

Lecture 2: Supply of Scientists: Shortages, Surpluses, and Cycles

1) Shortages; 2) Roy Model of Career Choice; 3) US/Global Supply; 4) Cobwebs and Minority Game

1) Never-Ending Shortages

2018 5th USA Science & Engineering Festival Expo, Lockheed Martin. April 7-8, 2018 Washington

Founded by entrepreneur Larry Bock and Lockheed Martin executives to address the **severe shortage in science and tech talent**, the USA Science & Engineering Festival..was developed to increase public awareness of the importance of science and to encourage youth to pursue careers in science and engineering by celebrating science in much the same way as society celebrates Hollywood celebrities, professional athletes and pop stars.

2015 Wall Street Journal Jan 27, Number of College Students Pursuing Science, Engineering Stagnates ... national push to increase workers' skills has little effect

2013 NYTimes editorial: December 7, Who Says Math Has to Be Boring? American students are bored by math, science and engineering. They buy smartphones and tablets by the millions but don't pursue the skills necessary to build them. Engineers and physicists are often portrayed as clueless geeks on television, and despite the high pay and the importance of such jobs to the country's future, the vast majority of high school graduates don't want to go after them. Nearly 90 percent of high school graduates say they're not interested in a career or a college major involving science, technology, engineering or math, known collectively as STEM, according to a survey of more than a million students who take the ACT test. **The number of students who want to pursue engineering or computer science jobs is actually falling, precipitously, at just the moment when the need for those workers is soaring.** Within five years, there will be 2.4 million STEM job openings.

2012 President's Council of Advisors on Science and Technology-- Economic projections point to a **need for approximately 1 million more STEM professionals** than the U.S. will produce at the current rate over the next decade if the country is to retain its historical preeminence in science and technology.

2011 February Steve Jobs told the president that Apple would have located **700,000 manufacturing jobs** in the United States instead of China if only Apple had been able to find enough U.S. Engineers;¹ Senator Schumer, Senate Judiciary subcommittee hearing on high skill immigration, called for stapling a green card to the diploma of every foreign student who earns a US STEM degree. Senator Cornyn, "As we all know, there is **a scarcity of qualified people for many jobs, particularly those in high technology.**"

2008 "U.S. companies face a severe shortfall of scientists and engineers with expertise to develop the next generation of breakthroughs." —Bill Gates

2005 NAS report Rising Above the Gathering Storm, headed by Norman Augustine, a retired chairman and CEO of Lockheed Martin sparked the mid-2000s shortage fears. Multiple editions of Rising Above editions and a 2011 sequel

2002 Op-Ed 1 October Web site of National Academies, Jerome H. Grossman, a member of the Government-University-Industry Research Roundtable & senior fellow at JFK: "The nation's pool of scientific talent hasn't been this shallow in decades ... **America's scientific, economic, and social well-being is at stake.**"

1989 Ominous Statistics Foretell Drastic Shortage Of Scientists. . . Richard C. Atkinson (Pres of AAAS) *Science* 2 August **1989**: Vol. 245. no. 4918, p. 584

IS IT REAL? TELL IT TO THE POST-DOCS AND GRAD STUDENTS!

Is There a Shortage of Scientists and Engineers? How Would We Know? Rand 2003 (http://www.rand.org/pubs/issue_papers/IP241/IP241.pdf). <http://www.issues.org/29.4/hal.html> from Issues in S&T What Shortages? The Real Evidence About the STEM Workforce;

E. Weinstein "How and Why Government, Universities, and Industry Create Domestic Labor Shortages of Scientists and High-Tech Workers" reviews bogus 1987 NSF projected shortfall of 675,000 scientists and engineers between 1990 and 2005.

"The truth is that there is little credible evidence of the claimed widespread shortages in the U.S. science and

¹"If Apple located its mfg in the US and paid the national average for electronics production worker wages, it would cost the company about \$42,000 per worker per year. In China, Apple's contract manufacturer, Foxconn, pays workers \$4,800 per year ... \$26 billion (yearly) more than the company's reported net profit for 2011."

engineering workforce. How can the conventional wisdom be so different from the empirical evidence? --**The Myth of the Science and Engineering Shortage** By Michael S. Teitelbaum

David Kaiser, MIT Physics and History of Science: "The market for physicists crashed in the 1970s, and has never recovered; and some of the current debate over scientific competitiveness needs to be seen in the context of this rapid expansion and deflation. Further, "these boom-and-bust cycles can shape what counts as 'real' science in a given context."

2005 NAS study of the scientific workforce Bridges to Independence, by a committee chaired by Thomas Cech, documented a genuine shortage not of homegrown scientists but of viable career opportunities for those scientists. and that the resulting "crisis of expectation" for young PhDs trapped in an overcrowded job market was damaging to the research enterprise. http://www.cjr.org/reports/what_scientist_shortage.php?page=all

What is a shortage? Rising wages. Short job-finding period for graduates. Long time to fill vacancies. Present value of lost output from not having workers.

But could be market manipulation... In early 2005, as demand for Silicon Valley engineers began booming, Apple's Steve Jobs sealed a secret and illegal pact with Google's Eric Schmidt to artificially push their workers wages lower by agreeing not to recruit each other's employees, sharing wage scale information, and punishing violators. On February 27, 2005, Bill Campbell, a member of Apple's board of directors and senior advisor to Google, emailed Jobs to confirm that Eric Schmidt "got directly involved and firmly stopped all efforts to recruit anyone from Apple." Later that year, Schmidt instructed his Sr VP for Business Operation Shona Brown to keep the pact a secret and only share information "verbally, since I don't want to create a paper trail over which we can be sued later."

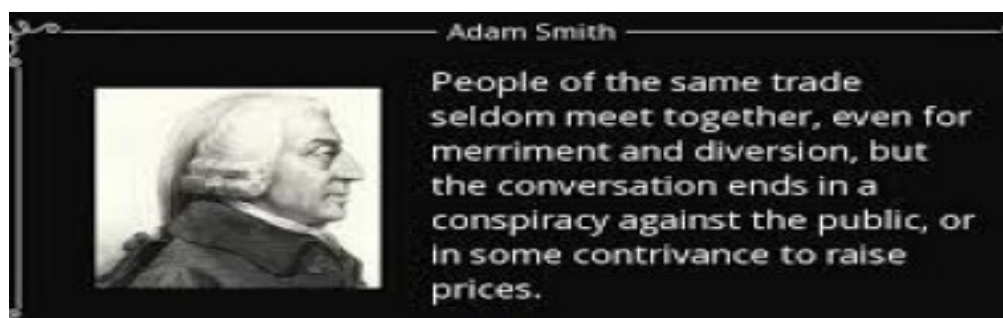
These secret conversations and agreements were exposed in a 2010 Department of Justice antitrust investigation that became the basis of a class action lawsuit filed on behalf of over 100,000 tech employees whose wages were artificially lowered — an estimated \$9 billion effectively stolen by the high-flying companies from their workers to boost corporate earnings – the \$9B is treble damages on estimated \$3B losses – \$140k per worker

Judge Rejects Settlement in Silicon Valley Wage Case; Tech Companies' Pact to Pay Affected Workers \$324.5 Million Is Deemed Too Small

Elder. Jeff. **Wall Street Journal (Online)** [New York. N.Y] 15 Jan 2015: n/a.

Judge approves \$415M settlement in Apple, Google wage case Sept 3, 2015 by Michael Liedtke

A federal judge has approved a \$415 million settlement that ends a lengthy legal saga revolving around allegations that Apple, Google and several other Silicon Valley companies illegally conspired to prevent their workers from getting better job offers. <https://phys.org/news/2015-09-415m-settlement-apple-google-wage.html#jCpead> more at:



If people can make money subverting the market they will try to do so. But **models of markets rarely assume that agent strategies mutate to undo market competition.**

STEM crisis or STEM surplus? Yes and yes

The last decade has seen considerable concern regarding a shortage of science, technology, engineering, and mathematics (STEM) workers to meet the demands of the labor market. At the same time, many experts have presented evidence of a STEM worker surplus. A comprehensive literature review, in conjunction with employment statistics, newspaper articles, and our own interviews with company recruiters, reveals a significant heterogeneity in the STEM labor market: the academic sector is generally oversupplied, while the government sector and private industry have **shortages in specific areas**. Yi Xue and Richard Larson, "Monthly Labor Review, U.S. Bureau of Labor Statistics, May 2015, <https://doi.org/10.21916/mlr.2015.14>.

Candidate for shortage today: Computer Science/Data Science

IBM Predicts Demand For Data Scientists Will Soar 28% By 2020

 Louis Columbus Forbes

Jobs requiring machine learning skills are paying an average of \$114,000. Advertised data scientist jobs pay an average of \$105,000 and advertised data engineering jobs pay an average of \$117,000.

59% of all Data Science and Analytics (DSA) job demand is in Finance and Insurance, Professional Services, and IT. (The Quant Crunch: How The Demand For Data Science Skills Is Disrupting The Job Market).

By 2020 the number of Data Science and Analytics job listings is projected to grow by nearly 364,000 listings to approximately 2,720,000. The most lucrative analytics skills include MapReduce, Apache Pig, Machine Learning, Apache Hive and Apache Hadoop. Data Science and Analytics professionals with MapReduce skills are earning \$115,907 a year on average, making this the most in-demand skill according to the survey. Data science and analytics professionals with expertise in Apache Pig, Hive and Hadoop are competing for jobs paying over \$100K

Computer science salaries rise with demand for new graduates

Network World | JUN 13, 2016

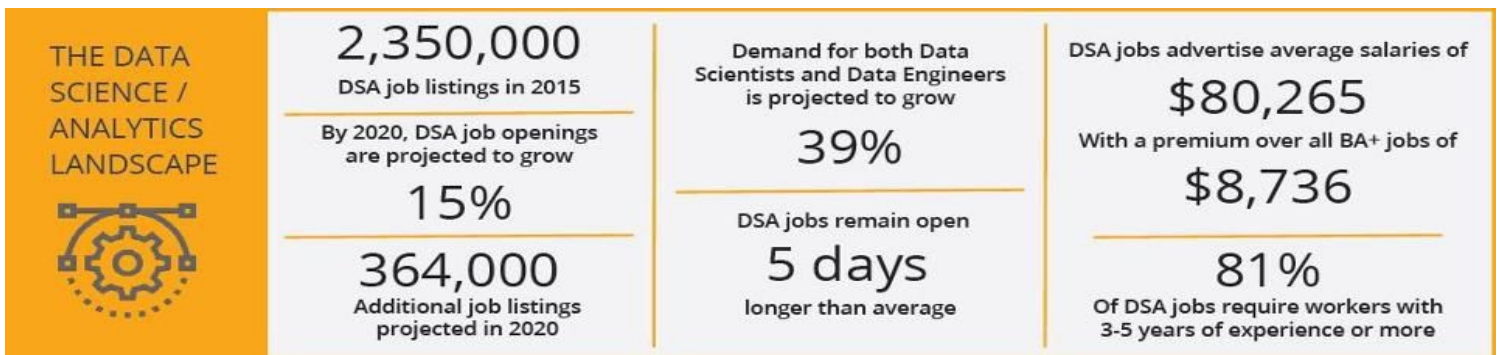
Competition for tech talent puts a high price on graduates with computer science degrees.

"It is a fierce competition for new graduates. The huge monoliths out there, like Facebook or Google or LinkedIn, are scooping up, in particular, the developers, programmers and engineers. They're scooping them up left and right

Data Scientist: The Sexiest Job of the 21st Century

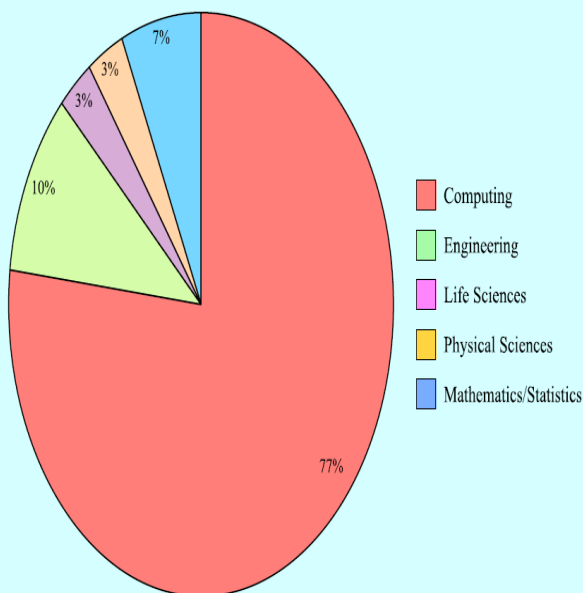
 Thomas H. Davenport D.J. Patil

OCTOBER 2012 Harvard Business Review



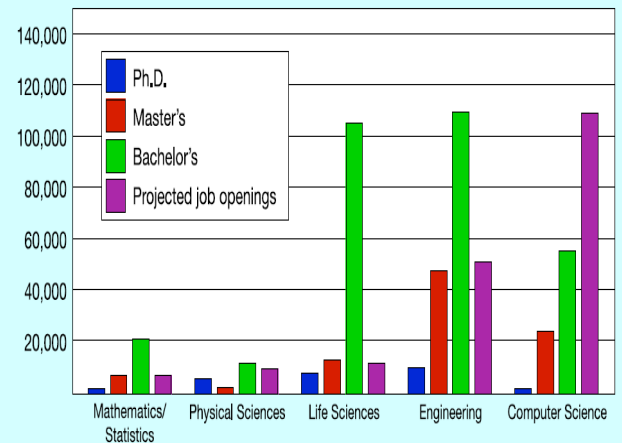
Computing Will See the Fastest Growth

Percentage of STEM Job Growth 2014-2024



Source: Bureau of Labor Statistics 2014-2024 projections.

Degree Production Falls Short



- Computing is the only major sector of the economy in which the number of jobs exceeds the supply of people with degrees.

Sources: Degree data from the National Center for Education Statistics 2014; projected annual job openings from the Bureau of Labor Statistics 2014-2024 projections. The idea for this graph comes from a presentation by John Sargent, Senior Policy Analyst, Department of Commerce, at the CRA Computing Research Summit in 2004.

2) Career Choice: Linking relative abilities to choices --The Roy Model

Comparative advantage says that people with high science/math skills (S) relative to money-making skills (M) will choose to get PhD while those with low S/M will choose MBA. As relative pay for PhDs vs MBAs changes the number of persons and ability distribution in the two fields will vary depending on correlation of M and S.

Case 1: If PhD/MBA pay rises and if S and M are **negatively correlated**, S skill falls in PhD while rises in MBA

Negative correlation case: Distribution of talents of people with fixed amount of M + S

	1	2	3	4	5	6	7	8	9	10
MBA (M)	10	9	8	7	6	5	4	3	2	1
PhD (S)	1	2	3	4	5	6	7	8	9	10
M/S	10	4.5	2.7	1.8	1.2	0.8	0.6	0.4	0.2	1/10

Person 1 has M skills. Person 10 has S skills. Persons in the middle has bit of both. If wages split the population between the occupations, those in the middle would be the **MARGINAL decision-makers** on which economics focuses. The margin changes as incentives move people to different choices. If the market pays \$1.00 for M skills and \$1.00 for S skills, 1-5 choose MBA, 6-10 choose PhD. Why? 1 makes \$9 more in MBA; 2 makes \$7 more ... while 6 makes \$1 more in science, etc. Average M of MBAs 1-5 is 8 while the average S of PhD 6-10 is 8.

Say wages in science increase to \$2.00: 4-5 will shift from MBA to PhD. At \$2 4 makes \$8 as a scientist vs \$7 as MBA while 3 still makes more as an MBA. The new science workers, 4 and 5, have lower S skills, so the average skill in science falls. But 4 and 5 had lower business skills than 1,2,3 so average M in business went up. Marginal people have lower ability than infra-marginal people, so that **special ability falls in growing field and increases in declining field**.

Uncorrelated, with same range 1...10 for MBA skills and PhD skills. Assume that everyone but #1 in PhD skill becomes an MBA. When pay for PhD rises it attracts #2 in PhD skill-- person with skill of 9. MBA skills uncorrelated so expected MBA ability will average 5.5 regardless of who becomes a PhD. Movers to PhD reduce average S skill of PhDs and S skill of MBAs. **Growing field gets more people but falling S ability. Declining field gets fewer and falling S.**

	Initial Situation: 1 PhD				PhD pay gain → 2 PhD		
	PhD ability	Average PhD Ability	Expected MBA ability		PhD ability	Average PhD Ability	Expected MBA ability
MBA	1-9	5	5.5		1-8	4.5	5.5
PhD	10	10	5.5		9, 10	9.5	5.5

But what if the productivity is positively correlated and relative ability varies

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
MBA	10	9	8	7	6	5	4	3	2	1
PhD	10	8.2	6.7	5.4	4.3	3.3	2.5	1.8	1.1	1/2
M/S	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2

Higher wages --> more people enter the area with increased relative pay, but the average ability in the skill that pays off in that field falls regardless of correlation. Declining field has a decrease in ability with positive correlation. Contrast with increased ability with negative correlation.

Perfectly positively correlated ability case where most able are top in all skills → single real ability so no comparative advantage. If PhD pays more everyone goes PhD. If MBA pays more everyone goes MBA – infinite elasticity of supply.

	1	2	...	10
MBA	10	9	1	so if M is \$1 and S is \$1 everyone will be on the margin
PhD	10	9	...	1

In 2017 HBS MBA median starting salary was \$135,000 + median signing bonus of \$25,000 (2/3rds get this) + median other rewards of \$25,000 (13%) for ~ \$155k (<http://www.hbs.edu/recruiting/mba/data-and-statistics/employment-statistics.html>). But HBS direct costs ~ \$98.4 per year. 40% of HBS are STEM graduates, so likely to have complementary skills with STEM. Median reported for all MBAs is \$110k.

<http://www.mba.com/us/the-gmat-blog-hub/the-official-gmat-blog/2015/july/estimate-your-post-mba-salary.aspx>.

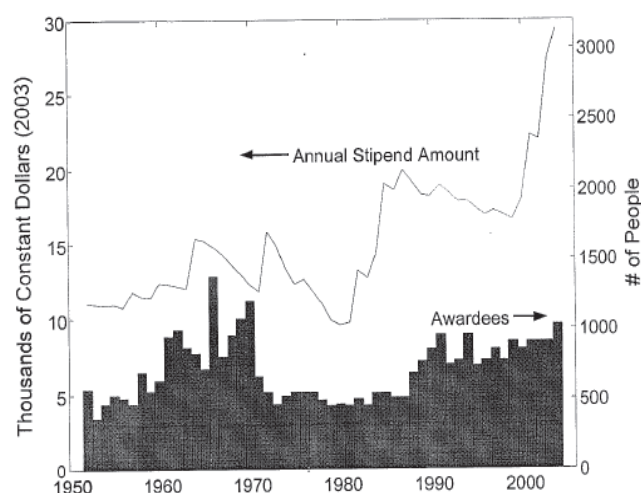
By contrast, PhD post-doc pay is ~\$45,000; PhD grad students earn ~\$35k per year. Early career pay varies from 72k for neuroscientist to 118k for computer science (<http://www.payscale.com/college-salary-report/majors-that-pay-you-back/phd>). But MBAs have experience & steep age-earnings profile → lifetime calculation to analyze choices.

Does the skill model fit data? Freeman, Chang, and Chiang 2009 analyze GRE scores from NSF's **Graduate Research Fellowship Program** (GRFP) that is designed "to ensure the vitality of the scientific and technological workforce in the United States and to reinforce its diversity (by supporting) ... outstanding graduate students in the relevant science, technology, engineering, and mathematics disciplines who are pursuing research-based master's and doctoral degrees" Applicants must be US citizens or nationals, or permanent resident aliens of the US.

March 17, 2017: NSF named 2,000 individuals as this year's recipients of awards from its GFRP chosen from over 13,000 applicants from wide range of scientific disciplines and from all states, as well as the District of Columbia, and U.S. commonwealths and territories. The group of 2,000 awardees is diverse, including 1,158 women, 498 individuals from underrepresented minority groups, 75 persons with disabilities, 26 veterans and 726 undergraduate seniors. The awardees come from 449 baccalaureate institutions.... Applicants are selected through the NSF peer review process. A complete list of those offered the fellowship for 2017 is available on FastLane.

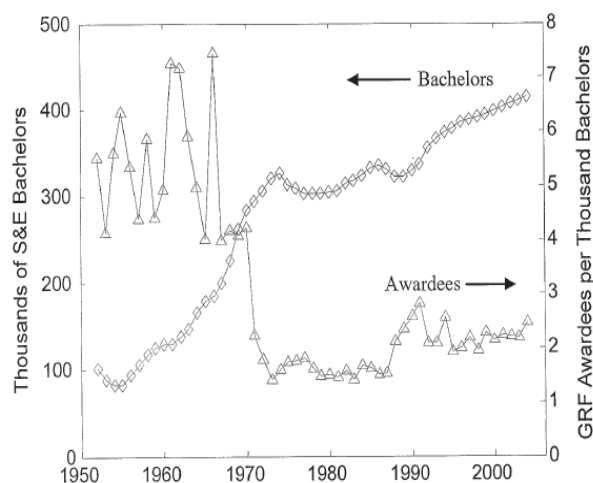
Value of awards and numbers of awards/number of undergraduate science majors have varied depending on non-job market related politics so largely random. Huge increase from 1999 to 2005 in amounts: \$15,000 to \$30,000. Later huge changes in numbers. This creates natural experiments to see response to money incentives and to number of awards: effect of money on #s apply and ability; effect of #awards on quality.

NSF Graduate Research Fellowship Program (1952 - 2004)



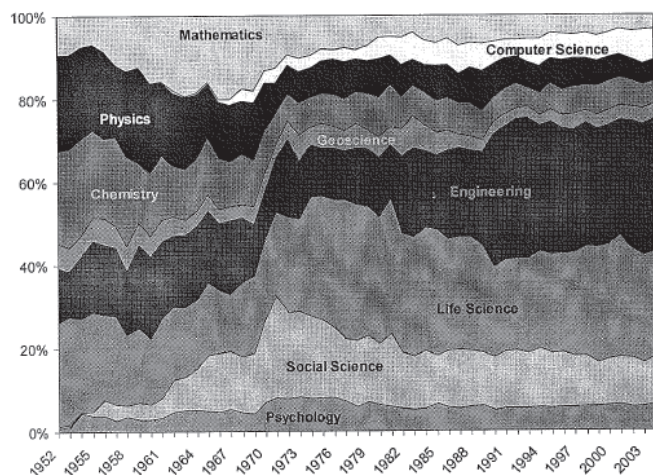
The number and value of GRF awards vary over time.

GRF Awardees as Proportion of S&E Bachelors (1952 - 2004)

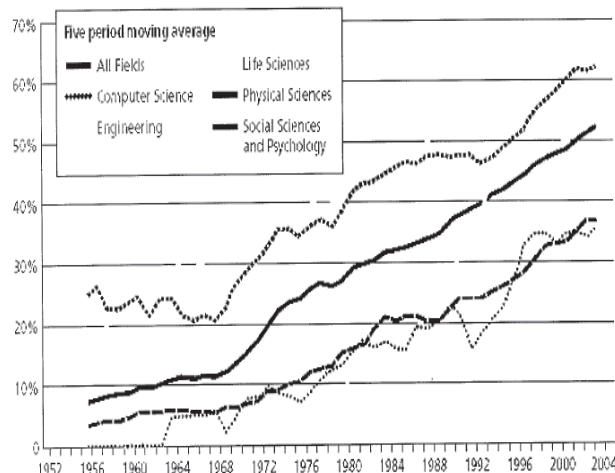


The number of awards per S&E baccalaureate has shifted downwards

Changed Distribution of GFRP Awardees by Field:
Decline of Physical Sciences bcs changed distribution of applicants



Percentage of NSF Fellowships Awarded to Women, 1952-2004

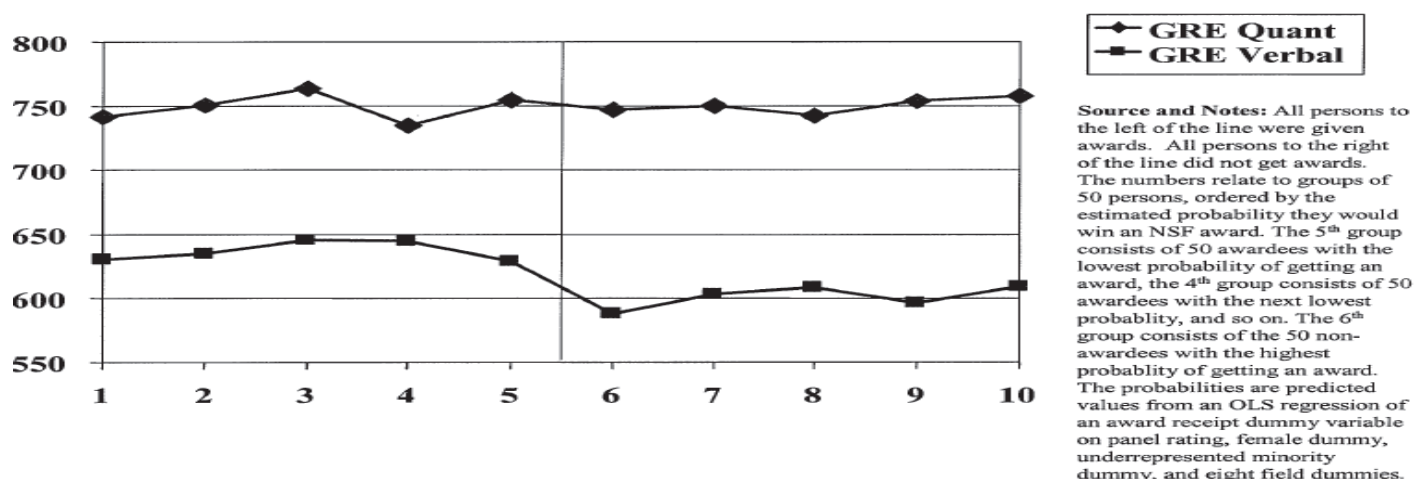


Source: Freeman et al. 2005; Harvard University and NBER 2005, Figure 2.1.

Question 1: As more people apply, we expect “less able/committed folk” to apply. To see if we have a thick/thin margin by measured scores we estimate what determines who gets an award:

	Offered Award		
	1955-98	1976-98	1976-98
Panel Rating			0.170 (0.001)
Reference Score	0.082 (0.001)	0.074 (0.001)	0.022 (0.001)
GRE Quant/100	0.034 (0.001)	0.035 (0.001)	-0.010 (0.001)
GRE Verbal/100	0.060 (0.001)	0.066 (0.001)	0.019 (0.001)
GPA	0.089 (0.002)	0.095 (0.003)	-0.010 (0.003)
Female		0.033 (0.002)	0.037 (0.002)
Minority		0.087 (0.004)	0.077 (0.003)
Field Effects	Yes	Yes	Yes
Year Effects	Yes	Yes	Yes
Observations	207498	107658	107597
R-squared	0.198	0.1793	0.2731

Now look at the skills of those who got awards and those who **might have if there were additional awards.**



Question 2: When the number or value of awards changes, what happens to applicants and to awardees? How many people apply? What are their skills? Then how many are accepted and what are their skills? Number accepted is “exogenous”: Final reduced form outcome are two equations:

1) $N = S_N(\#Awards, \$awards, X)$ # of applicants depends on stipend/outside salary and # of awards

Table 7. Determinants of Awardee Achievement, 1969 - 2004

	GRE Quant	GRE Verbal	GPA
Log(Number of Awards) by Field in Current Yr	-10.6 (1.80)	-21.8 (3.30)	-0.087 (0.01)
Log(Stipend/Outside Salary) in Previous Yr	29 3.3	35.4 6.1	-0.007 0.017
Field Effects	Yes	Yes	Yes
Field x Time Trend	Yes	Yes	Yes
Observations	324	324	270
R-squared	0.8943	0.684	0.7354

Source: Tabulated from NSF, Division of Graduate Education, Cumulative Index of the GRF Program and related datasets, as described in text. Outside salary are earnings of college graduates aged 21-25, tabulated from Current Population Survey.

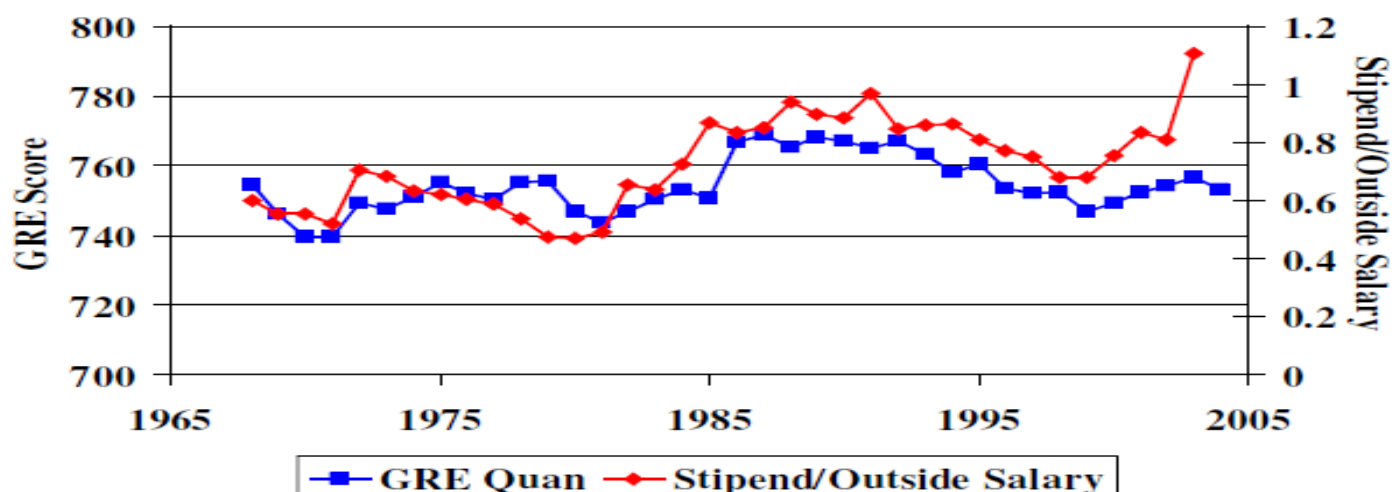
Effects on quality: 2) $Q = S_Q(\text{\#Awards}, \$\text{awards}, X)$

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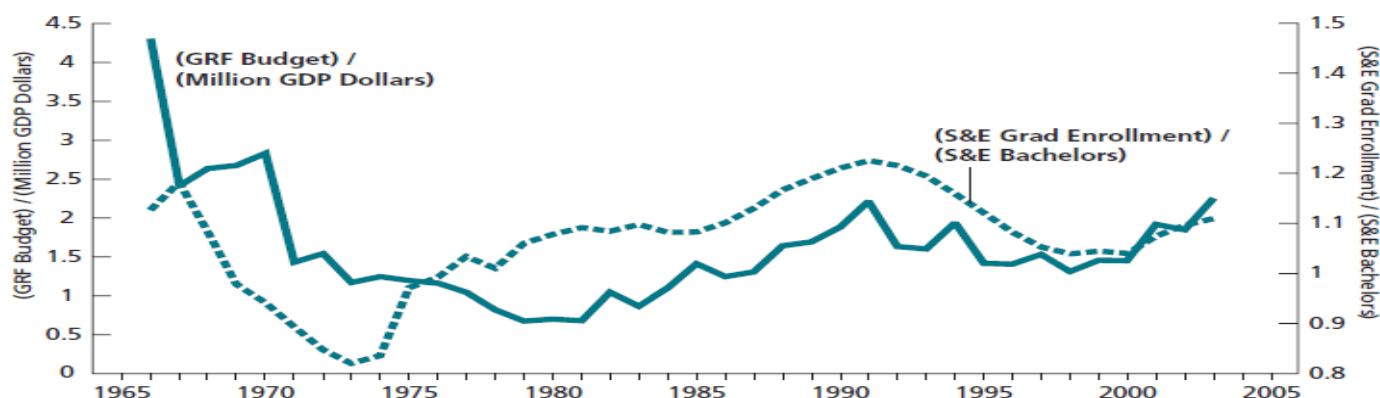
GRE Quantitative Scores of Awardees and Relative Stipend Value, 1968-2004



Source: NSF DGE, Cumulative Index of the GRF Program and related datasets. Salary data estimated from the Integrated Public Use Microdata Series (IPUMS) of the March Current Population Survey.

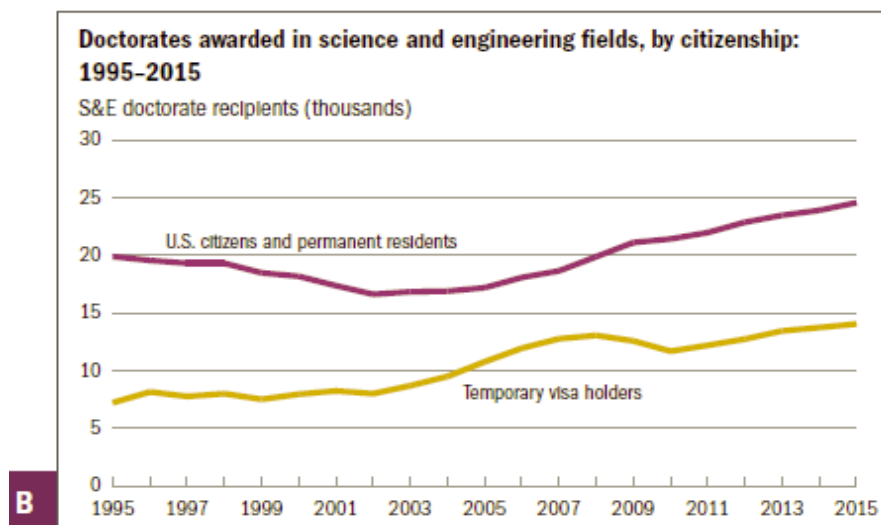
EXHIBIT 5B

Fraction of Science and Engineering Bachelor's Enrolling in Science and Engineering Graduate Programs Compared to Total GRF Budget, Divided by GDP

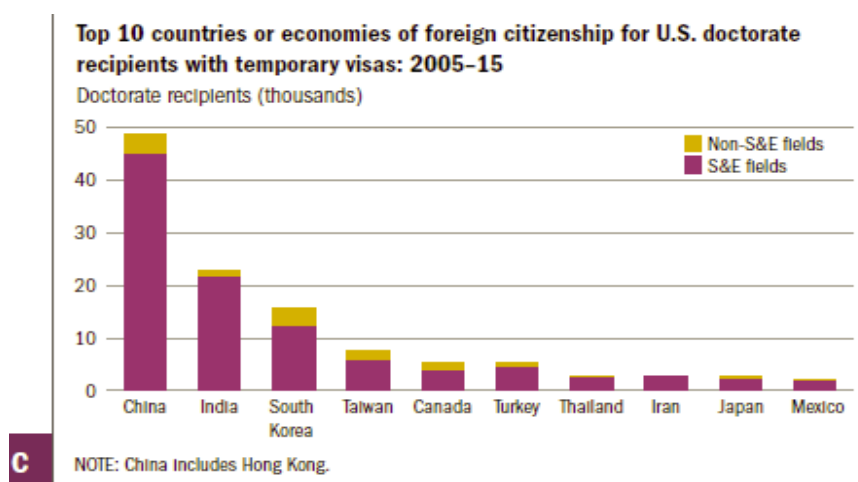


Source: GRF budget divided by GDP, as in Exhibit 5a; bachelor's graduates in science and engineering, as in Exhibit 5a. Enrollments in science and engineering graduate programs from NSF graduate students and postdoctorates in science and engineering (NSF 2004).

3.STEM ENROLLMENTS, DEGREES AND OCCUPATIONS:



Big trend increase in S&E PhDs graduating in US who were in BORN OVERSEAS --> highly elastic supply, particularly from low income countries. In 2015, foreign students earned 56% of all engineering doctorates, 51% of all computer sciences doctorates, 44% of physics doctorates, and 60% of the economics doctorates. % Foreign-born of full-time graduate students for science was 29.8% compared to 17.8% in 1980; for engineering 54.3% compared to 41.9% in 1980.



Tracking people by social security, 2/3rds are in US 5 years after PhD, with higher % from China, India,

Table 3-29

Five-year stay rates for U.S. S&E doctorate recipients with temporary visas at graduation, by selected country/region/economy: 2001-11
(Percent)

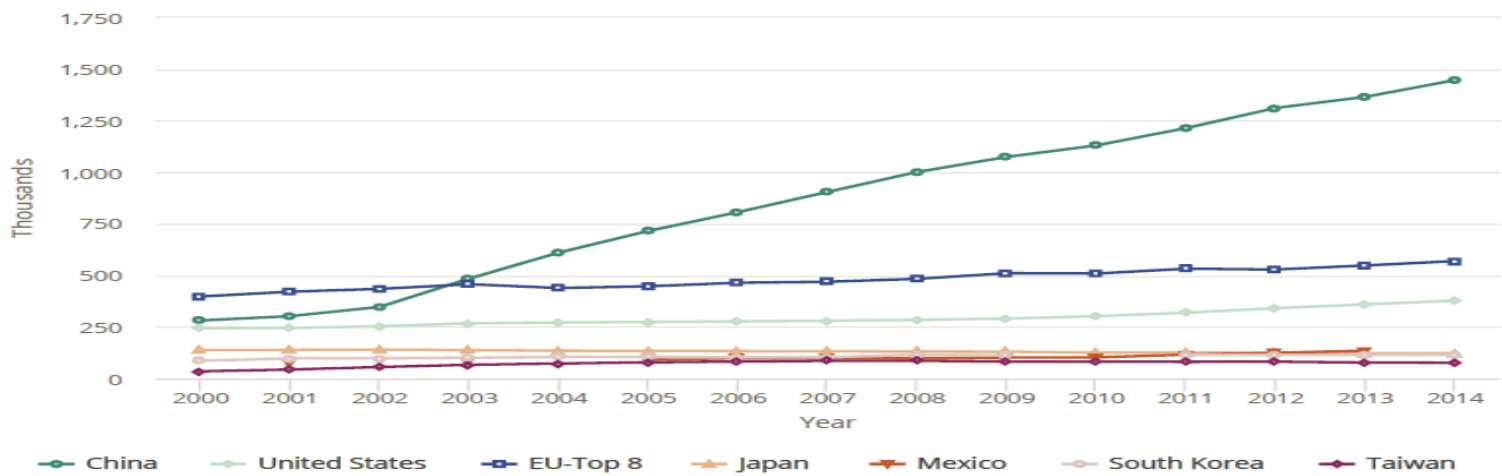
Country/region/economy	2001	2003	2005	2007	2009	2011
All countries/regions/economies	58	64	67	63	62	66
China	98	93	95	94	89	85
India	89	90	89	83	79	82
Europe	53	63	67	67	60	62
Canada	66	63	60	56	53	55
South Korea	22	36	44	42	42	42
Japan	24	39	41	33	40	38
Taiwan	41	48	52	43	37	38
Mexico	31	22	32	33	35	39
Brazil	26	26	31	32	33	37

NOTE: Data for each year reflect the stay rate in that year for the cohort that received their doctoral degrees 5 years earlier.

SOURCE: Finn M. 2014 (forthcoming). *Stay Rates of Foreign Doctoral Recipients from U.S. Universities: 2011*. Oak Ridge, TN: Oak Ridge Institute for Science and Education.

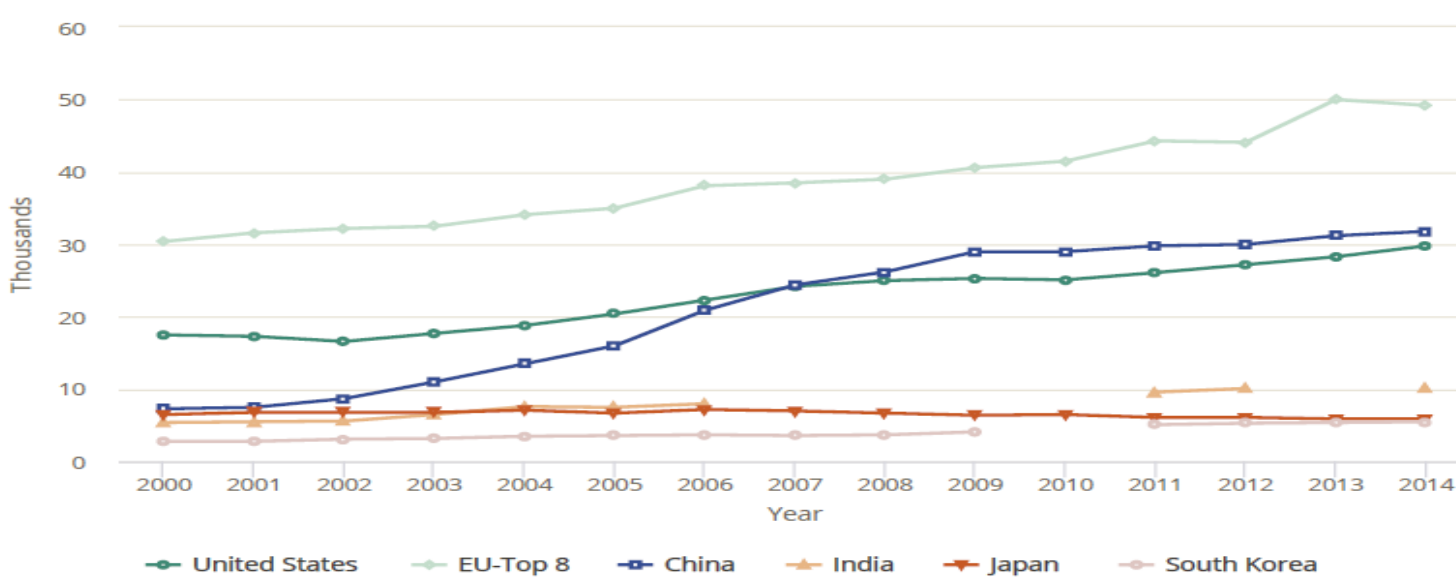
US share of world S&E PhD, MS, Bachelor's degrees in total and in S&E has fallen. Biggest increase is in China

First university natural sciences and engineering degrees, by selected country or economy: 2000–14



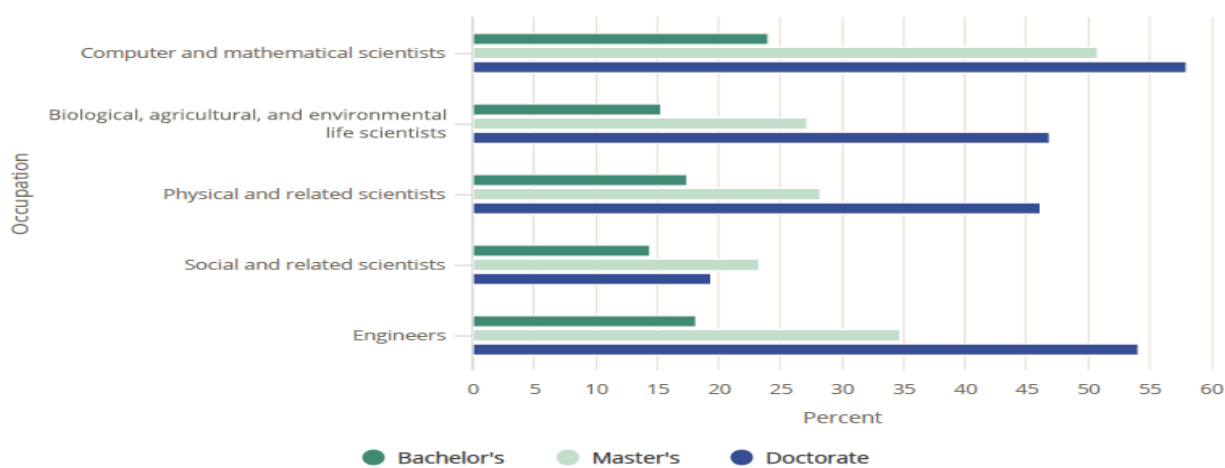
EU = European Union.

Natural sciences and engineering doctoral degrees, by selected country: 2000–14



China leveling off reflects policy to raise quality and stabilize quantity.

Foreign-born scientists and engineers employed in S&E occupations, by highest degree level and broad S&E occupational category: 2015



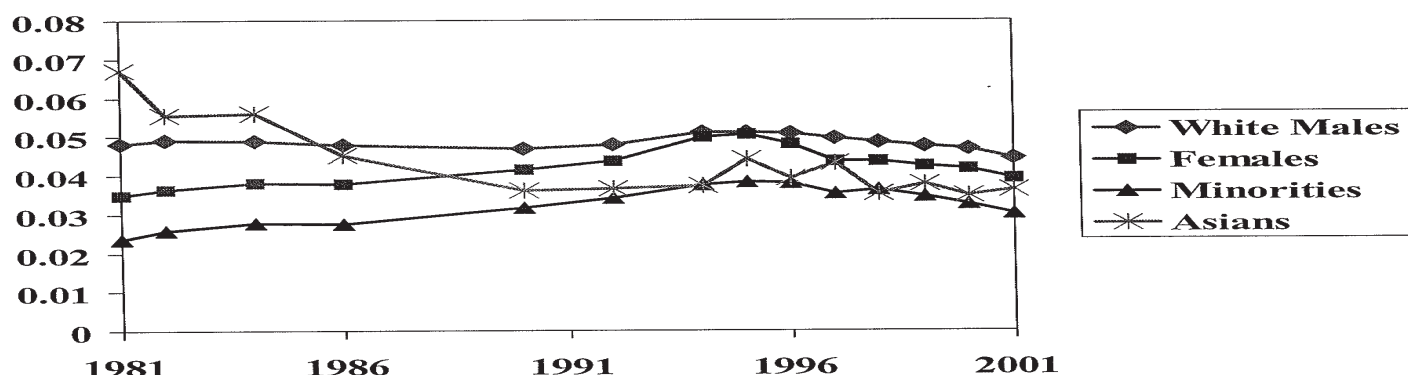
US is big draw in immigrants so that supply goes way beyond US degree grantees

INCREASING SUPPLY OF WOMEN:

In 2011, women were 50% of full-time graduate students in science compared to 33% in 1980; they were 24% of graduate students in engineering compared to 6% in 1980.

Why increased women getting PhDs in science? Trace it back to college major decisions. So why are women majoring in S&E at UG level? Can we trace this back to HS or earlier? Big drop off comes after graduation with changes in careers → nature of careers and biology and child-rearing practices.

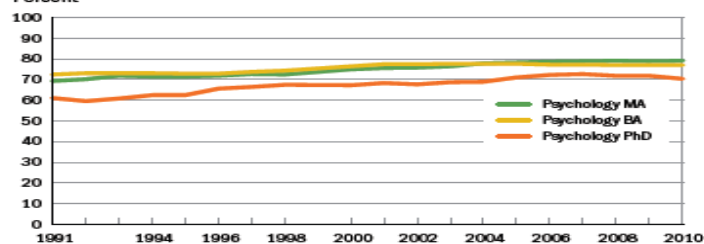
Ratio of Doctorates to 5-Year Lagged Bachelor's Degrees in S&E: By Demographic Group



	CHANGE IN	FRACTION OF INCREASE IN FEMALE TO MALE PH.D. RATIO EXPLAINED BY:		
	Log(Female/Male PhDs)	Rise in PhDs per 5 yr Lagged Bach Degr. Among Females	Rise in 5 Yr Lagged Female to Male Bach Degree Ratio	Drop in PhDs per 5 Yr Lagged Bach Degr. Among Males
All S&E	0.74	15.8%	69.7%	14.4%
Natural/Math	0.86	22.6%	69.6%	7.8%
Engineering	1.64	-9.2%	106.8%	2.4%
Social/Psych	0.78	5.8%	75.7%	18.5%

Large field differences in Female Participation

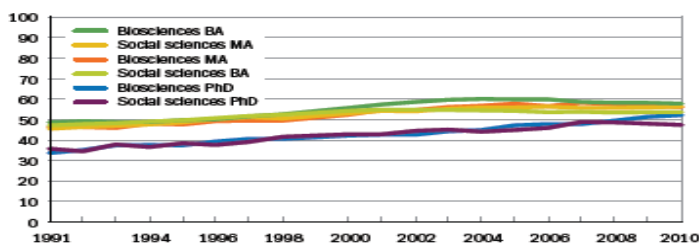
High participation field for women: Psychology, 1991-2010



NOTE: Data not available for 1999.

SOURCE: Women, Minorities, and Persons with Disabilities in Science and Engineering: www.nsf.gov/statistics/wmpd/.

Medium participation fields for women: Biosciences and social sciences, 1991-2010

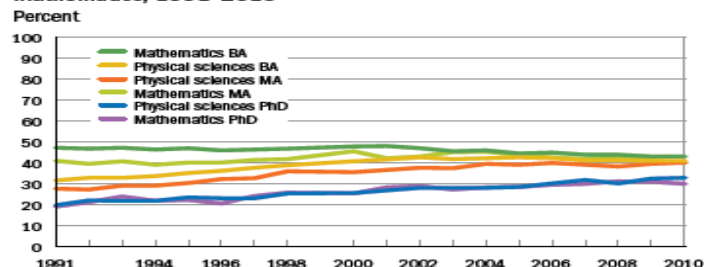


NOTE: Data not available for 1999.

SOURCE: Women, Minorities, and Persons with Disabilities in Science and Engineering: www.nsf.gov/statistics/wmpd/.

C Women's shares of degrees in the physical sciences and mathematics remain well below those of men, particularly at the doctorate level. Women's shares of mathematics degrees at the bachelor's and master's levels have declined since the early 2000s, but they have increased at the doctoral level.

Medium-low participation fields for women: Physical sciences and mathematics, 1991-2010

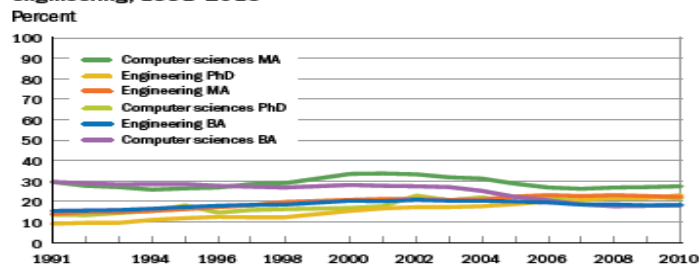


NOTE: Data not available for 1999.

SOURCE: Women, Minorities, and Persons with Disabilities in Science and Engineering: www.nsf.gov/statistics/wmpd/.

D Women's participation in engineering and computer sciences remains below 30%. In the 20 years since 1991, the proportion of women in engineering has increased, mostly at the master's and doctoral levels. Women's participation in computer sciences has increased considerably at the doctoral level (although numbers remain small) but has declined at the bachelor's level.

Low participation fields for women: Computer sciences and engineering, 1991-2010



NOTE: Data not available for 1999.

SOURCE: Women, Minorities, and Persons with Disabilities in Science and Engineering: www.nsf.gov/statistics/wmpd/.

Big issue is that share of principal investigators/professors of women falls far short of %PhDs. Will deal with this when we analyze tournaments and incentives.

University and Minority Issues: Under-represented groups enter in reasonable numbers but do not graduate in same rates: Retention as Key to supplies – Freeman Hrabowski National Academy Report.

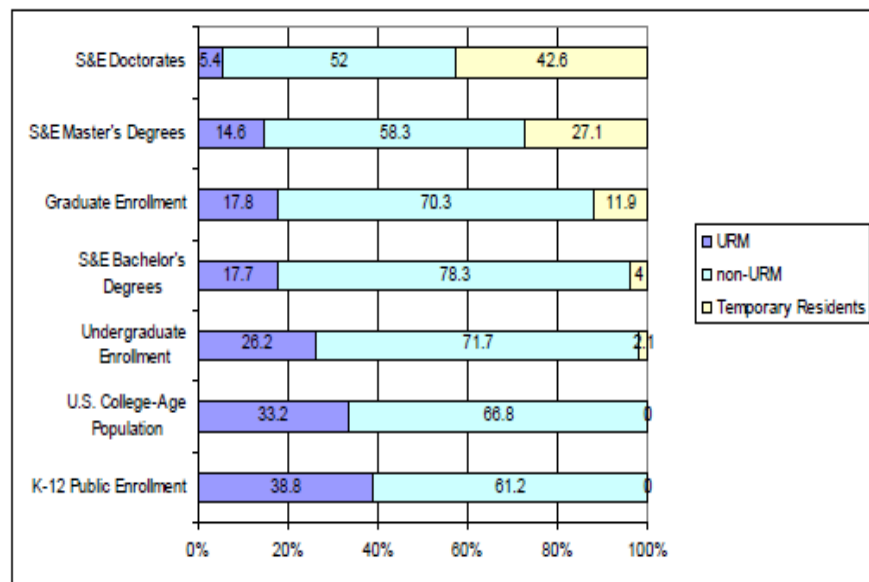


Figure 2-1 Enrollment and Degrees, by Educational Level and Race/Ethnicity/Citizenship, 2007

Sources: NCES, Digest of Education Statistics, 2008, Table 41.

NSF, Women, Minorities, and Persons with Disabilities, Tables A-2, C-6, E-3, and F-11

NSF, S&E Degree Awards, 2006, Table 3.

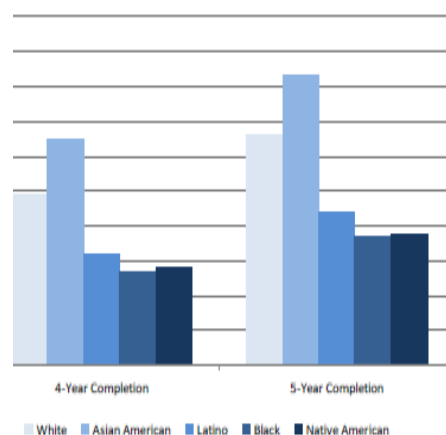
Table 2-2 Principal Investigators on NIH Research Grants, by Race/Ethnicity

Fiscal Year	White	African Americans ¹	Hispanic ²	Other ³
2000	86.2%	1.3%	2.9%	11.4%
2001	85.7%	1.3%	2.9%	12.1%
2002	85.2%	1.5%	3.1%	12.4%
2003	84.4%	1.6%	3.3%	13.2%
2004	83.5%	1.7%	3.3%	14.1%
2005	82.8%	1.7%	3.5%	14.8%
2006	82.1%	1.8%	3.5%	15.4%

¹Race Data may contain individuals reporting Hispanic ethnicity, as well as individuals reporting more than one race

² "All Hispanic" includes Hispanic Race, plus individuals reporting Hispanic Ethnicity (for these individuals the data includes individuals who are represented in one or more of the racial groups)

³ Includes Asian, Native Hawaiian or Pacific Islander, and American Indian or Alaska Native.



percentage of 2004 STEM Aspirants Who Completed STEM Degrees in Four Years, by Race/Ethnicity

University of California Los Angeles, Higher Education Research Institute.

Table 2-3 NSF Research Proposals and Awards, by Race/Ethnicity of PI, 2009

American Indian/Alaska Native	Proposals	78	% of Proposals	0.2%
	Awards	27	% of Funded	0.2%
	Funding Rate	35%		
Black/African American	Proposals	1,005	% of Proposals	2.5%
	Awards	290	% of Funded	2.2%
	Funding Rate	29%		
Hispanic Or Latino	Proposals	1,724	% of Proposals	4.2%
	Awards	529	% of Funded	4.0%
	Funding Rate	31%		
Native Hawaiian/Pacific Island	Proposals	20	% of Proposals	0.0%
	Awards	8	% of Funded	0.1%
	Funding Rate	40%		
Asian	Proposals	9,377	% of Proposals	23.1%
	Awards	2,426	% of Funded	18.2%
	Funding Rate	26%		
White, Not of Hispanic Origin	Proposals	28,476	% of Proposals	70.0%
	Awards	10,023	% of Funded	75.3%
	Funding Rate	35%		
All Races	Proposals	40,680	% of Proposals	100.0%
	Awards	13,303	% of Funded	100.0%
	Funding Rate	39%		

Source: National Science Foundation, NSF Enterprise Information System, as of October 1, 2009

4 COBWEB CYCLES VS RATIONAL EXPECTATIONS → Minority Game

1. Simplest model is that people look at “current” market and expect it to continue so they ignore responses of others and possible shifts in demand:

$$(1) \quad S = aW(-1) \quad [\text{Supply equation}]$$

$$(2) \quad W = bS + cZ \quad [\text{Wage equation}]$$

where S = supply, W = wages, Z = level of demand.

Substituting we obtain

$$(3) \quad S = abS(-1) + acZ(-1) \quad [\text{Cobweb equation}]$$

The result are fluctuations.

2. More sophisticated expectations processes such as adaptive expectations yield similar but more moderate cyclic patterns.

(1) $S = aW^*$ (expected wage for period based on evidence in period -1)

(2) $W^* = W^*(-1) + v(W(-1) - W^*(-1))$ ((expected wage for period based on adjusting previous expected wage in direction of last period's new information.

Applied over and over again it makes W^* a function of $W(-1)$, $W(-2)$, etc

(4) Rational expectations says $W^* = E(W)$ – on average expectations are right.

Data show cycles and difficulty in devising RE models that fit, but people still try. Blume-Kohout ME, Clack JW (2013) Are Graduate Students Rational? Evidence from the Market for Biomedical Scientists. PLoS ONE 8(12): e82759. <https://doi.org/10.1371/journal.pone.0082759>

Table 5. Comparison of cobweb and rational expectations models of PhD student enrollments.

	Cobweb Expectations			Forward-Looking, Rational Expectations	
	(1)	(2)	(3)	(4)	(5)
Relative Wage	3.355** (1.640)	2.864 (2.993)	3.857** (1.771)	−0.324 (0.334)	−0.492 (1.303)
Change in Relative Employment		0.530 (0.559)	0.222 (0.195)	0.305 (0.275)	−0.0179 (0.190)
Wages & Employment Joint Significance, p-value		<.001	0.038	0.438	0.928
Percent of Students with NIH Funding at Enrollment			0.853*** (0.156)		0.848*** (0.198)
First Lag, Relative Enrollment	1.551*** (0.258)	1.487*** (0.464)		1.019*** (0.0369)	
First-Stage F-statistic	23.71	65.72	2.227	6.914	4.747
Hansen's J-statistic	3.106	1.133	2.222	2.480	0.289
Hansen's J p-value	0.376	0.567	0.136	0.289	0.591
Observation-Years	8	8	8	8	8

***p<0.01, ** p<0.05, * p<0.1.

Standard errors robust to arbitrary heteroskedasticity are presented in parentheses below each coefficient estimate.

All results presented are from instrumental variables estimation, with outcome variable the log of the ratio of first-time, full-time enrollment in U.S. biomedical sciences graduate programs each year to bachelor's degrees in biological sciences and chemistry-related fields from U.S. institutions in the previous academic year. Models (1), (2), and (4) are dynamic first-order autoregressive (AR(1)) models, whereas models (3) and (5) are instead first-differenced to remove autocorrelation. Models (1), (2), and (3) correspond to cobweb expectations, with all explanatory variables measured at time of students' entry into graduate programs. Models (4) and (5) assess rational or forward-looking expectations, with the relative wage and employment variables measured six years after entry into the graduate program. We instrument for wages and employment with third and fourth lags of each of our two measures of pharmaceutical industry R&D expenditures, divided by the U.S. Gross Domestic Product. doi:10.1371/journal.pone.0082759.t005

In contrast with this evidence of significant support for the cobweb expectations assumption, columns (4) and (5) in Table 5 provide no evidence of forward-looking, rational expectations as a driver of graduate student enrollments. Specifically, we find no significant relationships between students' entry into graduate programs and either the relative wage for biomedical scientists, or the relative growth in job opportunities realized six years later. However, our point estimate of the effect of current changes in the NIH-funded percentage of full-time students on graduate student enrollments remains nearly identical and highly significant (0.85, p<.001).

Do students really know the pay and opportunities?

The Harvard UG bio major survey, 2000
Undergrad have realistic salary expectations
Postdoc \$28k
Just starting 38k vs MBA 69k
full professor 78k vs MBA 178k

What major sources tell them

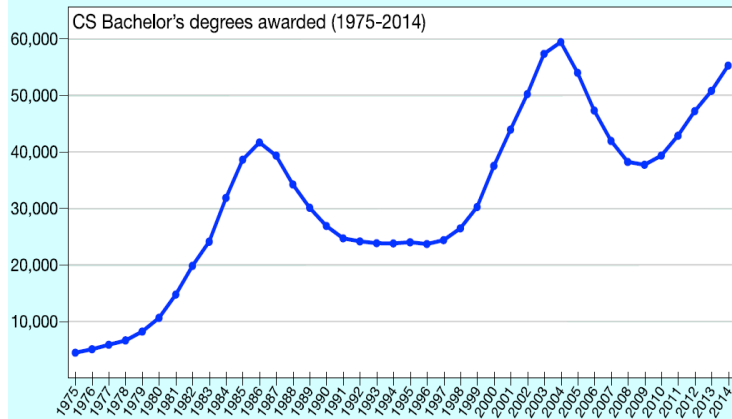
	Strong Mkt	Weak Mkt	Nothing
Professors	31%	23%	36%
Grad/PDs	24%	50%	13%

Do students see money as mattering in “real choice”? Asked “If you won a National fellowship for graduate study of \$40,000 a year would you go on to graduate work in science and engineering? Harvard students: 73% of science concentrators said yes, 40% of all students said yes, far above the 18% of all students who said they were intending on careers in science and engineering

Computer Science: 2017 Assessing and Responding to the Growth of Computer Science
Undergraduate Enrollments <http://nap.edu/24926>

Degree Production Has Been Cyclical

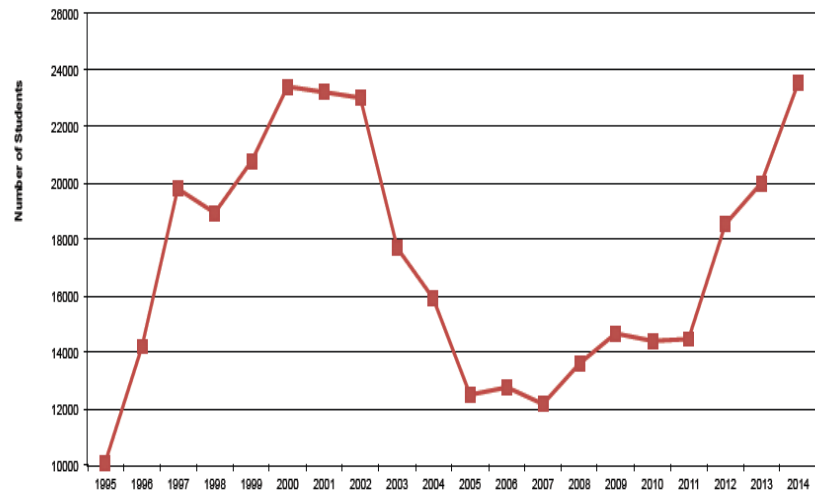
- Historical data show unequivocally that the number of CS degrees has risen and fallen sharply at various times in the past.



Source: National Center for Education Statistics, IPEDS database.

Figure B2. Newly Declared CS/CE Undergraduate Majors

CRA Taulbee Survey 2014



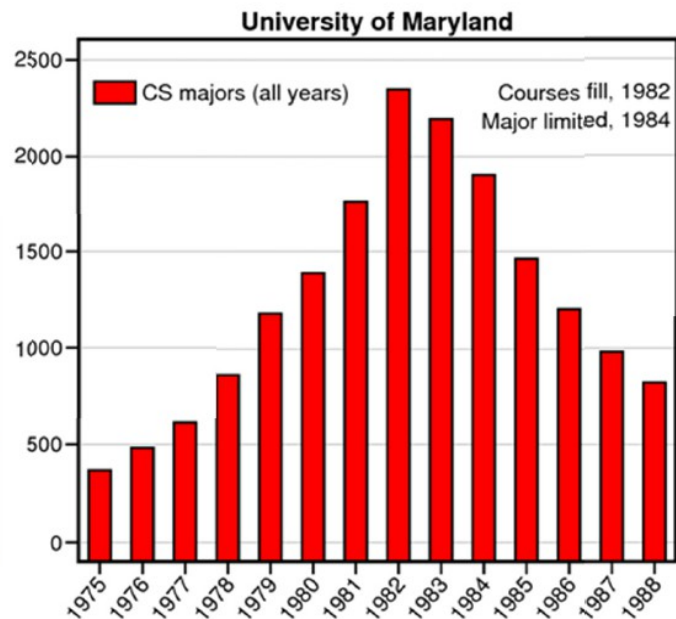
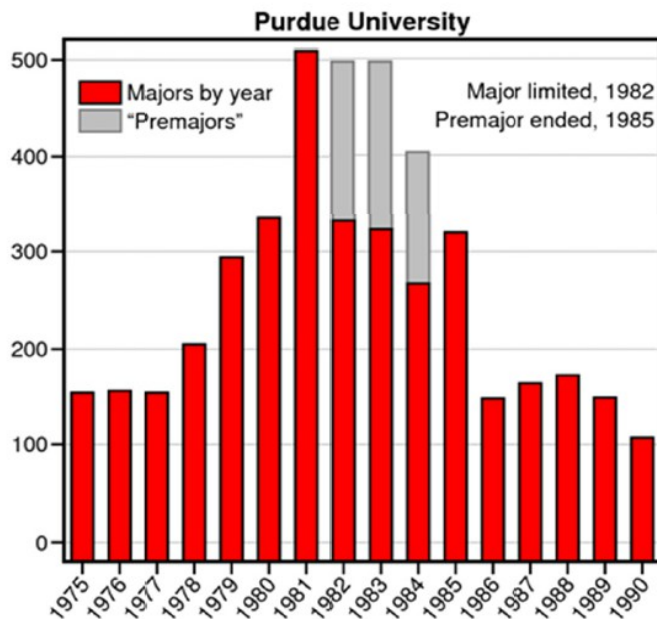
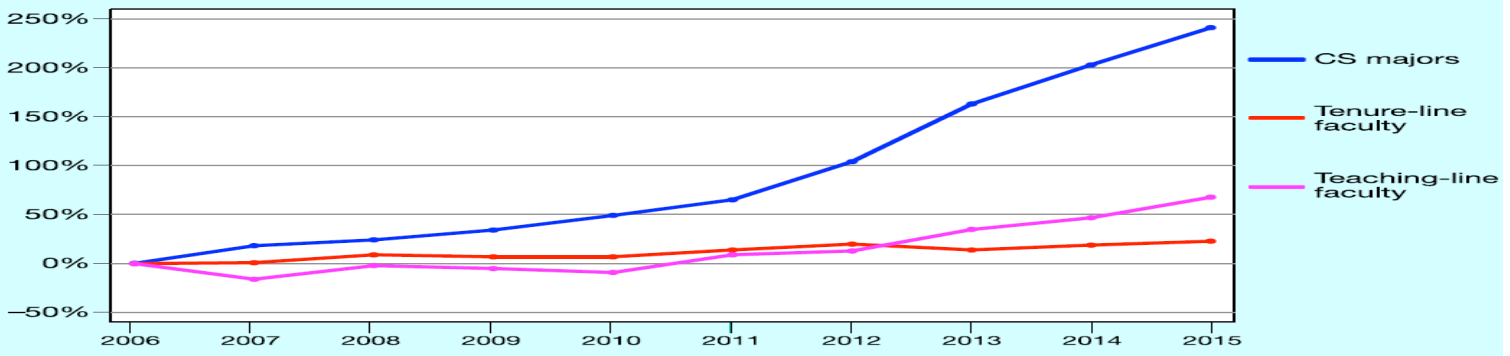
- But ...
- Although student reaction to the dot-com bust and offshoring were factors in the decline of the early 2000s, institutional actions to limit student enrollment played a major role in both of the earlier declines. Institutions take such actions when they cannot hire enough faculty to meet student demand.

The Shortage of Faculty Candidates

- According to the CRA Taulbee Survey, 1780 Ph.D. degrees in computer science were awarded in 2015.
- If only 18 percent of Ph.D. recipients take teaching positions in academia, that means there are only 320 new Ph.D.s available to fill faculty positions in the 1577 colleges and universities that offer CS Bachelor's degrees.
- On average, institutions can therefore expect to hire roughly 0.2 new Ph.D.s per year, or one Ph.D. every five years.
- Many institutions are looking for many more faculty to meet the expanding student demand. Northwestern University, for example, is seeking to hire 20 new computer science faculty. That number is 100 times the average institutional share.

Student vs. Faculty Growth

- Since 2008, the number of CS majors has skyrocketed
- Faculty numbers have not kept pace.



MINORITY GAME GETTING TO EQUILIBRIUM W/O RE

Decisions about investments in education involve implicit or explicit forecasts about the future. If you invest in a PhD in economics on the basis of current wage and employment conditions, the cobweb model warns that you may make a big mistake. It takes 5+ years to complete training, get your degree and enter the job market.

What will wages and conditions be like then?

If people follow adaptive/ other myopic expectations and are influenced by the choices of peers, you should expect that the current high earnings will produce a flood of people, which will depress the job market 5 or so years into the future, and reject econ in favor of the field with worst job market. But if you believe that many potential entrants will choose other disciplines because they think there will be a flood of students, go econ. The smart investor goes against the crowd.

But you should also take account of demand factors. If there is another economic meltdown, will the world want more economists or will it want to sacrifice them to the Invisible Hand? A meltdown would likely reduce R&D, producing a crisis that may flood economics with displaced physicists & mathematicians.

If you believe that people follow rational expectations and that the return to economics is high today because of a positive temporary demand/supply shock, you ought to base your decision on your estimate of the equilibrium earnings in the field.

But your assessment of the future ought depend on your view of the views/decisions of others. As in making investments in the stock market, it is not only the fundamental value that determines outcomes but the views of others. And, their view of the future depends on their view of your views. This problem has no deductive rational solution. It creates an infinite regress: If my decision depends on what I think you think, and yours depends on what you think I think, then mine will depend on what you think that I think you think I think.

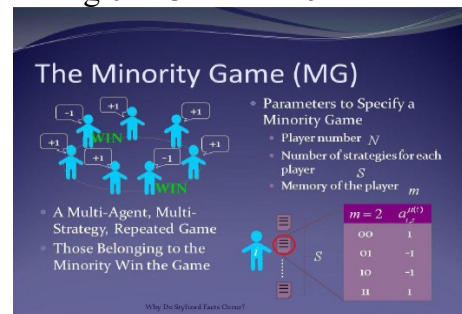
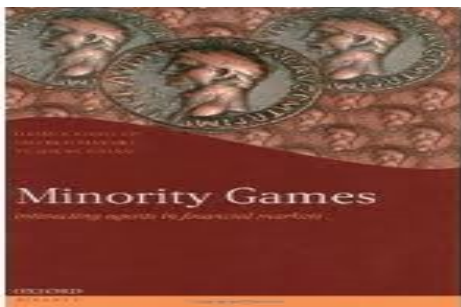
If everyone follows the same expectational rule, the result can be wild swings in the markets – manias as in finance. Need differences in opinion to have a chance for stable market.

If everyone has different expectations ... we have a variant of Brian Arthur's **El Farol Bar problem** --"a fierce assault on the conventions of standard economics." You want to go to the bar if less than 60% of the population go to the bar; but you don't want to go if more than 60% go. Your decision depends on your expectations of how many other people will go ... **but the decisions of the others depends on their expectations, so your decision depends on your expectation of their expectation.**

The great American philosopher, Yogi Berra, described the problem: "It's so crowded, no one goes there anymore---"² The problem is a general one in economics. If everyone goes into the fast lane, it is not fast anymore so should you stay in the slow lane? The unifying feature of the problems is that everyone wants to be in the minority – to buy when others are selling; to sell when everyone else is buying.

THE MINORITY GAME is a formal model of problems in which individuals interact by predicting **inductively** outcomes based on what others will do given public information of what happened in the past.

The model assumes an odd number of players – say 5 – who choose one of two alternatives 0 or 1. If 2 of the 5 choose 0 and the other 3 chooses 1, the two 0s are the winners. It assumes that the ideal is a well-balanced market, so that having a division of 2 of 3 or 15 of 29 is better than having 0 of 3 or 1 of 29 in the minority.



What simple reward structure captures the minority wins idea? Give each player **in the minority** 1 point. Then a nearly balanced outcome has the highest number of points. If three players, the distribution of rewards would be: all choose 0 or 1 – no points

one chooses 0 or 1 while others choose the opposite – 1 point

With five players, the distribution of rewards would be,

all choose 0 or 1, no points

one chooses 0/1 while others choose the opposite – 1 point

two choose 0/1, others choose the opposite, 2 points

Total rewards are highest when get near even split.

Another structure would be to have a player get "more" the more he is in the minority. If there are 5 players and I am the only one to pick 0, I win more than if two players who pick 0. In this case a way to represent the situation is to have persons choose -1 or 1 and to give each player

$G_i = -A_i \sum A_j$, where $A_j = 1$ or -1 , and A_j is for all the players except i .

The total score would be $\sum G_i$

With three players, if all pick -1 or 1, each gets -2 so total rewards are -6. If you pick 1 and everyone else picks -1 you get 2 and they get 0. Again total value is higher when closer to balance.

For a clear presentation and program to play with try <http://ccl.northwestern.edu/netlogo/models/MinorityGame>.

Physicists study the MG game using mean field theory of statistical mechanics, where they do not treat interactions among individual particles, which is a huge multi-body problem, but assume the average or aggregate of all other particles influences a given particle, an immense simplification. *"The MG is a complex dynamical disordered system which can be understood with techniques from statistical mechanics"*

"The logical structure of MG. At each point in time each agent observes public data on the recent behaviour of the market, and is asked to convert this observation into one of two possible actions: 1 or 0 (buy or sell). The agent's decisions is set by a personal **look-up table**, which prescribes a response to every possible market history."

² Other famous Yogisms: *It ain't over till it's over; "I usually take a two hour nap, from one o'clock to four." "If you don't know where you're going, you'll wind up somewhere else." ; "The future ain't what it used to be. "Why buy good luggage? You only use it when you travel." "It's deja vu all over again."*

MG is an inductive data-based solution that based on a rule/mapping that takes past history to a decision. The look-up table tells the agent what to do as a function of last M (usually 3) outcomes — ie if 1 won last 3 times then one strategy is 111—> 1 but another is 111-->0. **We can tell stories about thought process, but all we need is a rule.**

With M=3, there are $2^3 = 8$ possible histories: 000, 001, 010, 011, 100, 101, 110, 111, where 0 means choosing 0 was in the minority and 1 means choosing 1 was in the minority. Thus 000 means choosing 0 won three times in a row. The look-up table tells you what to do in each of these 8 possibilities. One strategy would be 000—> 1 (go with the losing 1 strategy on the assumption that many in the majority 1 will switch) or 000—>0 (go with the winner on the assumption that people in majority who decide to switch from 1 to 0 will be matched by people in the winning minority 0 who think many people in majority will pick 0).

Since for each of the 8 histories there are 2 decisions, 1 or 0, this gives $2^8 = 256$ possible strategies.

Strategies --> A B C ...

history decision

000	1	0	1	0
001	0	1	1	1
010	0	0	1	1
011	1	1	0	0
100	1	1	0	1
101	0	0	0	0
110	1	1	1	1
111	0	0	1	1

Given a strategy, the action of an agent is determined. Agents profit when they take a minority decision, buying when most decide to sell, or vice versa. The economics of the MG lies in the choice of strategies agents use, which is assumed to depend on how often it would have led to a profitable (i.e. minority) decision.

The usual assumption is that an agent has 2 of the 256 possible look-up tables in her repertoire. She calculates which look up table worked best in the past and uses it to make the choice of which to do in the next period. Could keep a running account of how well the strategies did in past 3, 5, ... N games. Put your money on the highest past scoring strategy you hold. If you had A and B in your portfolio, and A scored better over last 3, 5, etc periods you would use it for the next decision.

There are lots of strategies when period over which you assess strategies increases beyond 3 since the number is 2 raised to 2^m . so $m = 2$, 16; $m = 3$, 256; $m = 4$, 65536; $m = 5$, 42,949,67,296

The MG is dynamic in that agents always adapt strategies to events with no steady state or settling down. This is a *disordered system*. Worst outcome – everyone follows the same rule. Best is to be around balance. Artificial agent computer simulations and experiments with people show that the model has some validity.

Four features:

- 1 – All agents have common knowledge of outcomes – they know which choice was minority in the past
- 2 – **Agents use history of past outcomes to make decisions.**
- 3 – No agent collusion or insider information
- 4 – **Heterogeneous strategies**, as individuals convert information into expectations of future in different ways, which shows up in different rules that takes the past history into a decision.

You might expect a disordered system with no communication or planning to produce chaos. You would be wrong.

Simple MG models produce close to optimal market equilibrium – near balance -- with fluctuations.

Formal model has two parameters: M, number of periods whose outcomes determine the history for agent decisions, and N players. The other potential parameter is S, the number of strategies that players pick from the potentially large number possible. But space of all strategies is NS , so studies fix S at 2, and focus on N.. Each period, an agent computes how their (S=2) strategies would have done in the past, and choose the highest payoff strategy for the next period.

Optimal Outcome has ~ 50% choosing 0 and 1. BALANCED MARKET. A good measure of how far we fall short of balance is by taking standard deviation of outcomes from balanced market solution. If we use 1 and -1 to reflect choices and count numbers, the average is 0, with easy σ^2 measure of osse to society.

Consider with this metric three decision rules – random choice, perfect coordinated and Copy Neighbor. Let's see how they do with 3 players

	RANDOM				IDEAL COORDINATION				COPY NEIGHBOR			
Number Choosing 1		prob	Value	Sqrd		prob	Value	Sqrd		prob	Value	Sqrd
3	1/8	3	9		0				1/2	3	9	
2	3/8	1	1		1/2	1	1		0			
1	3/8	-1	1		1/2	-1	1		0			
0	1/8	-3	9		0				1/2	-3	9	

with σ^2 (9+3+3+9 =24) /8 = 3 (1+1)/2 = 1 (9+9)/2 = 9
 So worst is when everyone does the same and best is ideal coordination. Generalizing we have

	σ^2			σ^2/N		
# of players	3	5	N	3	5	N
Random	3	5	N	1	1	1
Coordinate	1	1	1	1/3	1/5	1/N
Do the Same	9	25	N ²	3	5	N

Note that random strategies give result that is closer to coordination than to “do the same”!

To see how the look-up table selection process works, people do computer simulations varying the number of histories (2^M) and number of players (strategies) with following results:

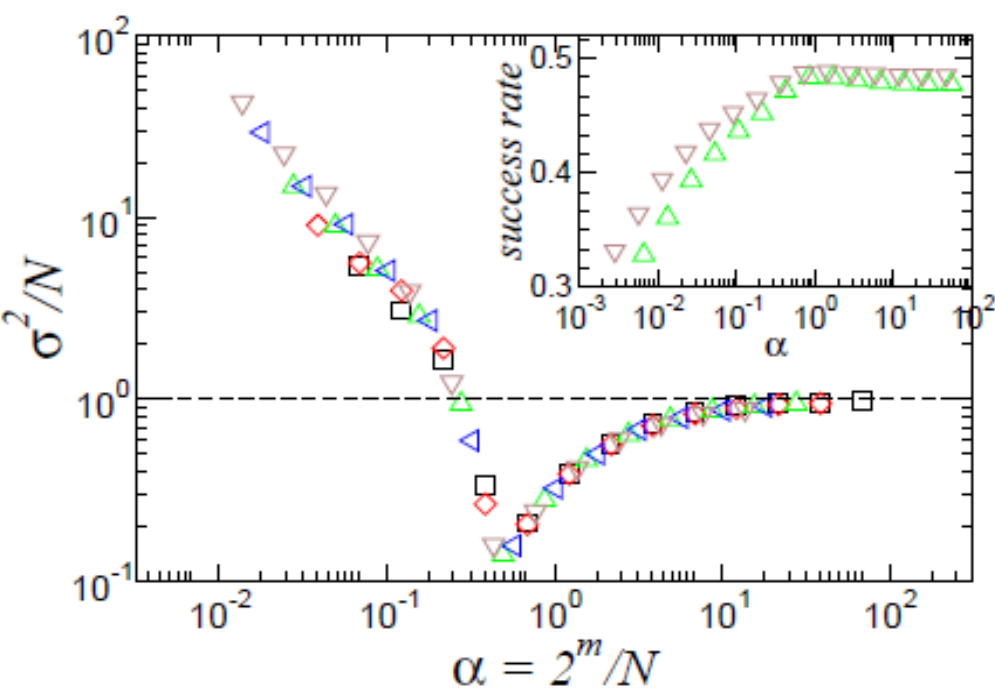


Figure 3: Volatility as a function of the control parameter $\alpha = 2^m/N$ for $s = 2$ and different number of agents $N = 101, 201, 301, 501, 701$ ($\square, \diamond, \triangle, \triangleleft, \nabla$, respectively). Inset: Agent’s mean success rate as function of α .

Simulations and analysis show that solutions depend on # of histories relative to # of players, $\alpha = 2^M/N$. This parameter measures how well the players cover the "history/possible strategy space".

If there are many more histories 2^M than players N so that α is large then $\sigma^2 \rightarrow N$, so get close to random, with no "implicit coordination" because lots of possible strategies or histories, then you learn from histories, get persistent behavior -- sparse space close to random

If there are many players N relative to strategies the choices effectively cover the space of possible strategies so that α is small, it can be **too small** \rightarrow "herd effect" as some players duplicate others \rightarrow inefficient outcomes σ^2 is larger than random. Can "interpret this" as reflecting situation where lots of players/strategies, agents "over react" to information.

If α is moderate, around 0.34 in simulations, size of winning group is around $(N-1)/2$, which yields σ^2/N for deviation $\rightarrow 0$ as N rises.

.When $\alpha = 2^M/N$ is small get cyclic cobweb style functions. With short memories, people respond to last period; with long memories/rational expectations much less fluctuations.

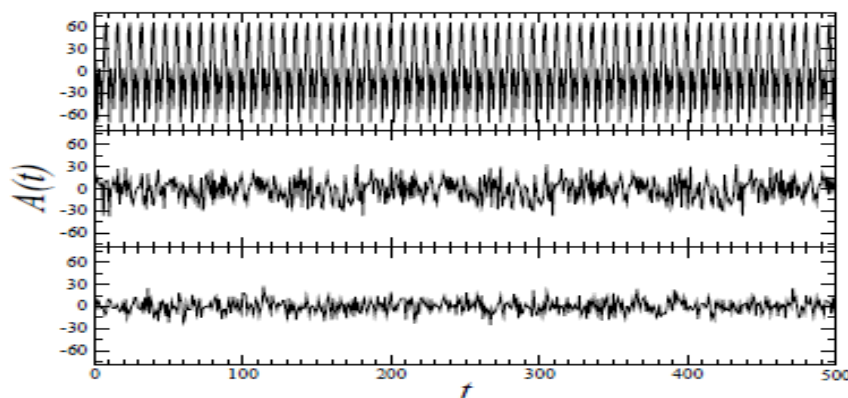


Figure 2: Time evolution of the attendance for the original MG with $g(x) = x$ and $N = 301$ and $s = 2$. Panels correspond to $m = 2, 7$ and $m = 15$ from top to bottom. Periodic patterns can be observed for $m = 2$ and $m = 7$.

Bottom line: **You get something like a market clearing equilibrium without rational expectations and no price mechanism but with cycles and no steady state. It depends on people having very different expectations – “local behavior as opposed to global behavior?”**

