

The Burden of Knowledge and the
'Death of the Renaissance Man': Is
Innovation Getting Harder?

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1 Overview

- What happens if innovators face an increasing educational burden as technology progresses?
- Implications for long-run growth
- Testable implications for innovators:
 - Educational attainment
 - Specialization
 - Teamwork
- Time and cross-sectional dimensions
- Empirical evidence using microdata

--◆-- US R&D Workers (Left Axis) --■-- Real US R&D Expenditures (Left Axis) --- US Private Sector MFP growth (Right Axis)

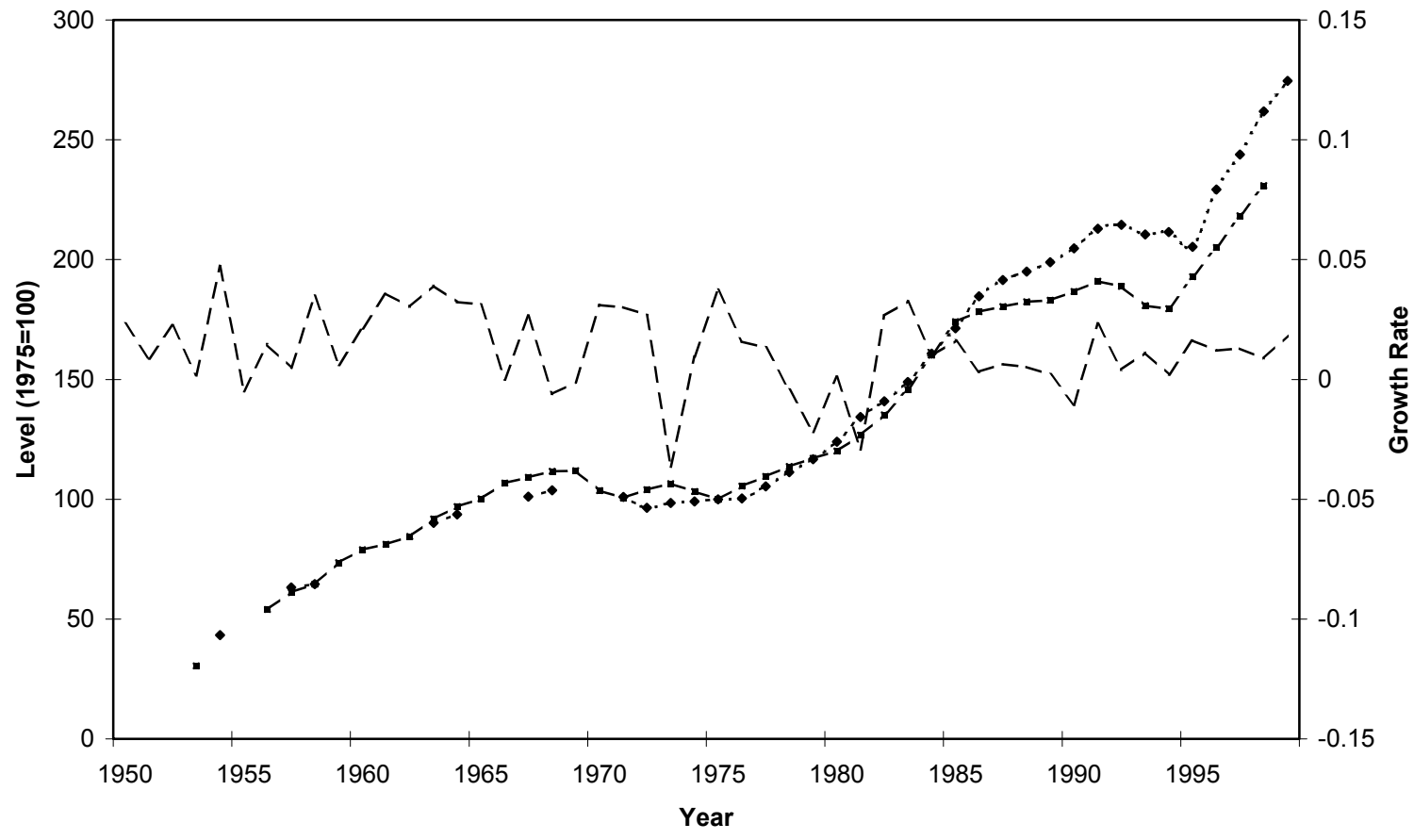
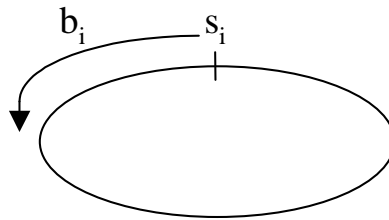


Figure 2.1: Rising Research Intensity, Flat Productivity Growth

2 The Model

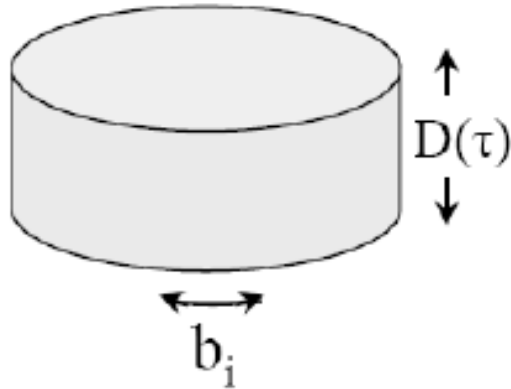
- There is a continuum of fields of knowledge, arranged around a unit circle.



The circle of knowledge

- If one chooses to become an innovator, one must make two additional decisions:
 - (1) Where on the circle to locate oneself (s_i)
 - (2) How broadly to educate oneself (b_i)
- At a point in time, the depth of knowledge at each point s on the circle is $D(t)$.

- An innovator will acquire an amount of knowledge: $b_i D(\tau)$



- Tradeoff:
 - More education costs more to acquire
 - More education makes innovator more productive
- Evolution of tradeoff:
 - Distance to the frontier, $D(t)$, changes
 - Value of knowledge changes

2.1 Steady-state growth

- Ceteris paribus, the greater the rate at which knowledge accumulates, the lower the growth rate. Magnitude of effect depends on importance of broad expertise to innovator productivity.
- Increasing value of new knowledge can offset rising burden of knowledge, preserving steady-state growth
- Depending on parameter values, increasing R&D effort produces either (i) explosive growth, or (ii) becomes a necessary condition for positive steady-state growth.
 - Given that growth is not exploding, model suggests that, without increasing R&D effort, growth will eventually stop.
- Is there a rising burden of knowledge?

2.2 Testable Predictions

- Time series
 - Educational attainment increasing
 - Specialization increasing only if distance to knowledge frontier increasing substantially
 - Team size is increasing if specialization is increasing.
- Cross section (extended model)
 - Greater depth of knowledge within a field => greater specialization, greater teamwork in that field
 - But educational attainment is invariant across fields!

3 Evidence

3.1 Data

- Hall, Jaffe, Tratjenberg (2001) data set
 - All USPTO utility patents, 1975-2000 (2.1 million observations)
 - Technological category of patent, citations, etc
 - Name and address of all inventors listed with a patent
- Age Data: www.AnyBirthday.com
 - Subset of HJT 2001 for which inventors' birth dates were found using www.AnyBirthday.com
 - Produces ages for 56,000 inventors.

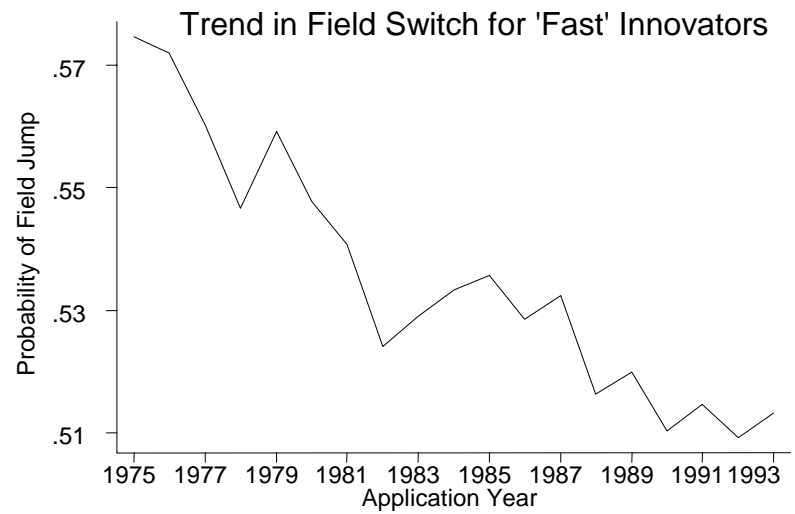
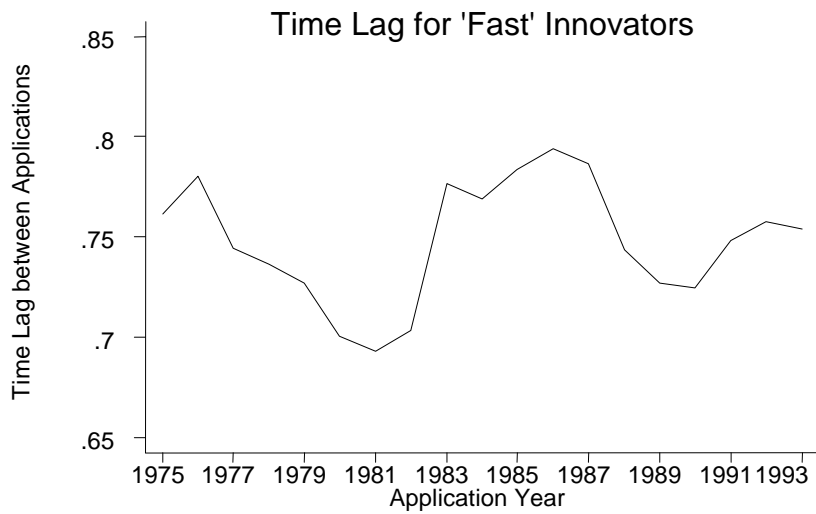
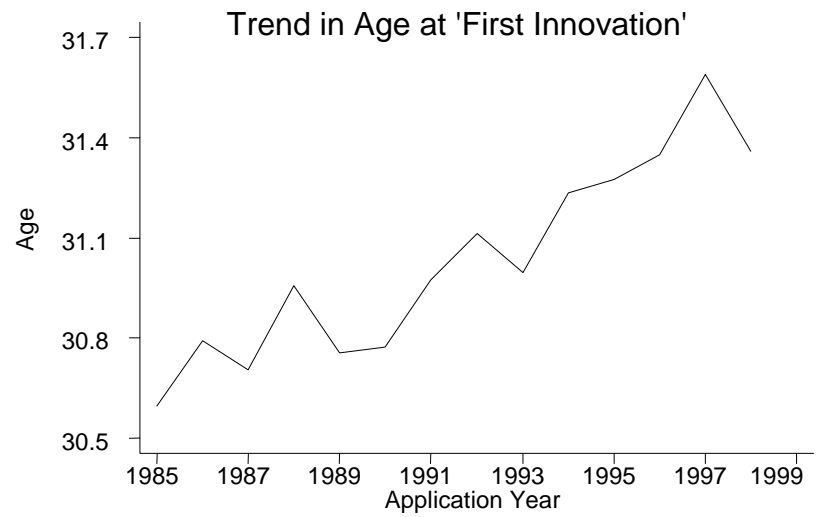
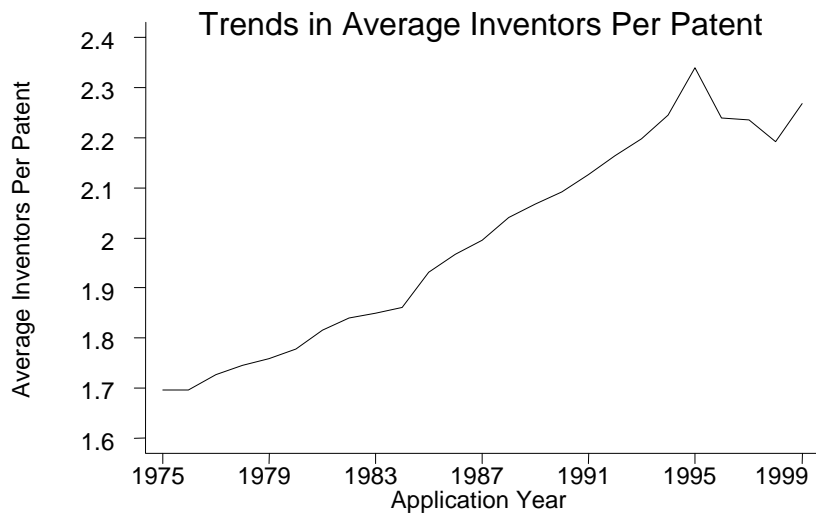


Figure 1: Basic Time Trends

3.2 Other Evidence

- Age
 - Age at which Nobel Prize winning research and great technological inventions is performed rises by 6 years over 20th Century, with large drop in presence of great inventions early in life-cycle. (Jones 2005)
 - Lengthening doctorates, rise of post-doctorates (Jones 2005, NRC 1990, Tilghman et al, 1998)
- Teamwork in sciences
 - Steep upward trends in journal coauthorship across all scientific fields, 1981-1999 (Adams, 2004)
 - Numerous field-specific studies show rising coauthorship trends going back as far as 1900

4 Conclusions

- Model provides parsimonious explanation for a range of descriptive evidence.
- Increasing specialization and increasing teamwork despite increased educational attainment are consistent with rising burden of knowledge.
- A rising burden of knowledge has negative implications for long-run growth.

Table 1: Age Trends among Great Innovators

	Dependent Variable: Age at Great Achievement	
	Nobel Prize Winners	Great Inventors
Year of Great Achievement (in 100's)	5.83 ^{***} (1.37)	4.86 ^{**} (2.31)
Number of observations	544	286
Time span	1873-1998	1900-91
Average age	38.6	39.0
R ²	0.032	0.016

NOTES:

(i) This table borrows from Jones (2004). Age trends are measured in years per century. Standard errors are given in parentheses.

(ii) Nobel Prize winners include all winners in Physics, Chemistry, Medicine, and Economics. Great inventors are taken from technological almanacs listing the great inventions of the 20th century.

** Indicates 95% confidence level. *** Indicates 99% confidence level.

Table 2: Trends in Inventors per Patent

		Dependent Variable: Inventors per Patent						
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Application Year		.0293 (.0001)	.0261 (.0001)	.0262 (.0001)	.0251 (.0001)	.0244 (.0002)	.0306 (.0002)	.0180 (.0003)
Foreign Patent		--	.444 (.002)	.416 (.002)	.141 (.004)	.146 (.004)	US Only	Foreign Only
Technological Field Controls	Broad	--	Yes	--	--	--	--	--
	Narrow	--	--	Yes	Yes	Yes	Yes	Yes
Assignee Code		--	--	--	Yes	Yes	Yes	Yes
Number of Observations		2,016,377	2,016,377	2,016,377	2,016,377	1,506,956	1,123,310	893,067
Period		1975-1999	1975-1999	1975-1999	1975-1999	1975-1996	1975-1999	1975-1999
Mean of Dependent Variable		2.03	2.03	2.03	2.03	1.97	1.82	2.29
Per-decade Trend as % of Period Mean		14.4%	12.9%	12.9%	12.4%	12.4%	16.8%	7.9%
R ²		.02	.08	.10	.12	.13	.12	.10

Table 3: Trends in Age at First Innovation

		Dependent Variable: Age at Application						
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Application Year		.0657 (.0095)	.0666 (.0095)	.0671 (.0095)	.0671 (.0099)	.0687 (.0097)	.0530 (.0107)	.0584 (.0109)
Technological Field Controls	Broad	--	Yes	--	--	--	--	--
	Narrow	--	--	Yes	Yes	Yes	--	Yes
Assignee Code		--	--	--	Yes	Yes	--	Yes
Team Size		--	--	--	--	-.0630 (.0273)	--	-.0348 (.0306)

Number of observations		6,541	6,541	6,541	6,541	6,541	5,102	5,102
Period		1985- 1999	1985- 1999	1985- 1999	1985- 1999	1985- 1999	1985- 1999	1985- 1999
Age Range		25-35	25-35	25-35	25-35	25-35	23-33	23-33
Mean of Dependent Variable		31.0	31.0	31.0	31.0	31.0	29.3	29.3
Per-decade Trend as % of Period Mean		2.1%	2.1%	2.2%	2.2%	2.2%	1.8%	2.0%
R ²		.007	.010	.020	.020	.021	.005	.018

Table 6: Mean differences across Technological Categories

Technological Classification (Hall et al. 2001)			Age at First Innovation		Inventors per Patent		Probability of Field Jump	
6	36	Code	Obs	Mean	Obs	Mean	Obs	Mean
Chemical (1)	Agriculture, Food, Textiles	11	12	31.1	16,100	2.41	2,500	0.48
	Coating	12	53	29.2	29,800	2.23	4,300	0.64
	Gas	13	17	30.3	9,200	1.96	1,700	0.59
	Organic Compounds	14	51	29.5	59,600	2.56	7,000	0.34
	Resins	15	44	29.3	67,200	2.51	7,500	0.36
	Miscellaneous—Chemical	19	331	29.3	197,100	2.23	29,500	0.43
	Entire category			508	29.4	379,200	2.33	52,100
Computers & Communications (2)	Communications	21	264	29.3	92,700	1.99	15,000	0.41
	Computer Hardware & Software	22	162	29.8	80,400	2.26	10,200	0.44
	Computer Peripherals	23	37	29.3	22,100	2.37	2,800	0.51
	Information Storage	24	43	28.9	41,300	2.21	6,700	0.39
	Entire category			506	29.4	236,700	2.16	34,500
Drugs & Medical (3)	Drugs	31	74	29.9	65,200	2.90	6,300	0.25
	Surgery & Medical Instruments	32	268	29.8	59,900	1.86	12,400	0.29
	Biotechnology	33	46	30.5	22,700	2.75	1,800	0.38
	Misc—Drugs & Medical	39	68	29.1	13,600	1.66	3,500	0.35
	Entire category			456	29.8	161,500	2.39	23,800
Electrical & Electronic (4)	Electrical Devices	41	111	29.3	61,000	1.77	12,700	0.48
	Electrical Lighting	42	90	29.6	31,300	1.96	5,700	0.43
	Measuring & Testing	43	116	29.2	57,700	1.94	10,000	0.51
	Nuclear & X-rays	44	52	29.7	30,200	2.08	4,700	0.50
	Power Systems	45	128	29.4	68,900	1.94	13,000	0.51
	Semiconductor Devices	46	49	29.3	44,700	2.25	7,100	0.34
	Misc—Electrical	49	104	29.1	49,100	1.97	8,900	0.51
	Entire category			650	29.3	343,300	1.97	61,700
Mechanical (5)	Materials Processing & Handling	51	241	29.4	100,000	1.79	21,700	0.48
	Metal Working	52	87	28.8	58,100	2.11	10,400	0.54
	Motors, Engines & Parts	53	83	29.4	73,300	1.85	16,200	0.41
	Optics	54	57	29.0	48,000	2.15	8,100	0.37
	Transportation	55	273	29.0	56,800	1.66	12,000	0.45
	Misc—Mechanical	59	449	29.1	96,800	1.64	22,400	0.49
	Entire category			1,190	29.1	433,300	1.83	90,500
Others (6)	Agriculture, Husbandry, Food	61	250	29.1	41,200	1.75	7,600	0.41
	Amusement Devices	62	269	29.4	20,900	1.41	4,300	0.37
	Apparel & Textile	63	211	29.1	32,400	1.57	7,600	0.37
	Earth Working & Wells	64	100	29.6	27,800	1.69	6,600	0.36
	Furniture, House Fixtures	65	346	29.1	41,000	1.42	9,400	0.50
	Heating	66	58	30.0	26,300	1.75	6,100	0.48
	Pipes & Joints	67	45	29.2	17,100	1.58	4,500	0.61
	Receptacles	68	298	29.4	40,700	1.51	10,100	0.47
	Misc—Others	69	846	29.2	167,800	1.73	35,200	0.48
	Entire category			2,423	29.3	415,600	1.64	91,000

NOTES

- (i) Age at first innovation includes observations of those innovators who appear after 1985 in the data set and between the ages of 23 and 33. Results are similar, with higher mean and even less variance, for 25-35 year olds.
- (ii) Probability of field jump is probability of switching categories for solo innovators using 36-category measure.