Lecture 5: Supply of Scientists: Shortages, Surpluses, and Cycles;

I)Shortages; 2)Roy Model; 3)US/Global Supply; 4)Cobwebs and Minority Game;

Never-Ending Shortages and Recruitment Efforts

USA Science and Engineering Festival EXPO 2020 Washington The 3-day Festival Expo is the culminating event of year-round school programming and ancillary events, taking place April 24-26, 2020 at the Walter E. Washington Convention Center … draws upwards of 300,000 people ... that celebrate the excitement of STEM ... and turn our focus towards the future of education and employment in the fields of science, technology, engineering, and mathematics. With thousands of hands-on activities, conversations with STEM mentors, and exciting stage shows, the Festival connects directly with the next generation of innovators and ignites a long-lasting passion for STEM. Founded by entrepreneur Larry Bock and Lockheed Martin executives to address the severe shortage in science and tech talent … 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 NYT 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 n**eed 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 <u>Rising Above the Gathering Storm,</u> 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 1October 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 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*

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... Foxconn pays workers $4,800 per year (a $26 billion diff >net profit for 2011."

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... " boom-and-bust cycles".

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

And in 2019 a very different story about lifetime incomes,

The New York Times | https://nyti.ms/30du9Uk

ECONOMIC VIEW

In the Salary Race, Engineers Sprint but English Majors Endure

By David Deming

Published Sept. 20, 2019 Updated Oct. 1, 2019

For students chasing lasting wealth, the best choice of a college major is less obvious than you might think.

The conventional wisdom is that computer science and engineering majors have better employment prospects and higher earnings than their peers who choose liberal arts.

This is true for the first job, but the long-term story is more complicated.

The advantage for STEM (science, technology, engineering and mathematics) majors fades steadily after their first jobs, and by age 40 the earnings of people who majored in fields like social science or history have caught up.

This happens for two reasons. First, many of the latest technical skills that are in high demand today become obsolete when technology progresses. Older workers must learn these new skills on the fly, while younger workers may have learned them in school. Skill obsolescence and increased competition from younger graduates work together to lower the earnings advantage for STEM degree-holders as they age.

Second, although liberal arts majors start slow, they gradually catch up to their peers in STEM fields. This is by design. A liberal arts education fosters valuable "soft skills" like problem-solving, critical thinking and adaptability. Such skills are hard to quantify, and they don't create clean pathways to high-paying first jobs. But they have long-run value in a wide variety of careers.

Computer science and engineering majors between the ages of 23 and 25 who were working full time earned an average of $61,744 in 2017, according to the Census Bureau's American Community Survey. This was 37 percent higher than the average starting salary of $45,032 earned by people who majored in history or the social sciences (which include economics, political science and sociology). Large differences in starting salary by major held for both men and women.

Men majoring in computer science or engineering roughly doubled their starting salaries by age 40, to an average of $124,458. Yet earnings growth is even faster in other majors, and some catch up completely. By age 40, the average salary of all male college graduates was $111,870, and social science and history majors earned $131,154 — an average that is lifted, in part, by high-paying jobs in management, business and law.

The story was similar for women. Those with applied STEM majors earned nearly 50 percent more than social science and history majors at ages 23 to 25, but only 10 percent more by ages 38 to 40.

One reason for the narrowing gap is that STEM jobs change rapidly, and workers must constantly learn new skills to keep up. In a recent working paper with a Harvard doctoral student, Kadeem Noray, I calculated how much the skills required for different jobs changed over time. Help-wanted ads for jobs like software developer and engineer were more likely to ask for skills that didn't exist a decade earlier. And the jobs of 10 years ago often required skills that have since become obsolete. Skill turnover was much higher in STEM fields than in other occupations.

For data from ACS: https://www.census.gov/programs-surveys/acs/news/updates/2019.html
https://lehd.ces.census.gov/data/pseo_experimental.html

We can also see this by looking at changes in college course catalogs. One of the largest and most popular courses in the Stanford computer science department is CS229 — Machine Learning, taught by the artificial intelligence expert and entrepreneur Andrew Ng. This course did not exist in its current form until 2003, when Professor Ng taught it for the first time with 68 students, and very little like it existed anywhere on college campuses 15 years ago. Today, the machine learning courses at Stanford enroll more than a thousand students.

In contrast, much less has changed in my home discipline, economics, where we still mostly offer the classics like intermediate microeconomics or public finance.

Since new technical skills are always in high demand, young college graduates who have them earn a short-run salary premium. Yet when the job changes, these now experienced workers must learn new technical skills to keep up with fresh college graduates and a constant stream of talent from abroad.

The result is slower salary growth and high exit rates from the STEM work force. Between the ages of 25 and 40, the share of STEM majors working in STEM jobs falls from 65 percent to 48 percent. Many of them shift into managerial positions, which pay well but do not always require specialized skills.

Why do the earnings of liberal arts majors catch up? It's not because poetry suddenly pays the bills. Midcareer salaries are highest in management and business occupations, as well as professions requiring advanced degrees such as law. Liberal arts majors are more likely than STEM graduates to enter those fields.

A traditional liberal arts curriculum includes subjects, like philosophy and literature, that seemingly have little relevance in the modern workplace. Yet many of the skills most desired by employers are also quite abstract.

According to a 2018 survey by the National Association of Colleges and Employers, the three attributes of college graduates that employers considered most important were written communication, problem-solving and the ability to work in a team. Quantitative and technical skills both made the top 10, alongside other "soft" skills like initiative, verbal communication and leadership. In the liberal arts tradition, these skills are built through dialogue between instructors and students, and through close reading and analysis of a broad range of subjects and texts.

Liberal arts advocates often argue that education should emphasize the development of the whole person, and that it is much broader than just job training. As an educator myself, I agree wholeheartedly.

But even on narrow vocational grounds, a liberal arts education has enormous value because it builds a set of foundational capacities that will serve students well in a rapidly changing job market.

To be clear, I am not suggesting that students should avoid majoring in STEM fields. STEM graduates still tend to have high earnings throughout their careers, and most colleges require all students — including STEM majors — to take liberal arts courses.

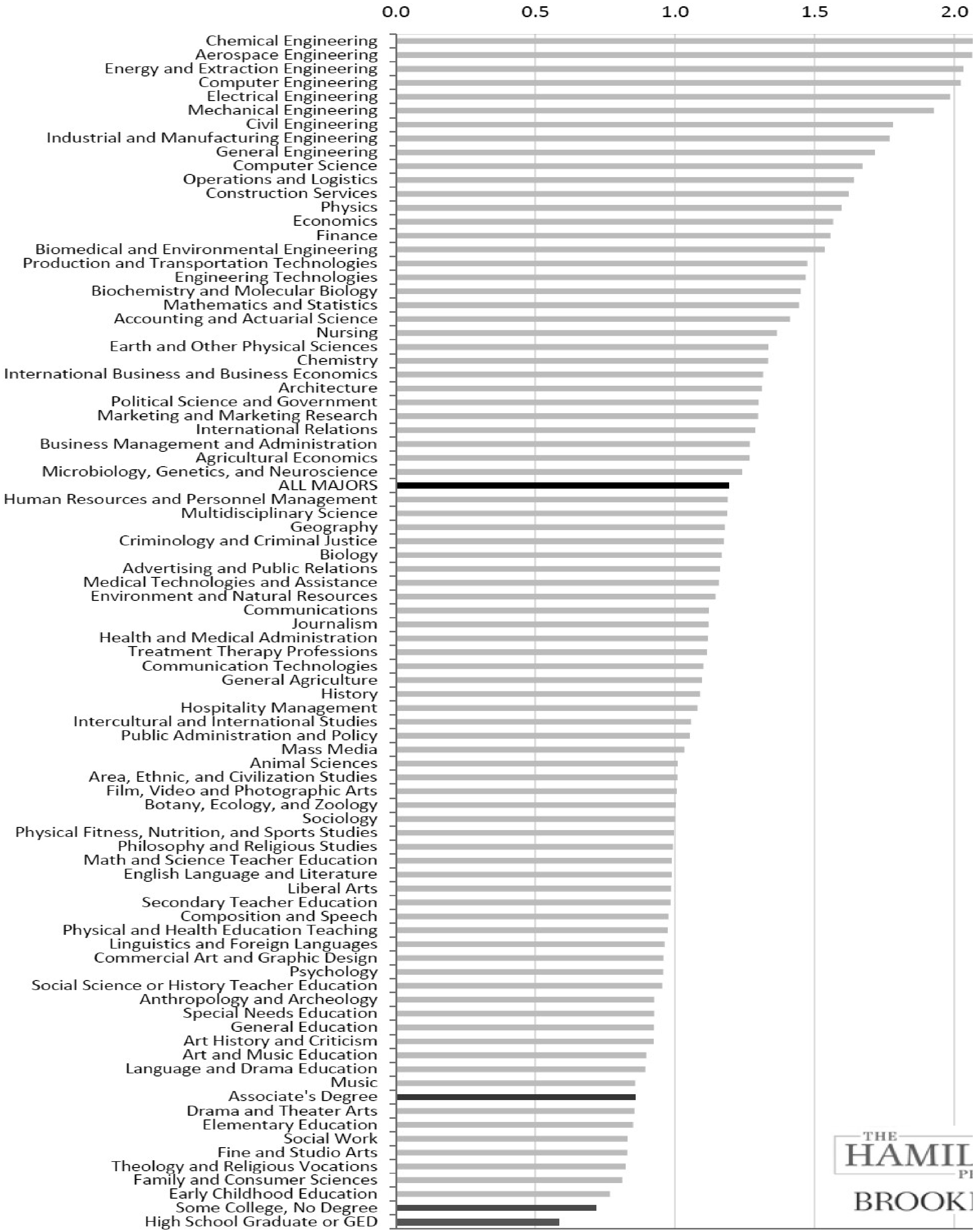
But I do think we should be wary of the impulse to make college curriculums ever more technical and career focused. Rapid technological change makes the case for breadth even stronger. A four-year college degree should prepare students for the next 40 years of working life, and for a future that none of us can imagine.

A team of analysts who were on … takes objection to this analysis, based on … and is seeking to get letter/story in NYT that tells a different story. Last time a team of experts tried to get NYT to correct their "shortage " headline with the erroneous claim that Americans were not pursuing STEM majors, the NYT refused to correct themselves. My bet is they will also reject any "correction" but there are issues worth exploring and interpretations worth disputing.

ASSIGNMENT: IS IT BETTER FOR YOUR $$$ CAREER – SCI-ENG OR LIB ARTS? Here are some questions that can be addressed. Group of engineering educ specialists are awaiting your evidence!

1)Economics stresses lifetime incomes which given discounting makes early career earnings advantages more important. See https://www.hamiltonproject.org/papers/major_decisions_what_graduates_earn_over_their_lifetimes This does not fit with theme of this article. Why? How do these folk calculate lifetime earnings from cross section data?
2)High-pay jobs to liberal arts majors likely to come from MBAs, Law degrees, etc that require 2-3 years of additional schooling and that may cost the students high tuition fees. How does this impact lifetime earnings?
3)What is best path to very high income/top of corporations – Lib Arts or Math major?L ook at whole distribution.
4)Does the sluggish pace of progress in non-science/tech fields signify something bad for the economy writ large or is this a mistaken view?
5)Would looking at courses taken as opposed to majors give a different view?
6) Where are **expectations of the future** in these calculations?

Figure 2a: Median Lifetime Earnings, by College Major (millions of dollars)



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.

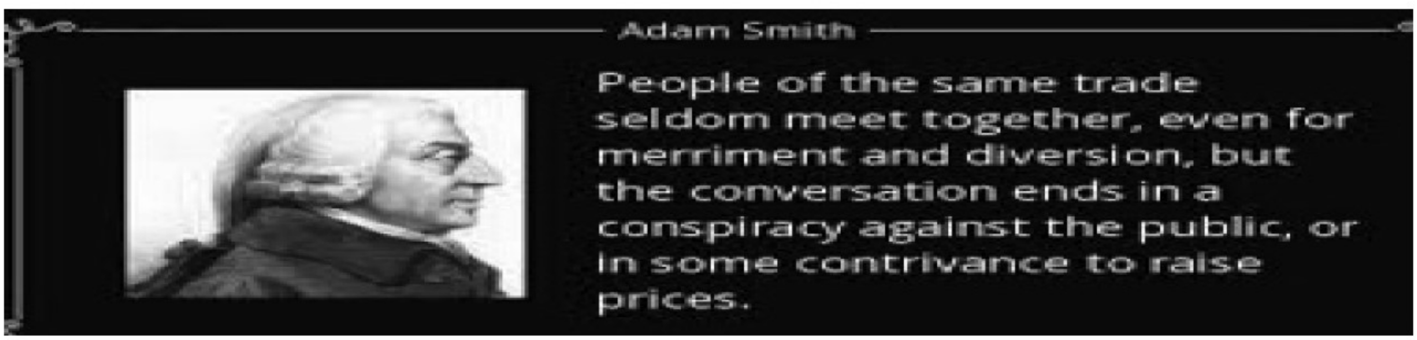
Or market manipulation… In early 2005, as demand for Silicon Valley engineers began booming, Apple's Steve Jobs sealed a secret and illegal pact with Google's Eric Schmidt to artificially push their workers wages lower by agreeing not to recruit each other's employees, sharing wage scale information, 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... even though major result in PD games is that more CC, where C is Google and Apple cooperating to rip off their workers.**

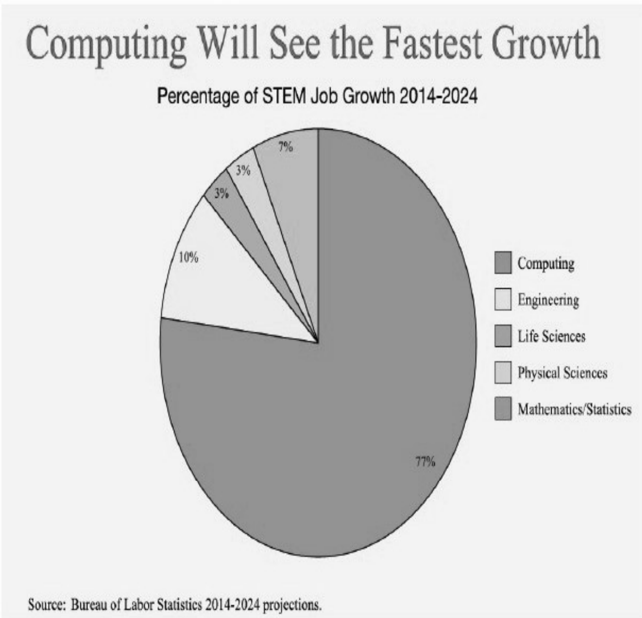
STEM crisis or STEM surplus? Yes and yes … The last decade has seen considerable concern regarding a shortage of science, technology, engineering, and mathematics (STEM) workers to meet the demands of the labor market. At the same time, many experts have presented evidence of a STEM worker surplus. A 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.

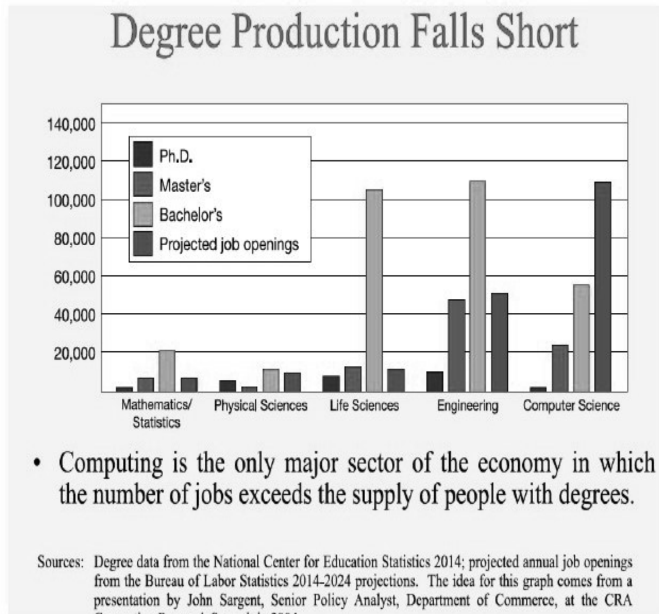
Candidate for shortage today: Computer Science/Data Science
IBM Predicts Demand For Data Scientists Will Soar 28% By 2020 Louis Columbus Forbes … Jobs requiring machine learning skills are paying an average of $114,000. Advertised data scientist jobs pay an average of $105,000 and advertised data engineering 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 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 compete for jobs paying over $100K.

Data Scientist: The Sexiest Job of the 21st Century Thomas H. Davenport D.J. Patil

OCTOBER 2012 Harvard Business Review





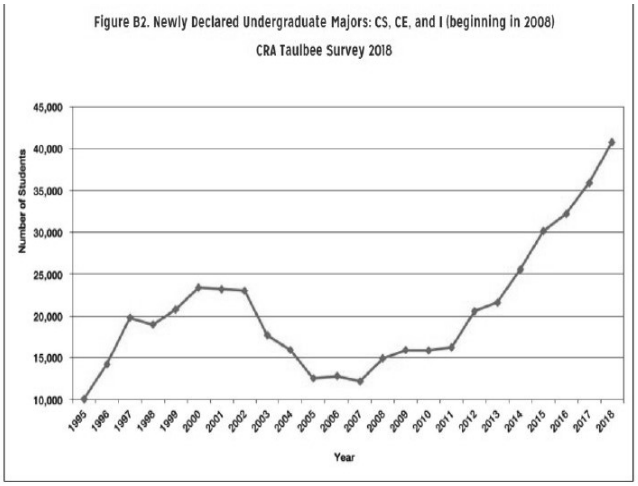
But it is all about market conditions which fluctuate, not about "intrinsics" of job

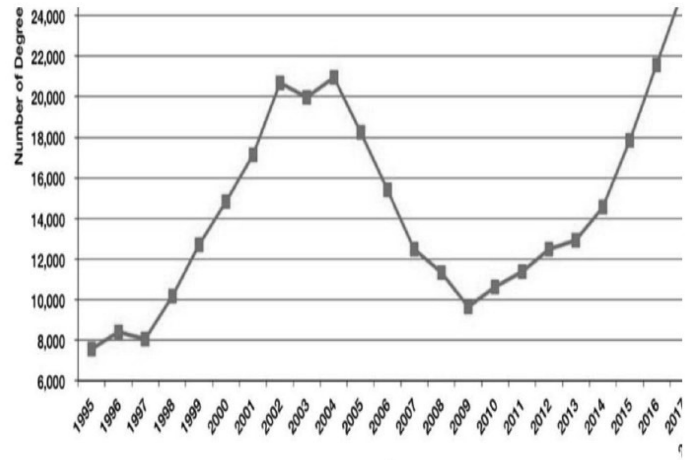
Sounds good and is repeated throughout the Internet. It's 2020 and wages and unemployment stats show boom in computer science/data science remains strong. NACES Most Recent Data on starting pay

Figure 1: CHANGES IN PRELIMINARY REPORTED AVERAGE STARTING SALARIES, 2019 & 2018

BROAD CATEGORY	
COMPUTER & INFORMATION SCIENCES	
2019 Average Salary	$81,292
2018 Average Salary	$73,768
Percent Change	10.2%
ENGINEERING	
2019 Average Salary	$69,180
2018 Average Salary	$65,455
Percent Change	5.7%
MATHEMATICS & STATISTICS	
2019 Average Salary	$68,785
2018 Average Salary	$65,349
Percent Change	5.3%
ENGINEERING TECHNOLOGIES	
2019 Average Salary	$60,473
2018 Average Salary	$57,267
Percent Change	5.6%
HEALTH PROFESSIONS & RELATED PROGRAMS	
2019 Average Salary	$54,175
2018 Average Salary	$52,711
Percent Change	2.8%
BUSINESS	
2019 Average Salary	$53,912
2018 Average Salary	$51,872
Percent Change	3.9%
SOCIAL SCIENCES	
2019 Average Salary	$53,729
2018 Average Salary	$44,047
Percent Change	22.0%
MULTI/INTERDISCIPLINARY STUDIES	
2019 Average Salary	$50,302
2018 Average Salary	$48,966
Percent Change	2.7%

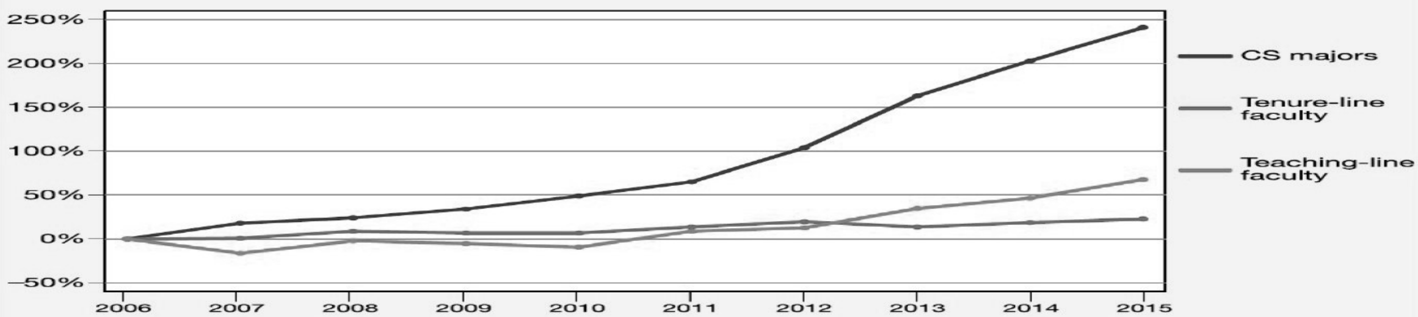
Student Behavior Shows Cyclic Boom-and-bust in Comp Scie followed by BOOM





Student *vs.* Faculty Growth

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

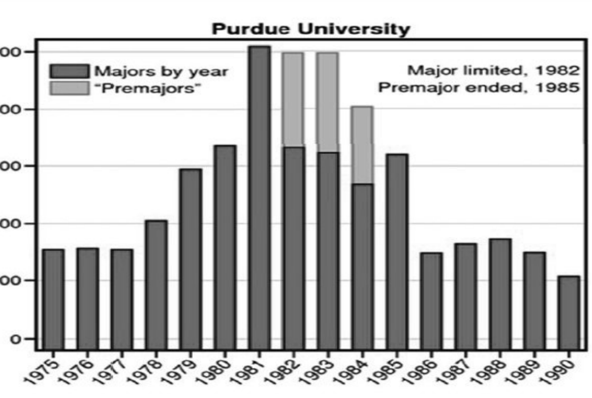


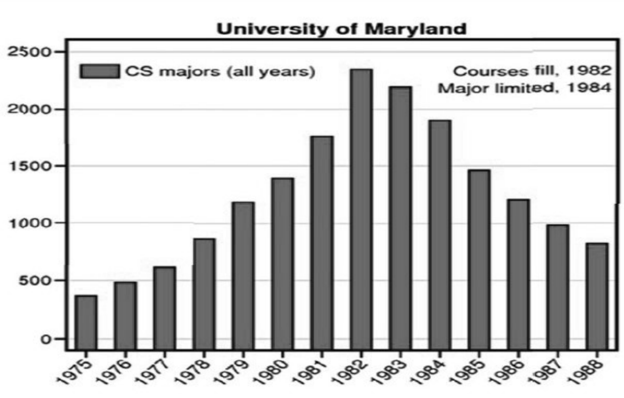
Source: CRA, *Generation CS*, February 2017

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.

2. 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.





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 make $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

	1	2	3	4	5	6	7	8	9	10
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 2018 HBS MBA median starting salary was $140,000 + median signing bonus of $25,000 (2/3rds get this) +median other rewards of $29,000 (14%) for ~ $160k (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. See for more detail https://www.mba.com/mbas-and-business-masters/articles/your-salary/estimate-your-post-mba-salary

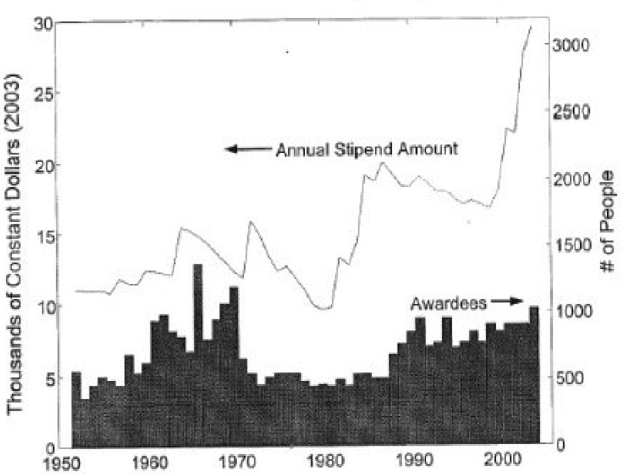
By contrast, PhD post-doc pay is ~$45,000; PhD grad students earn ~$35k per year. Early career pay varies from 72k for neuroscientist to 118k for computer science (http://www.payscale.com/college-salary-report/majors-that-pay-you-back/phd). But MBAs have experience & steep age-earnings profile → lifetime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

NSF graduate fellowships disproportionately go to students at a few top schools By Jane C. Hu Aug. 26, 2019 According to Science Careers' analysis of this year's recipients, the 10 schools with the most grad student awardees amassed 31% of all the grants. And 14% of recipients are at the top three alone: the University ofCalifornia (UC), Berkeley; the Massachusetts Institute of Technology (MIT); and Stanford University. More broadly, in 2017 86% of awards went to students at R1 (very high research activity) institutions Just 0.3% went to historically black colleges and universities, Among awardees' undergraduate institutions, according to an analysis of GRFP winners between 2011 and 2018 by statistical geneticist Natalie Telis, three schools—UC Berkeley, MIT, and Cornell University—swept 10% of the awards. The top 10 schools accounted for 25% of awards, and the top 30 made up about 50% of the entire pool.

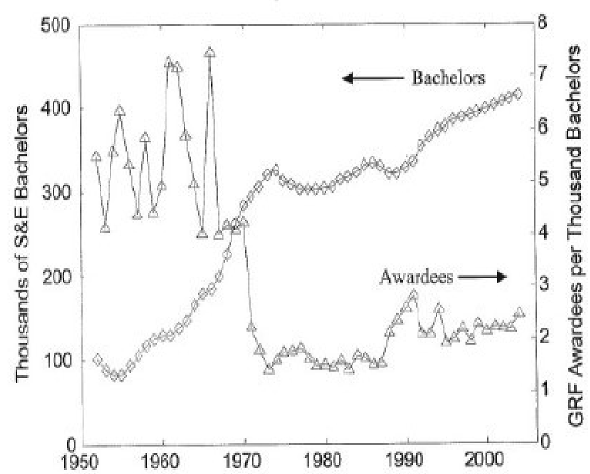
Value of awards and numbers of awards/number of undergraduate science majors have varied depending on non-job market related politics so largely random. Huge increase from 1999 to 2005 in amounts: $15,000 to $30,000. Today $34,000 plus $12,000 for university. Later huge changes in numbers. This creates 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.

F Graduate Research Fellowship Program (1952 - 2004)



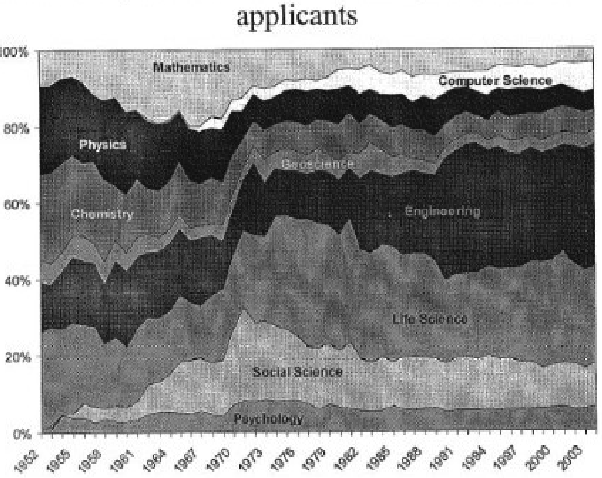
The number and value of GRF awards vary over time.

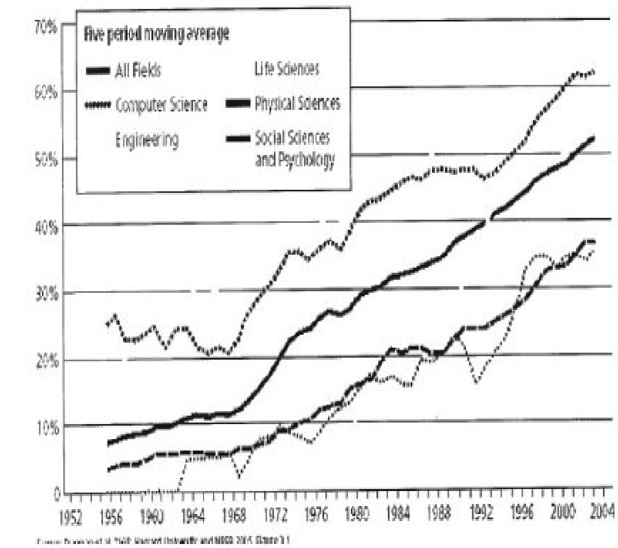
GRF Awardees as Proportion of S&E Bachelors (1952 - 2004)



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

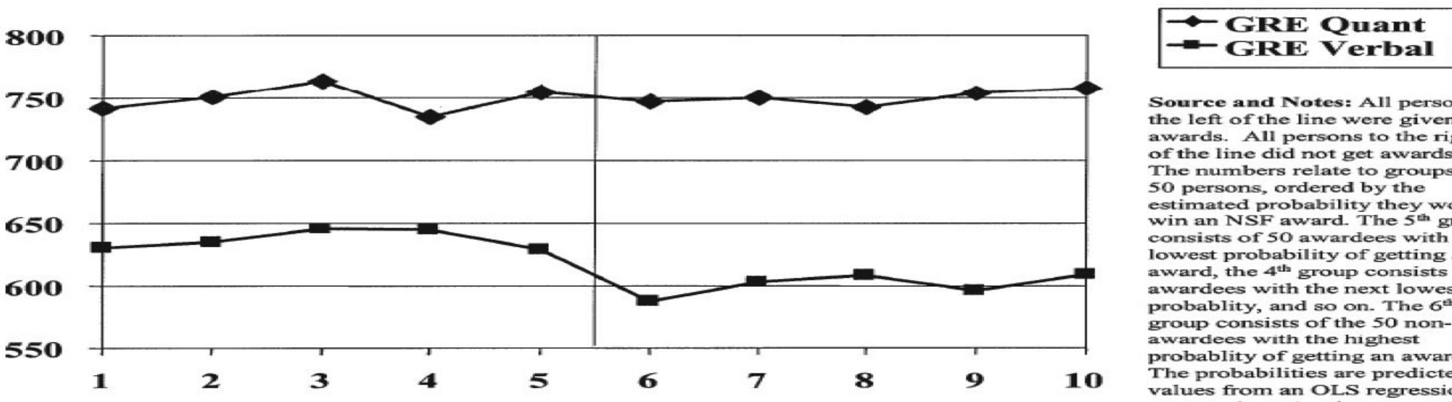
Changed Distribution of GFRP **Awardees by Field:** ecline of Physical Sciences bcs changed distribution of applicants





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:

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



Source and Notes: All persons to the left of the line were given awards. All persons to the right of the line did not get awards. The numbers relate to groups of 50 persons, ordered by the estimated probability they would win an NSF award. The 5th group consists of 50 awardees with the lowest probability of getting an award, the 4th group consists of 50 awardees with the next lowest probablity, and so on. The 6th group consists of the 50 non-awardees with the highest probablity of getting an award. The probabilities are predicted values from an OLS regression of an award receipt dummy variable on panel rating, female dummy, underrepresented minority dummy, and eight field dummies.

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:

Table 7. Determinants of Awardee Achievement, 1969 - 2004

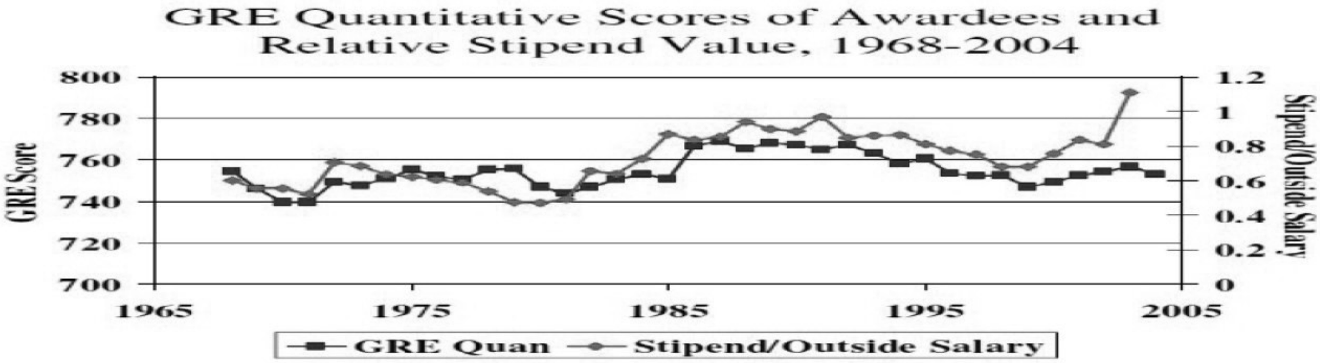
	GRE Quant	GRE Verbal	GPA
Log(Number of Awards) by Field in Current Yr	-10.6 (1.80)	-21.8 (3.30)	-0.087 (0.01)
Log(Stipend/Outside Salary) in Previous Yr	29 3.3	35.4 6.1	-0.007 0.017
Field Effects	Yes	Yes	Yes
Field x Time Trend	Yes	Yes	Yes
Observations	324	324	270
R-squared	0.8943	0.684	0.7354

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.

NUMBER OF APPLICANTS DEPENDS ON STIPEN/OUTSIDE SALARY AND NUMBER OF AWARDS SIZE OF AWARD PROGRAM

	Dep Var: ln(applicants in academic field in current year)			
	(1)	(2)	(3)	(4)
Log(Bachelor's Degs) by Field in Current Yr	0.195	0.304	0.298	0.516
	(0.057)	(0.063)	(0.062)	(0.066)
Log(Stipend/Outside Salary) in Previous Yr	0.996	0.916	0.852	0.772
	(0.084)	(0.060)	(0.059)	(0.056)
Unemp Rate for College Grads Age 21-25		0.049		
		(0.013)		
Unemp Rate for All College Grads			0.104	0.094
			(0.024)	(0.022)
Log(Awards/Bachelor's Degs) by Field in Previous Yr				0.349
				(0.054)
Field Effects	Yes	Yes	Yes	Yes
Field x Time Trend	Yes	Yes	Yes	Yes
Observations	324	234	234	234
R-squared	0.8931	0.955	0.9561	0.9634

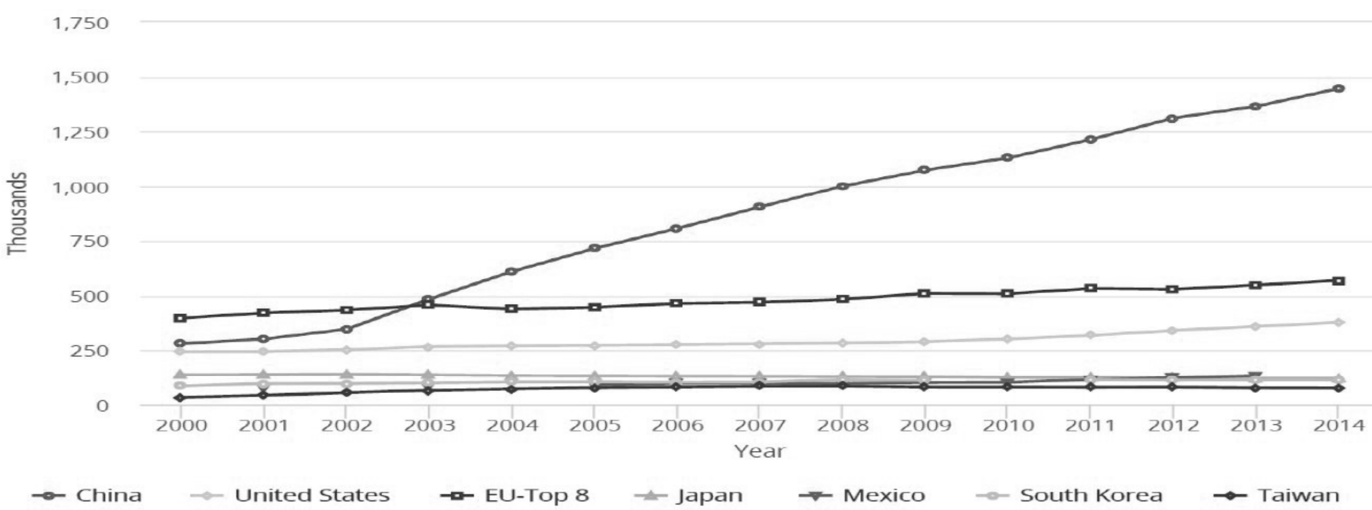
Bottom Line: Spend more, get more



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.

3.3.STEM ENROLLMENTS, DEGREES AND OCCUPATIONS:

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



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.

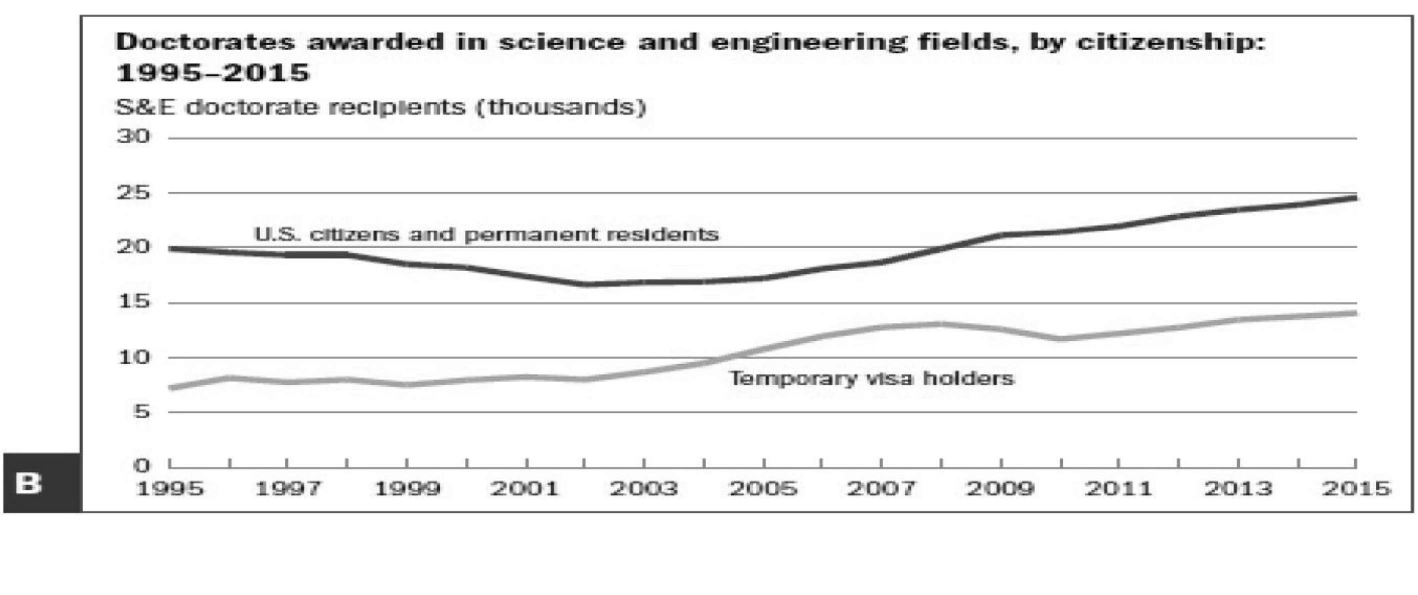
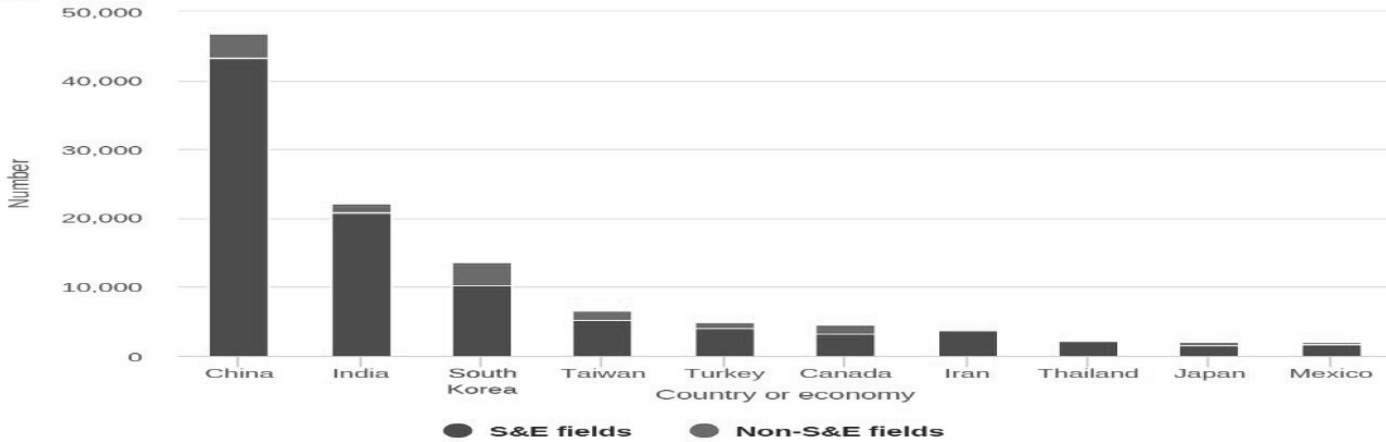


FIGURE 1-C

Top 10 countries or economies of foreign citizenship for U.S. doctorate recipients with temporary visas: 2008–17

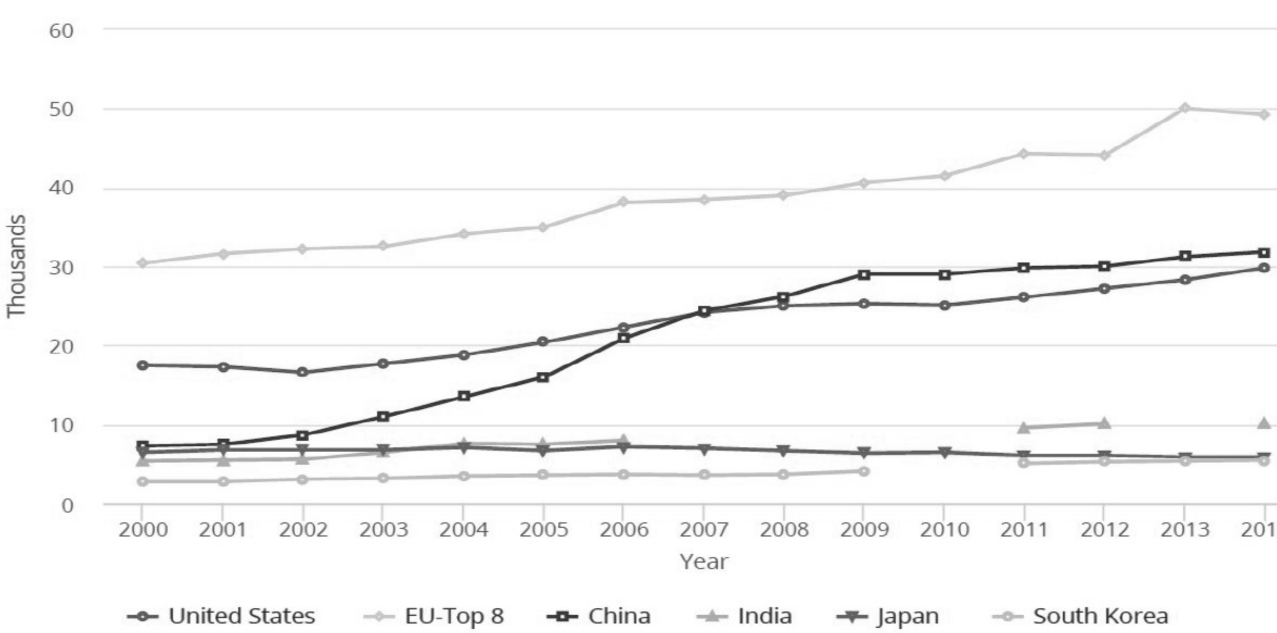


Tracking people by social security, 2/3rds are in US 5 years after PhD, with higher % from China, India,

Table 6. Temporary Residents Receiving S/E Doctorates in 2007-2009 Who Were in the United States in 2013, by Country/Region of Citizenship at Time of Doctorate

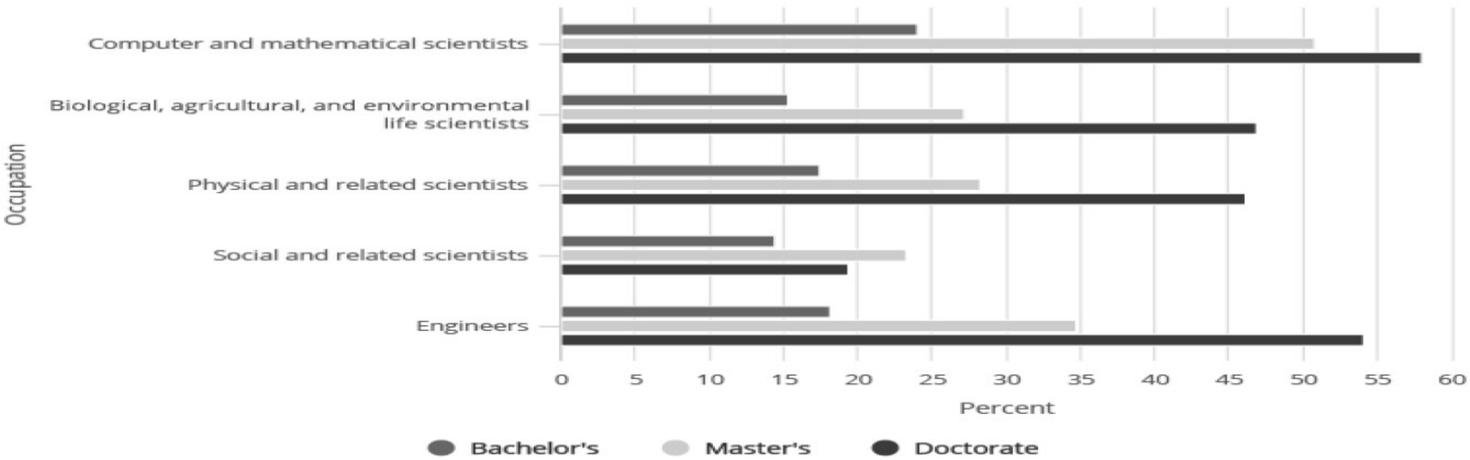
Country/Region of Origin	Foreign Doctorate Recipients	5-Year Stay Rate (Percent)	Foreign Doctorate Recipients	10-Year Stay Rate (Percent)
China *(including Hong Kong)*	12,300	84	7,500	86
India	6,300	85	2,400	86
South Korea	3,200	54	2,400	32
West Asia	3,200	59	2,500	52
Europe	4,100	63	3,800	68
North and South America	3,600	55	3,100	49
All other	6,200	53	4,800	36
Total, all countries/regions	**38,800**	**70**	**26,400**	**62**

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



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

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

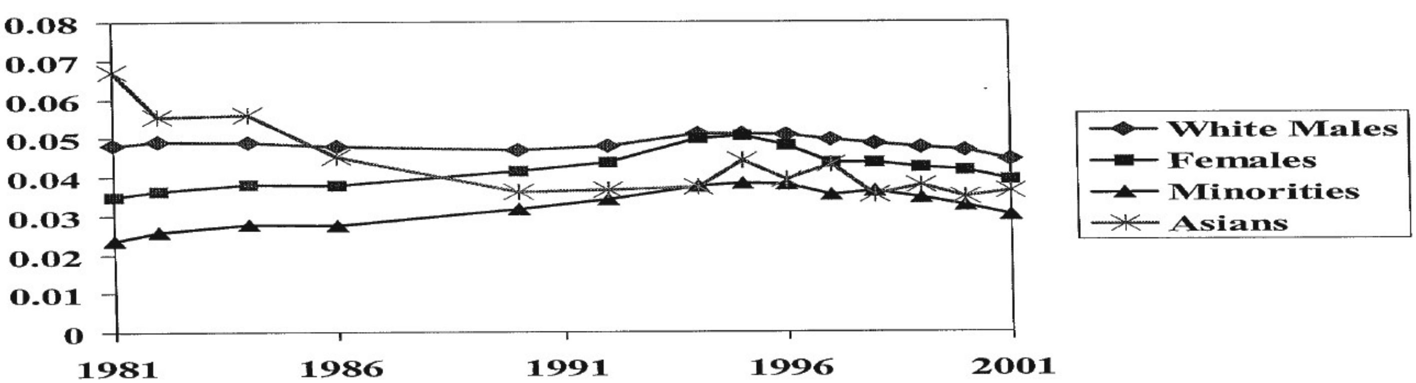


INCREASING SUPPLY OF WOMEN:

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. In 2017 women had 47% of PhDs in science; 55% in life sciences; 25% in engineering.

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



Source: Authors' tabulations from data obtained from the Survey of Earned Doctorates and the U.S. Department of Health, Education, and Welfare.

	CHANGE IN Log(Female/Male PhDs)	FRACTION OF INCREASE IN FEMALE TO MALE PH.D. RATIO EXPLAINED BY:		
		Rise in PhDs per 5 yr Lagged Bach Degs. Among Females	Rise in 5 Yr Lagged Female to Male Bach Degree Ratio	Drop in PhDs per 5 Yr Lagged Bach Degs 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%

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) $S = aW(-1)$ [Supply equation]

(2) $W = bS + cZ$ [Wage equation]

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

Substituting we obtain

(3) $S = abS(-1) + acZ(-1)$ [Cobweb equation]

The result are fluctuations.

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

(1)S= a W*(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**	2.864	3.857**	−0.324	−0.492
	(1.640)	(2.993)	(1.771)	(0.334)	(1.303)
Change in Relative Employment		0.530	0.222	0.305	−0.0179
		(0.559)	(0.195)	(0.275)	(0.190)
Wages & Employment Joint Significance, p-value		**<.001**	**0.038**	0.438	0.928
Percent of Students			0.853***		0.848***
with NIH Funding at Enrollment			(0.156)		(0.198)
First Lag, Relative Enrollment	1.551***	1.487***		1.019***	
	(0.258)	(0.464)		(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).

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.

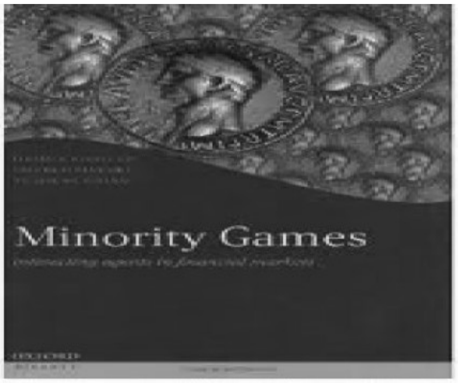
If everyone follows the same expectational rule, the result can be wild swings in the markets – manias as in finance. Need differences in opinion to have a chance for stable market.

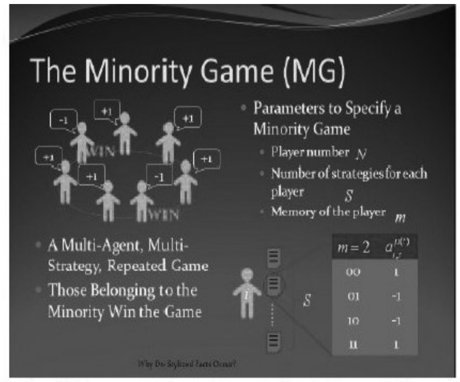
If everyone has different expectations … we have a variant of Brian Arthur's **El Farol Bar problem --"**a fierce assault on the conventions of standard economics." You want to go to the bar if less than 60% of the population go to the bar; but you don't want to go if more than 60% go. Your decision 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---" 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

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

The total score would be ΣG_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.

Also, it is famous as a Swiss Children's Game

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."

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 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 osses 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:

Simulations and analysis show that solutions depend on # of histories relative to # of players, $\alpha = \mathbf{2^M/N}$. 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 σ^2—> 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 ao that α is small, it can be **too small** —>"herd effect" as some players duplicate others —> 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.

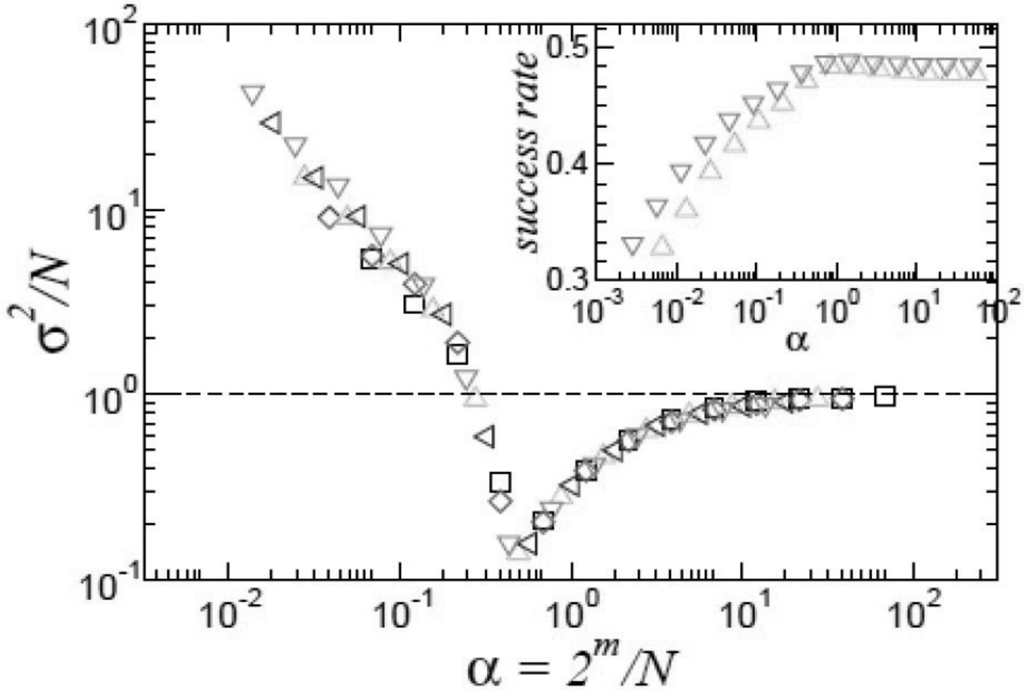


Figure 3: Volatility as a function of the control parameter $\alpha = 2^m/N$ for $s = 2$ and different number of agents $N = 101, 201, 301, 501, 701$ (□, ◇, △, ◁, ▽, respectively). Inset: Agent's mean success rate as function of α.

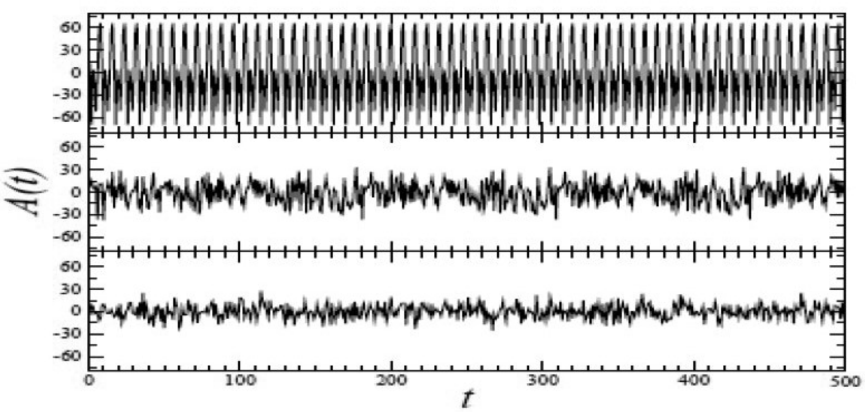


Figure 2: Time evolution of the attendance for the original MG with $g(x) = x$ and $N = 301$ and $s = 2$. Panels correspond to $m = 2, 7$ and $m = 15$ from top to bottom. Periodic patterns can be observed for $m = 2$ and $m = 7$.

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?"**