ALL MANUFACTURING	0.020***	0.023***	0.019***
	(0.004)	(0.002)	(0.002)
Textile	0.101***	0.081***	0.104***
	(0.027)	(0.018)	(0.018)
Chemical	−0.003	0.017***	0.010**
	(0.009)	(0.006)	(0.005)
Fabricated metal products	0.059***	0.049***	0.048***
	(0.020)	(0.012)	(0.011)
Machinery And Computer Equipment	0.034***	0.025***	0.020***
	(0.012)	(0.008)	(0.007)
Electronic And Other Electrical Equipment	0.029***	0.024***	0.022***
	(0.009)	(0.006)	(0.005)
Transportation Equipment	0.002	0.000	0.000
	(0.017)	(0.012)	(0.010)
Measuring, Analyzing, And Controlling Instruments	−0.000	0.009	0.010
	(0.011)	(0.007)	(0.006)
Pharmaceuticals	−0.020	0.018	0.011
	(0.015)	(0.011)	(0.009)

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Growth, Productivity, and Innovation

Table: Labour productivity growth$_t$-growth$_t$ relationship, OLS coefficients.

Relative productivity growth is positively correlated to relative firm growth in all sectors

Dep. variable: average sales growth over different year windows	1-YEAR	3-YEARS	5-YEARS
ALL MANUFACTURING	0.251***	0.115***	0.080***
	(0.005)	(0.003)	(0.002)
Textile	0.216***	0.112***	0.067***
	(0.057)	(0.027)	(0.020)
Chemical	0.180***	0.106***	0.091**
	(0.012)	(0.008)	(0.006)
Fabricated metal products	0.268***	0.098***	0.065***
	(0.033)	(0.014)	(0.011)
Machinery And Computer Equipment	0.330***	0.131***	0.092***
	(0.015)	(0.008)	(0.006)
Electronic And Other Electrical Equipment	0.288***	0.129***	0.084***
	(0.010)	(0.005)	(0.004)
Transportation Equipment	0.457***	0.188***	0.110***
	(0.033)	(0.016)	(0.012)
Measuring, Analyzing, And Controlling Instruments	0.223***	0.110***	0.076***
	(0.013)	(0.007)	(0.005)
Pharmaceuticals	0.154***	0.143***	0.111***
	(0.017)	(0.014)	(0.010)

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Growth, Productivity, and Innovation

Table: Patent intensity$_{t-1}$-growth$_t$ relationship, OLS coefficients.

Relative patent stock/sales is positively correlated to relative firm growth in "patent intensive" sectors

Dep. variable: average sales growth over different year windows	1-YEAR	3-YEARS	5-YEARS
ALL MANUFACTURING	0.105***	0.056***	0.039***
	(0.005)	(0.003)	(0.002)
Machinery And Computer Equipment	0.041	0.049*	0.054***
	(0.041)	(0.025)	(0.020)
Electronic And Other Electrical Equipment	0.128***	0.107***	0.075***
	(0.021)	(0.013)	(0.010)
Transportation Equipment	−0.057*	0.099***	0.103***
	(0.037)	(0.024)	(0.020)
Measuring, Analyzing, And Controlling Instruments	0.243***	0.238***	0.247***
	(0.044)	(0.027)	(0.021)
Pharmaceuticals	0.147***	0.067***	0.047***
	(0.010)	(0.006)	(0.004)

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Growth, Productivity, and Innovation

Table: Diversification$_{t-1}$-growth$_t$ relationship, OLS coefficients.

Among patenting firms, relative diversification (especially as measured by Herfindhal index), is positively correlated to relative firm growth

Dep. variable: average sales growth over different year windows	1-YEAR	3-YEARS	5-YEARS
Diversification measure: Herfindhal index			
ALL MANUFACTURING	0.014^{**}	0.013^{***}	0.012^{***}
	(0.006)	(0.004)	(0.003)
Machinery And Computer Equipment	0.034^{*}	0.027^{**}	0.031^{***}
	(0.019)	(0.012)	(0.009)
Electronic And Other Electrical Equipment	0.002	0.012	0.010
	(0.016)	(0.010)	(0.008)
Transportation Equipment	0.030	0.030^{**}	0.029^{**}
	(0.022)	(0.014)	(0.012)
Measuring, Analyzing, And Controlling Instruments	−0.015	0.015	0.024^{*}
	(0.023)	(0.015)	(0.012)
Pharmaceuticals	0.111^{**}	0.045	0.038^{*}
	(0.055)	(0.029)	(0.023)

Notes: Controls: sales. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Growth, Productivity, and Innovation

Table: Diversification$_{t-1}$-growth$_t$ relationship, OLS coefficients.

Dep. variable: average sales growth over different year windows	1-YEAR	3-YEARS	5-YEARS
Diversification measure: (log) # IPC classes			
ALL MANUFACTURING	0.005***	0.005***	0.004***
	(0.001)	(0.001)	(0.001)
Machinery And Computer Equipment	0.014***	0.013***	0.013***
	(0.005)	(0.003)	(0.002)
Electronic And Other Electrical Equipment	0.002	0.006**	0.005**
	(0.004)	(0.003)	(0.002)
Transportation Equipment	−0.004	−0.002	−0.002
	(0.005)	(0.003)	(0.002)
Measuring, Analyzing, And Controlling Instruments	−0.003	0.002	0.002
	(0.006)	(0.004)	(0.003)
Pharmaceuticals	0.028**	0.011	0.009
	(0.014)	(0.007)	(0.006)

Notes: Controls: sales. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Final remarks

1. Persistent heterogeneity at all levels of observation robustly confirmed
2. Industry evolution shaped by extreme growth events and (mild) persistence in growth
3. Some effect of differential productivities (and innovativeness) upon differential competitiveness

Next Steps in Our Research

- Get deeper into the statistical properties of growth and survival of different "types" of firms
- Examination of statistical outliers in growth persistence to explore organizational factors not observable in large sample datasets
- Mapping firms strategies and capabilities into sectoral characteristics (for sure the drivers of growth are different in semiconductors vs textiles vs pharmaceuticals...)
- Extending all the analysis to the European industry: to what degrees institutional differences matter?

Thank you!

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