Mexican Science in a Global Context

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Preamble

- This document summarizes the main results of the project "Assessing Mexican Science and Technology Productivity: International Benchmarking and an Analysis of SNI Researchers". A companion report includes a more complete analysis and discussion of the themes presented here, including full bibliographic references and data sources

- This project was supported by CONACYT - Consejo Nacional de Ciencia y Tecnologia in Mexico under a collaborative agreement with Carnegie Mellon University

- This work, its analysis, conclusions and recommendations, is the sole responsibility of the researchers and does not reflect the opinions of CONACYT, Carnegie Mellon or ITAM

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   - Costs and Outcomes for SNI researchers
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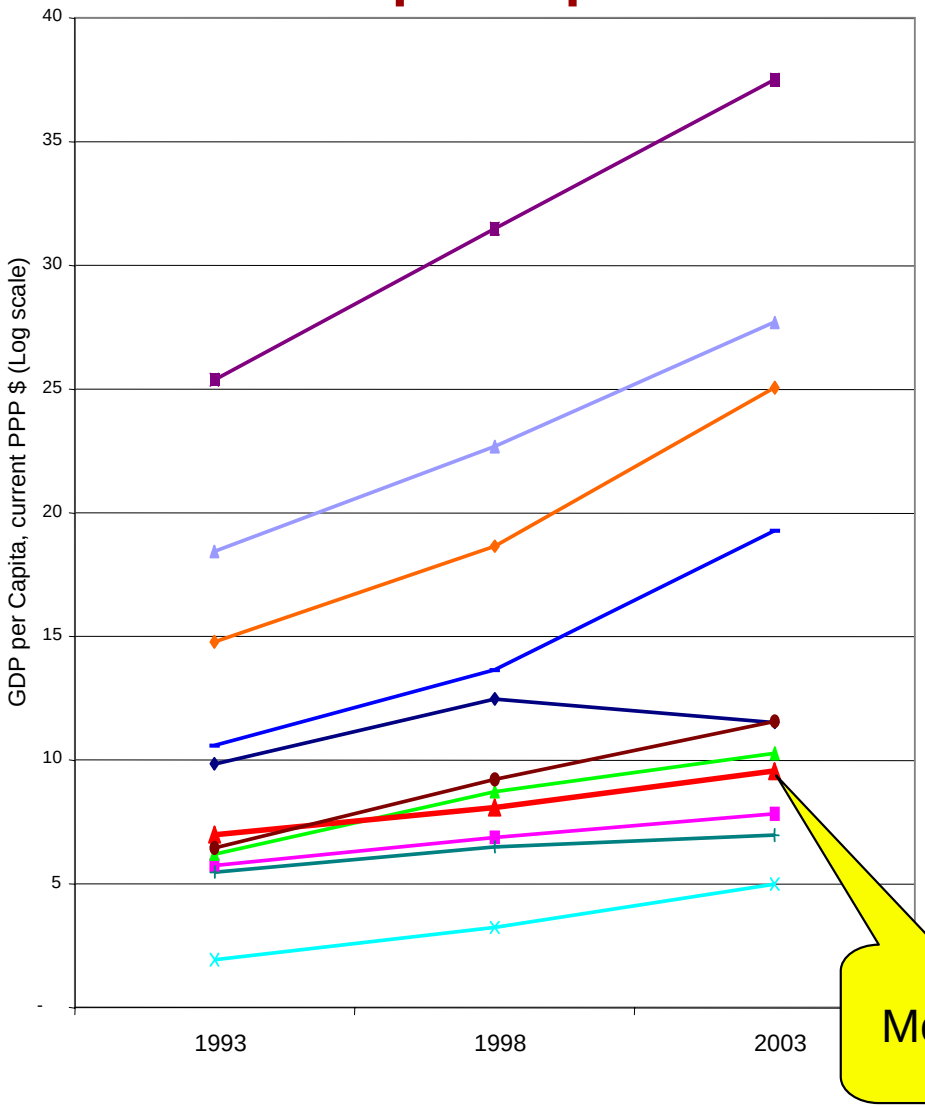
The Approach towards Benchmarking Mexican Science

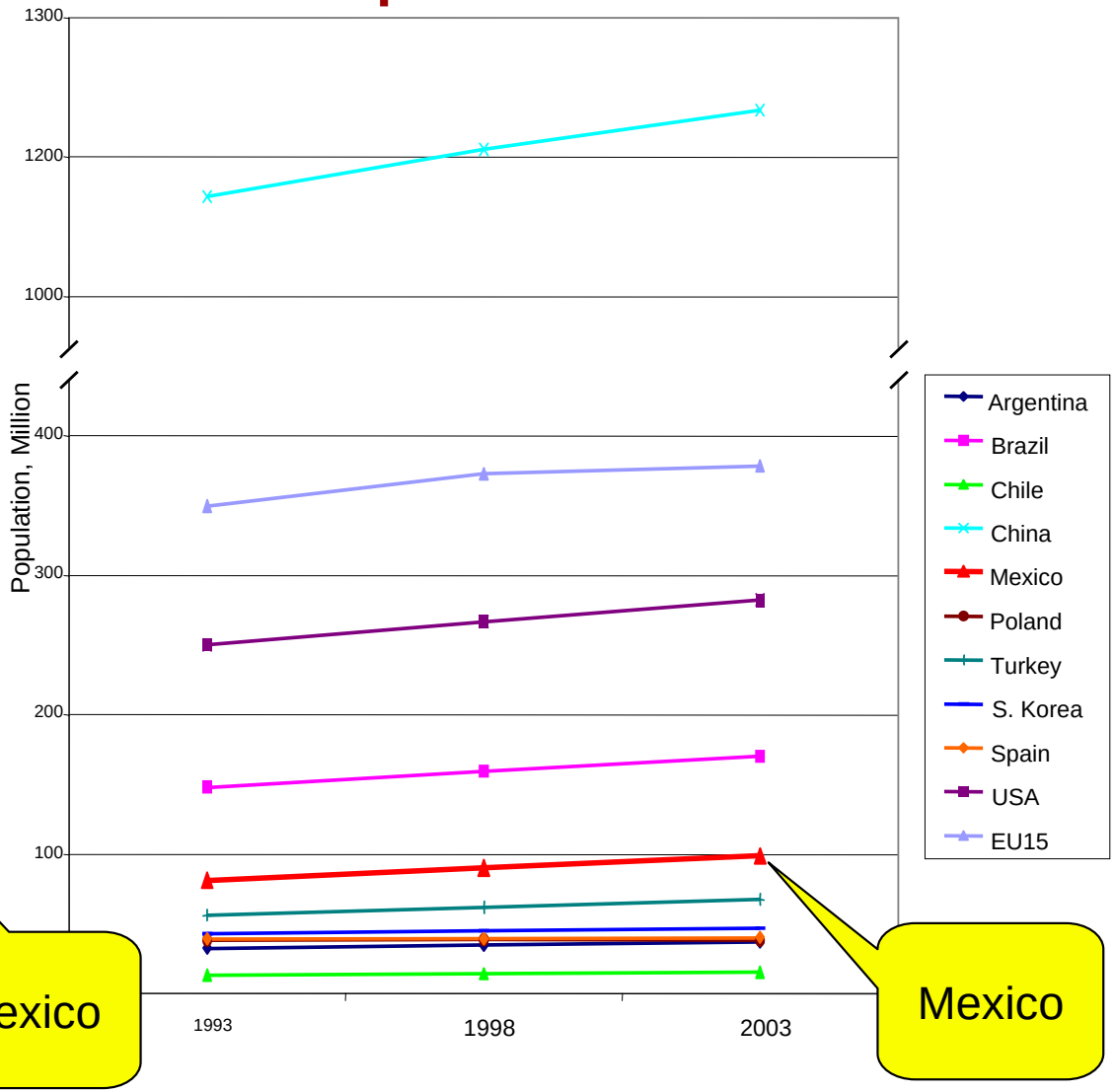
- Benchmark countries:
  - Baseline group of seven developing nations: Argentina, Brazil, Chile, China, Mexico, Poland, and Turkey
  - Two mid-tier developed nations: Spain and South Korea
    - Significant improvements in economic and scientific terms in the last two decades
    - Face language barriers when trying to publish in International (mostly English) peer review Journals
  - Two top-tier developed nations: The United States, and the European Union (EU15 – before the 2004 ascension)
    - general benchmarks
- Dimensions
  - Inputs: Absolute and relative expenditures and human resources
  - Outputs and Impact: Papers and Citations, Researcher Productivity
  - Efficiency: Inputs vs. outputs

Economic Development and Relative Size

GDP per capita



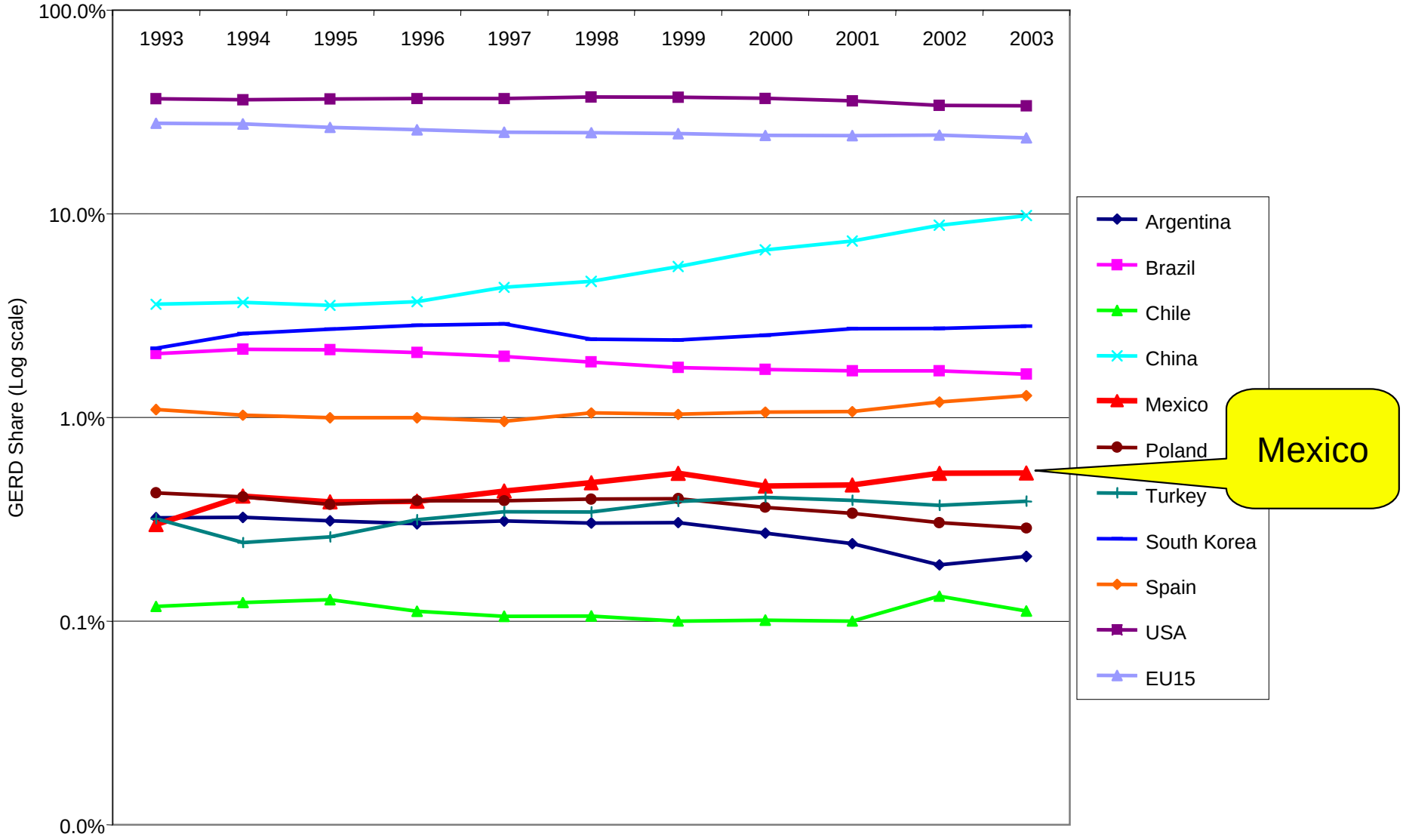
Population



- Mexico ranked 6th in GDP/Capita in 1993 within group, but it had declined to 8th in 2003
- Mexico's GDP per capita growth rate was among the lowest, ranked fourth from the bottom
- Mexico is the 5th most populous country in the group and one the fastest growing in population

Share of GERD by Nation-Region Over Time

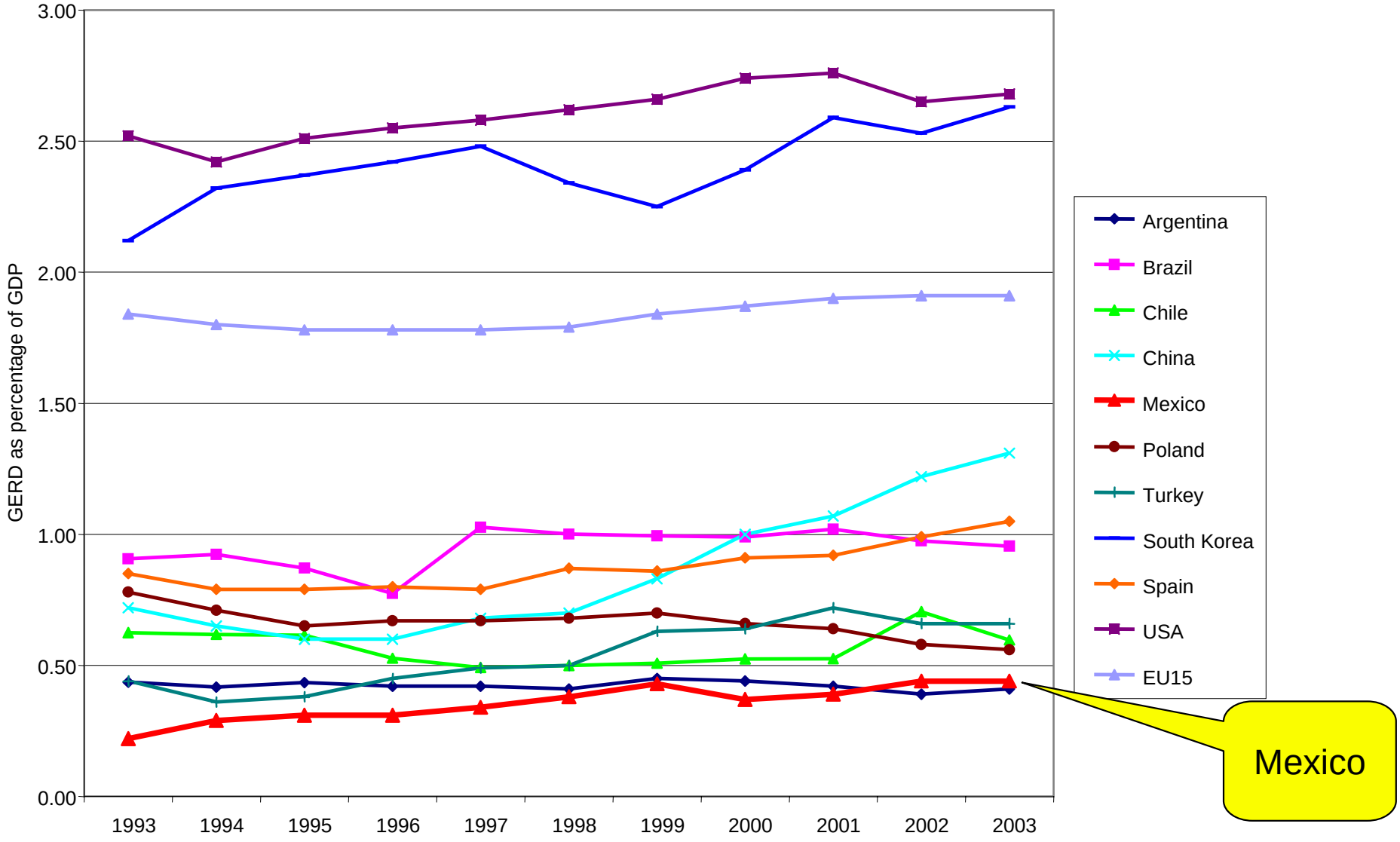
GERD: Gross Expenditures in Research & Development



- As part of the International Science and Technology Pool, the contribution of Mexico may apparently be in level with its economic size and presence in the world
- And Mexico's relative contribution has been increasing since 1993

Country GERD as percentage of GDP

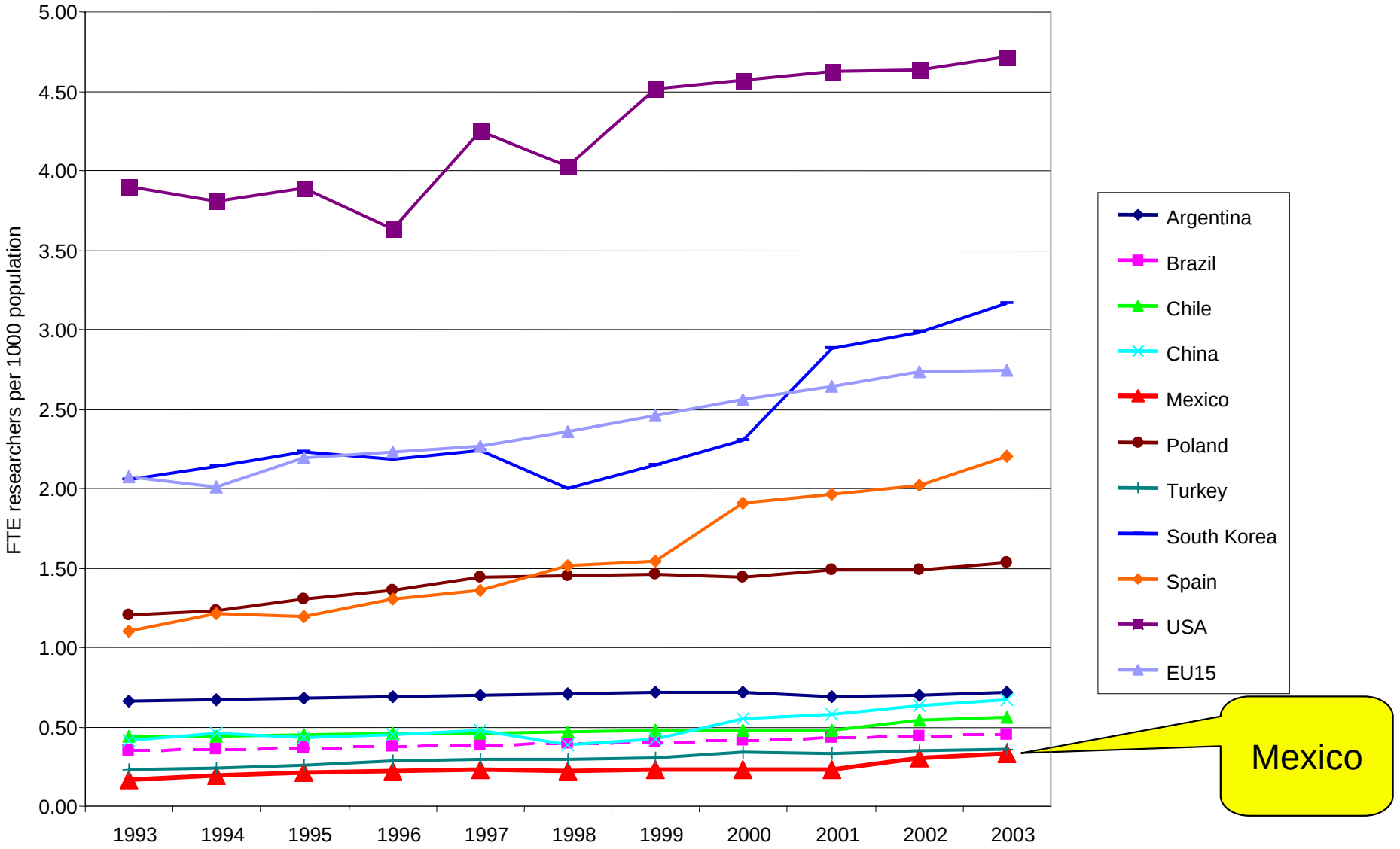
GERD: Gross Expenditures in Research & Development; GDP: Gross Domestic Product



- But as a share of its economic size, Mexico is at the very bottom of the Benchmark countries
- Only above Argentina – which faced a major economic crisis in the last years
- And, while it grew in the period 1993-2000, its investment has leveled off since 1999

Number of FTE researchers per 1000 population

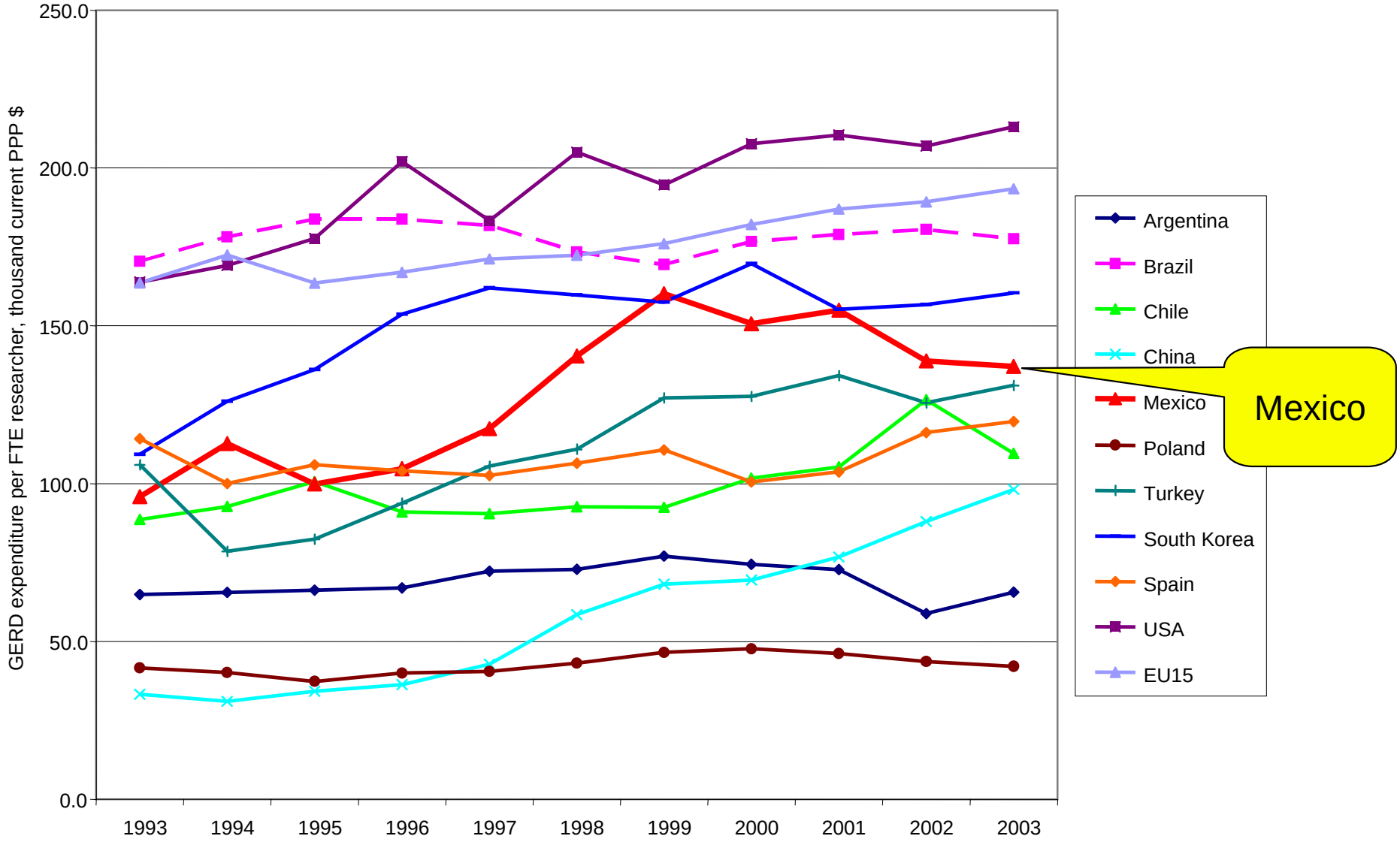
FTE: Full Time Equivalent



- And the investment is the lowest when measured in researchers as a share of the population
- Note that this important gap exists in relation to a number of nations that have levels of economic development above that of Mexico

GERD per FTE researcher

GERD: Gross Expenditures in Research & Development; FTE: Full Time Equivalent



- But investment per researcher is comparable to the other benchmark economies, in fact above many of the other nations that invest more in Science and Technology
- Important growth in 93-98 but a drastic reduction after that, dropping 3.8% from 99-03

Mexican Science in a Global Context – An Assessment

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What we observe:

- Contribution of Mexico to international R&D pool apparently in level with its presence in the world
- But relative to its economic size or population, it is at the very bottom of benchmark countries in terms of R&D investment
- Yet, R&D investment per researcher average when compared to benchmark nations

What we conclude:

- Mexican S&T pool is very small – Little investment in R&D with small size of research system commensurate to investment

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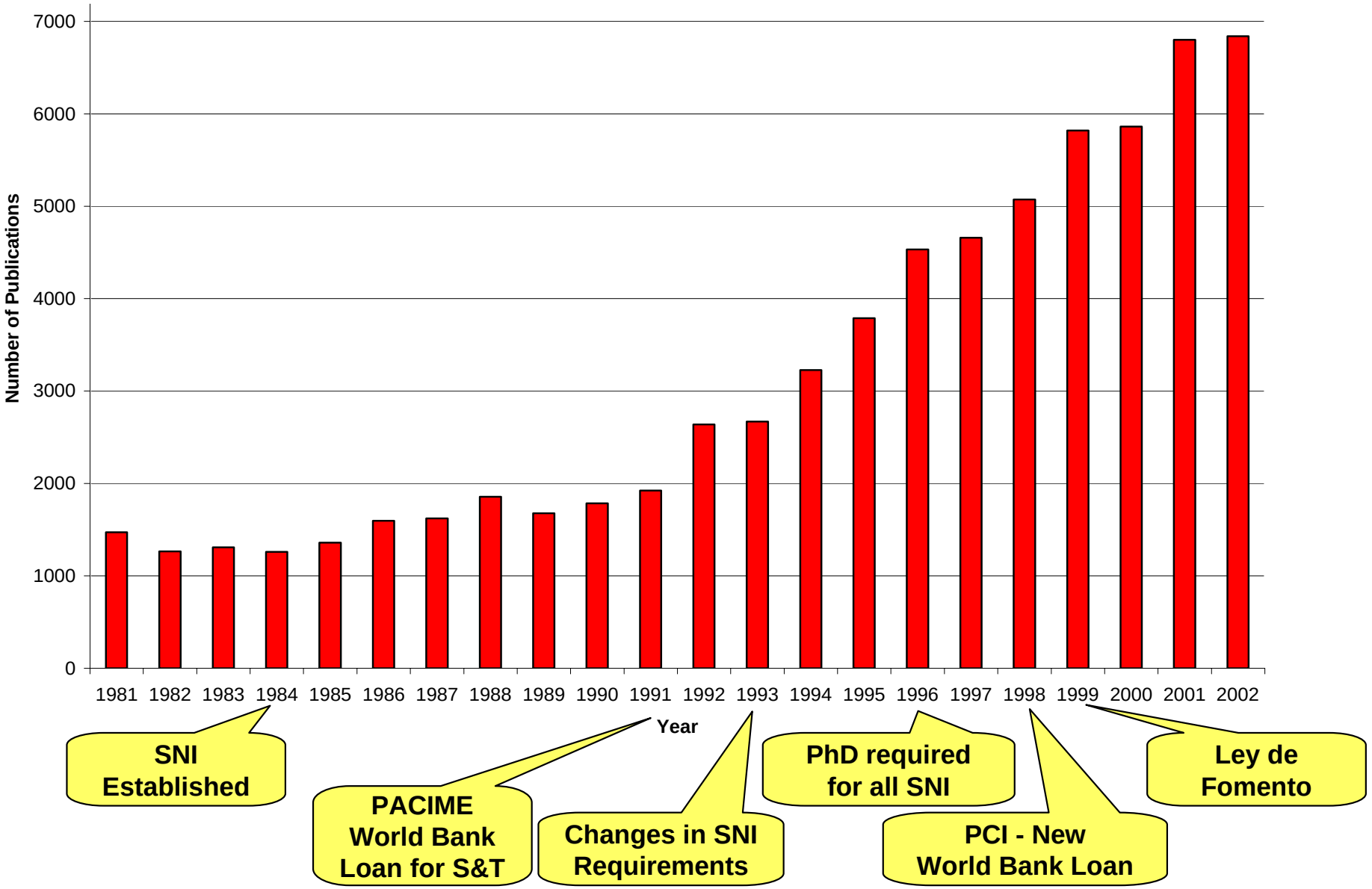
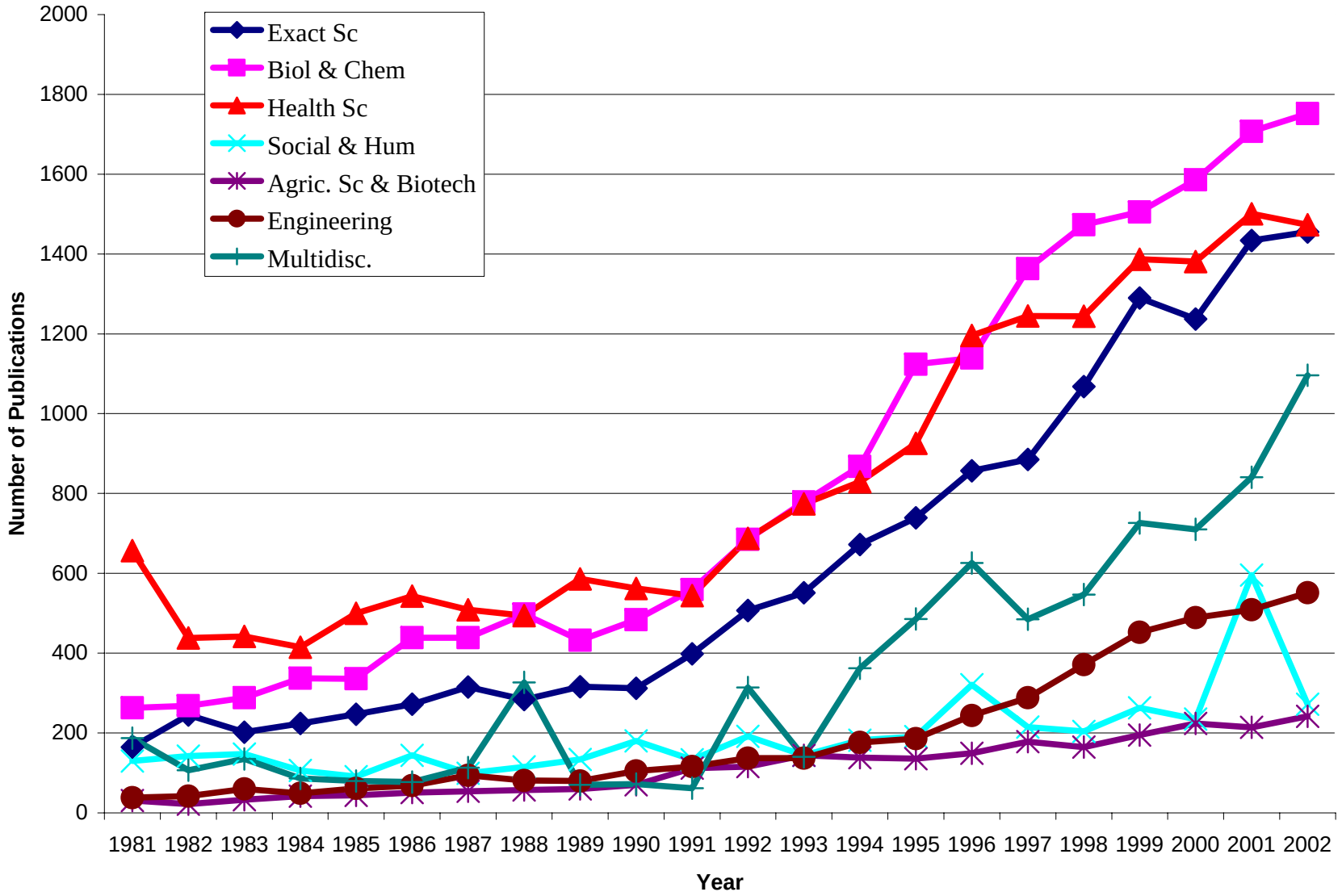
ISI Published Papers by Mexican Researchers



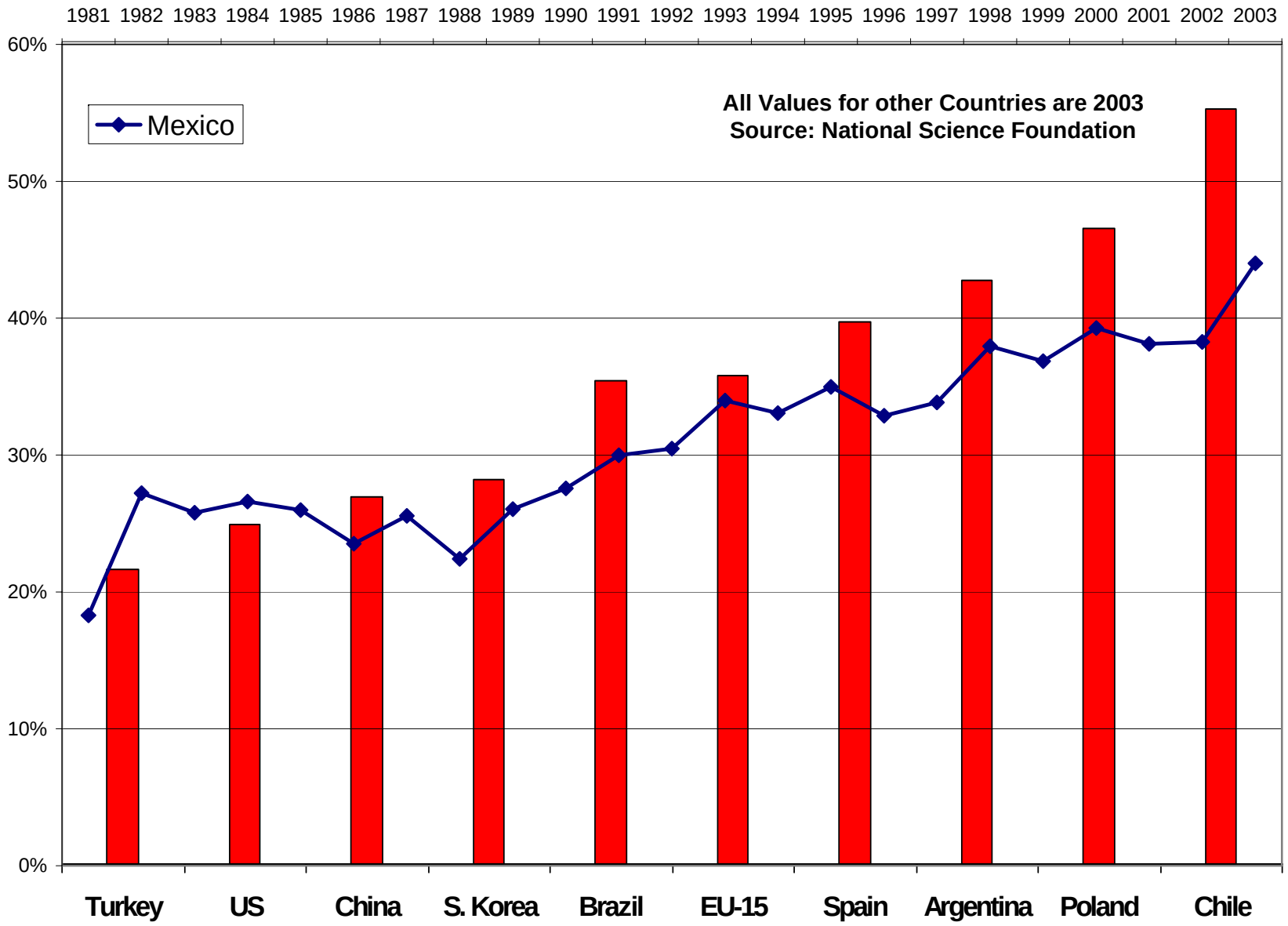
- Over the last two decades, Mexico has greatly expanded its absolute level of scientific output in terms of international peered reviewed publications
- Publications have increased at rate of 6% per year throughout the period, 9% since nineties

Evolution of Mexican Publications by Area of Knowledge



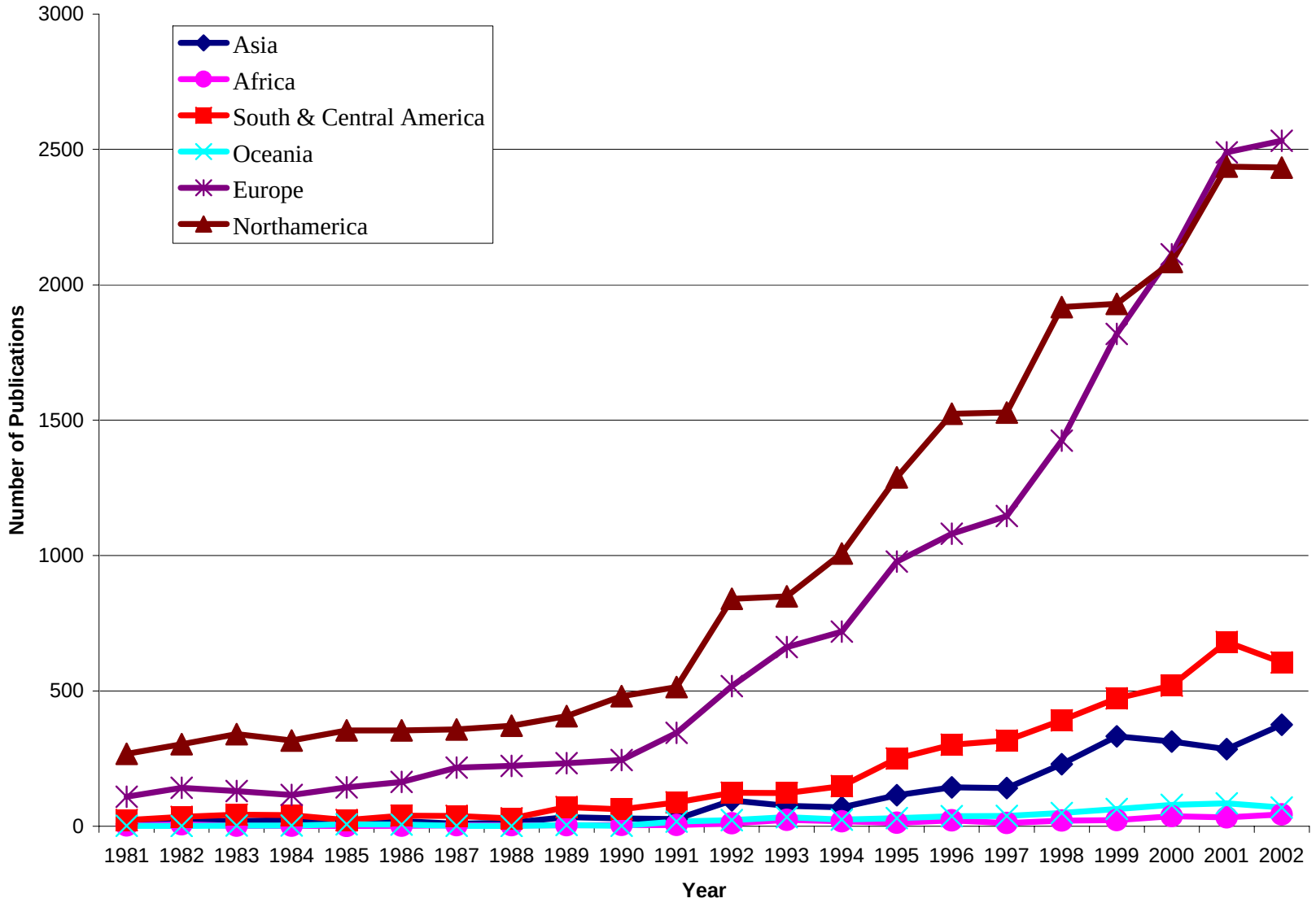
- Growth in publications has been observed across all areas of knowledge
- Increase in publications in Biology and Chemistry has been the largest, while in Agricultural Sciences and, especially in Social and Humanities, the increase has been modest

Proportion of Publications with International Coauthors



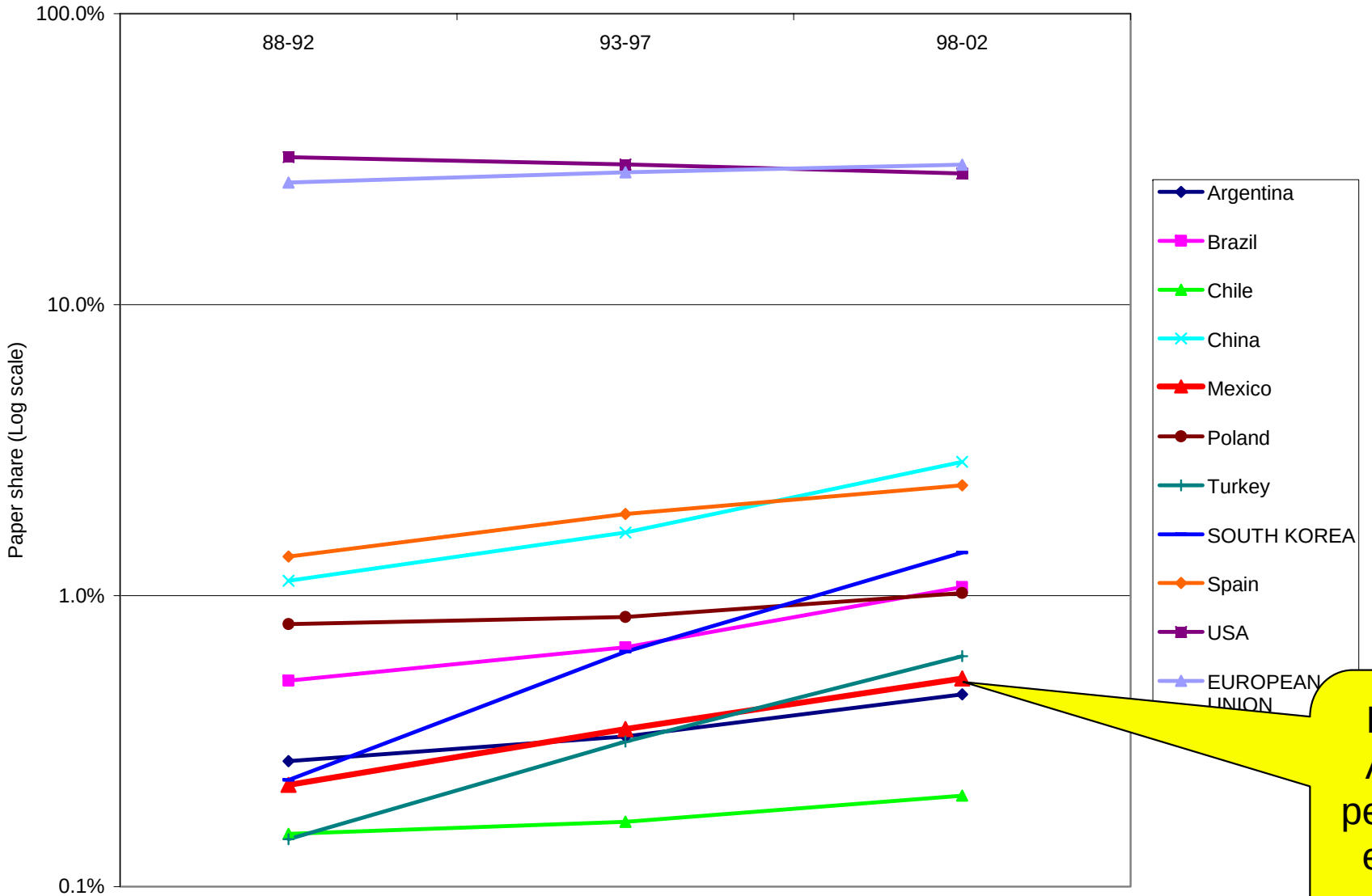
- The research system is also becoming much more international
- Share of publications with international co-authors rose from 18% in 1981 to 44% in 2003
- Mexico is now among the most internationalized S&T systems in the group

Number of Publications with International Coauthors. Distinction by regions.



- Top areas for collaboration are the US and the EU
- Growth has been particularly strong in the EU, which overcame the US as top collaborator
- Collaborations with other regions have also increased, especially with South/Central America

World Share of ISI Papers



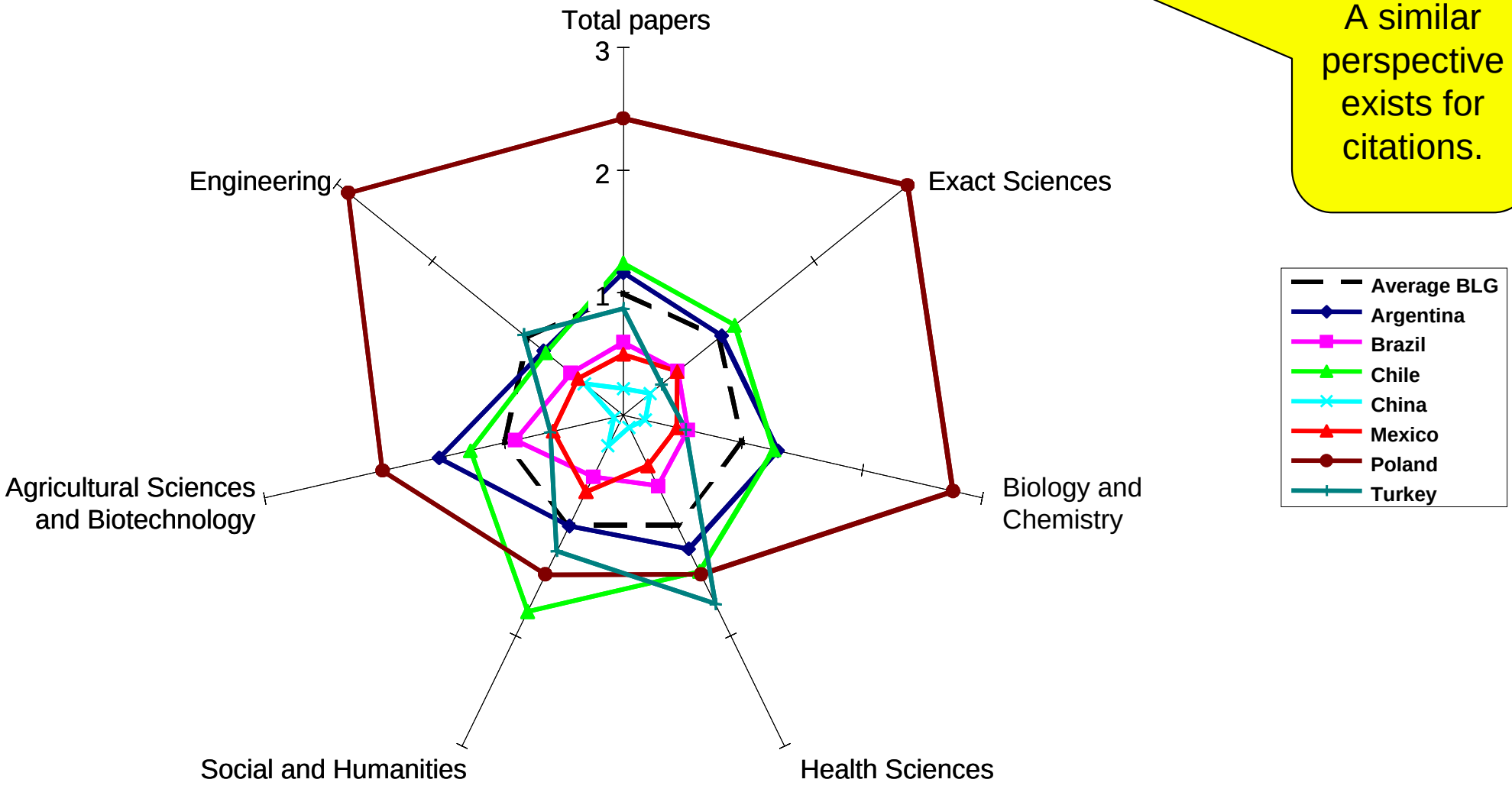
Mexico - A similar perspective exists for citations

- Mexico has the third lowest share of ISI published papers among the benchmarking group, only above Chile, a much smaller nation, and Argentina, who faced a major economic crisis
- It seems to be slowly catching up only to Brazil and Spain

Papers in Mexico Against Baseline Group – Areas of Knowledge

Adjusted by Population

National strength in different disciplines, papers adjusted by population
(Average baseline group, 98-02)

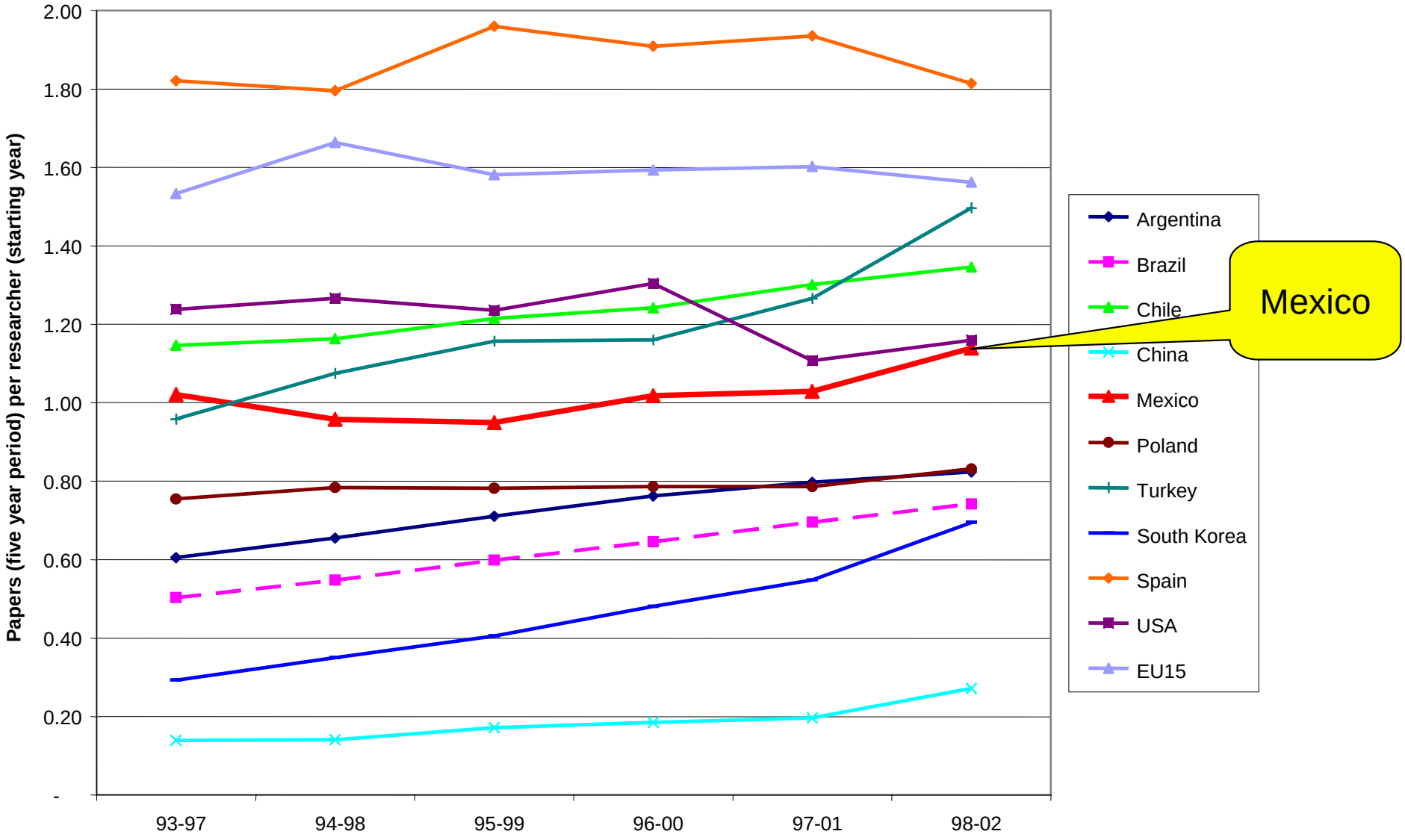


A similar perspective exists for citations.

- Mexico has a gap relative to remaining benchmark nations - except China - across all areas
- Most nations have a relatively unbalanced portfolio of scientific capabilities, with China particularly strong in Eng., Social & Hum. and Brazil very active in Health and Agri & Bio.

ISI Publications per FTE Researcher

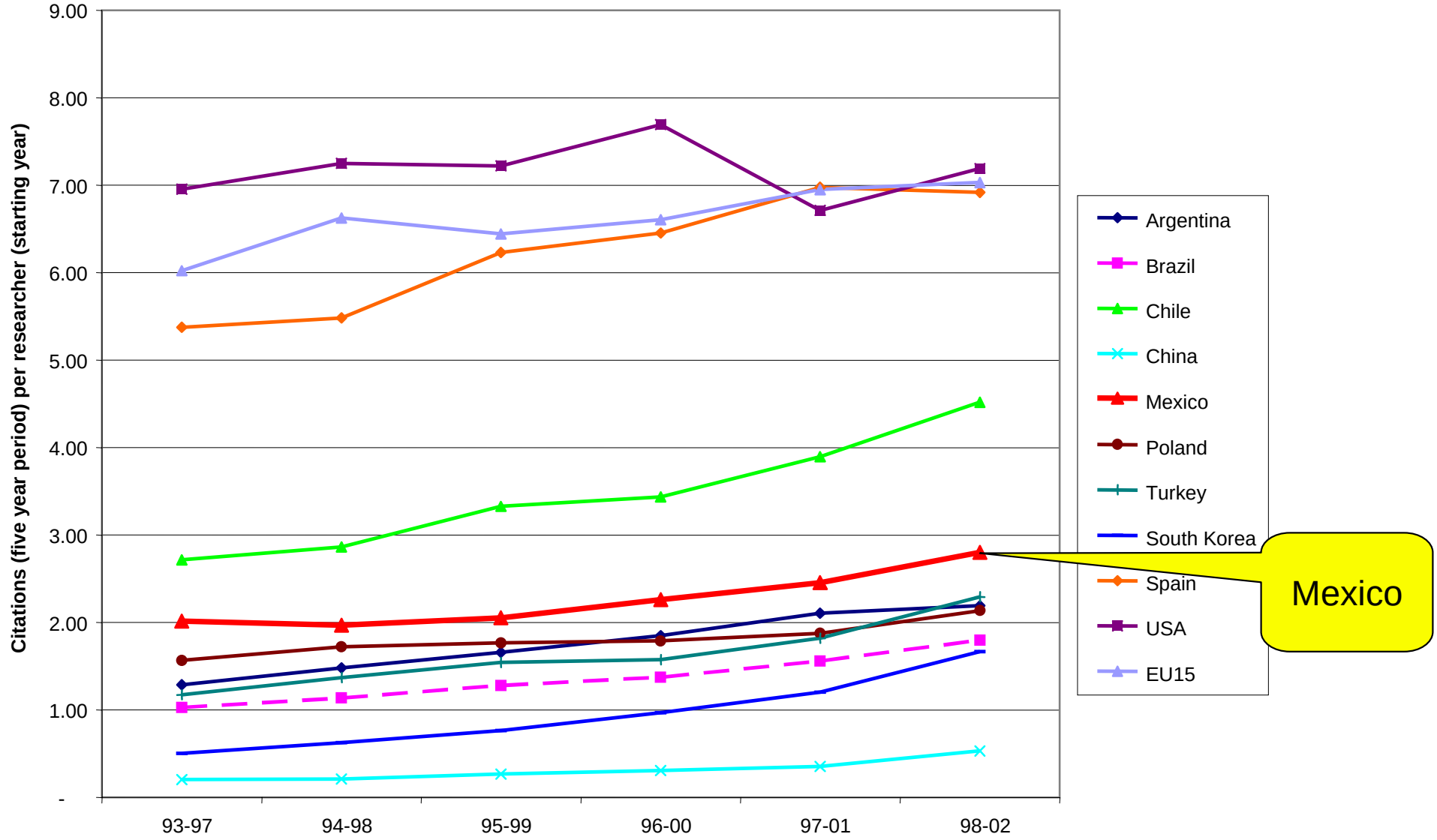
FTE: Full Time Equivalent



- But average level of individual researcher scientific productivity in Mexico is close to US levels and above nations such as Brazil and South Korea
- However it has a low growth rate when compared to other benchmark developing economies

ISI Citation count per FTE Researchers

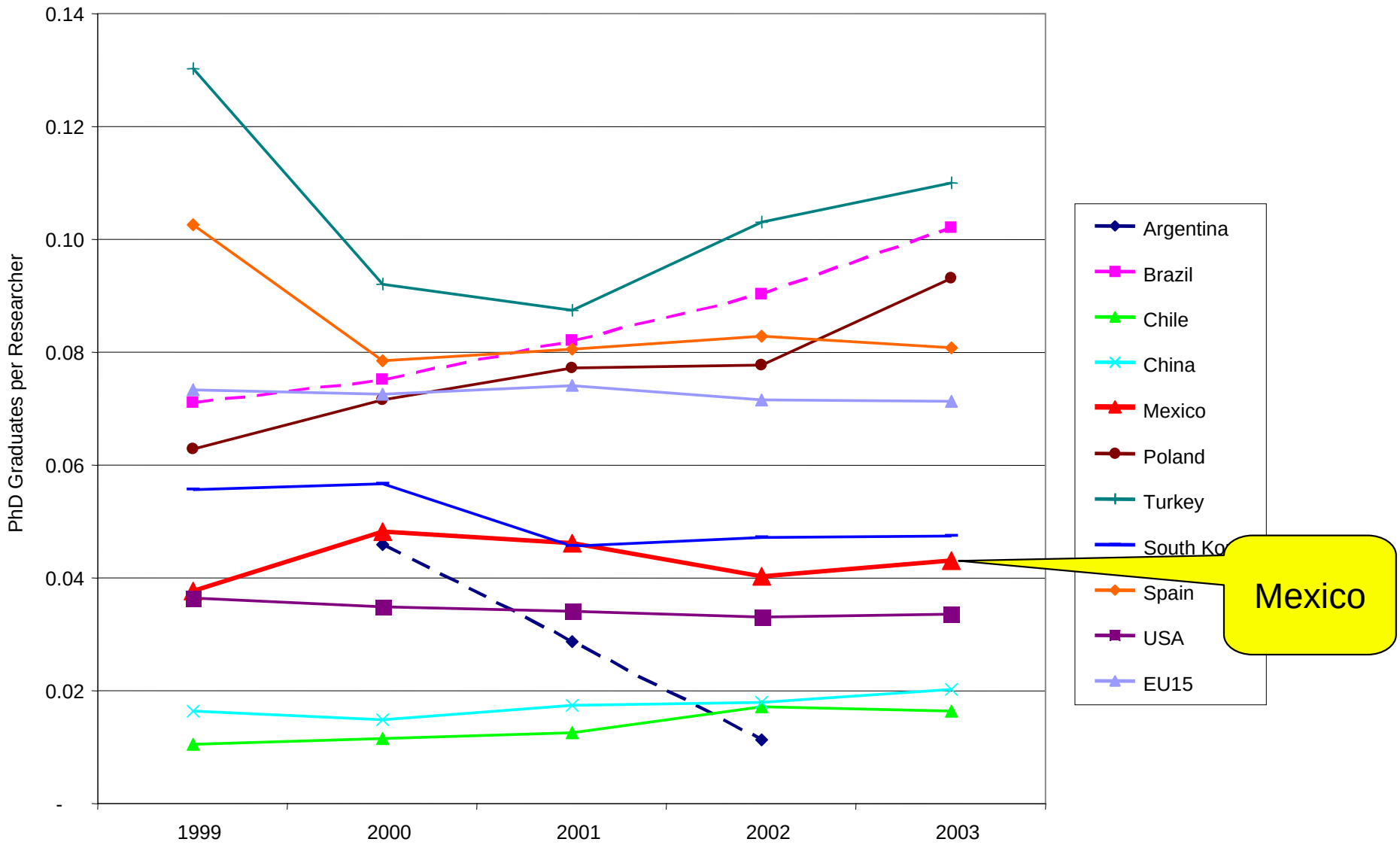
FTE: Full Time Equivalent



- And Mexican researchers have high impact, ranking second among the catching up nations
- But other developing countries are growing faster (except for Poland)
- Turkey and South Korea in particular are growing at a much faster pace than Mexico

PhD Graduates per FTE Researcher

FTE: Full Time Equivalent



- But the development of human capital, measured in new PhDs, is lower than other benchmark nations and much below in performance when compared to papers and citations
- This lower output has been constant in the last 5 years, potentially threatening the future…

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1. Science Impact & Efficiency: Mexico vs. benchmark nations
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What we observe:

- Mexican S&T output growing in size, internationalization and diversity over the last decade across all areas of knowledge
- But when compared to benchmark countries, it is close to the bottom in terms of total output and impact – across all areas
- Yet, on an individual researcher basis, output and especially impact compares very favorable against other nations, even the US
- Though in the last few years other benchmark nations are catching up on Mexico on individual researcher productivity and impact

What we conclude:

- On an individual researcher basis, the Mexican S&T system is quite active and productive – more than many comparable nations
- But its very small size – due to little investment - limits overall output and international impact

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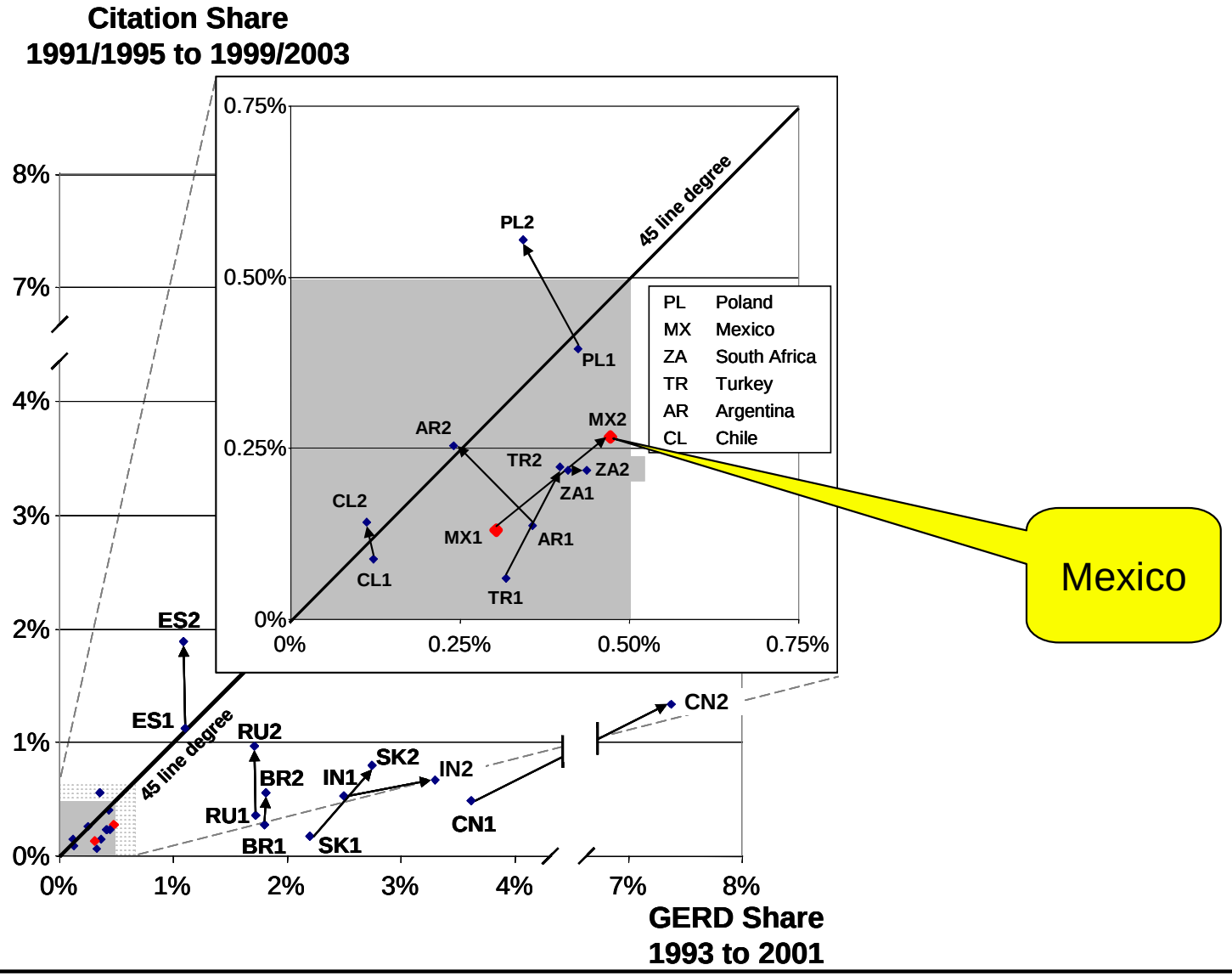
R&D Expenditure and Contribution to Science over time

R&D: Research and development; GERD: Gross Expenditure on Research and Development

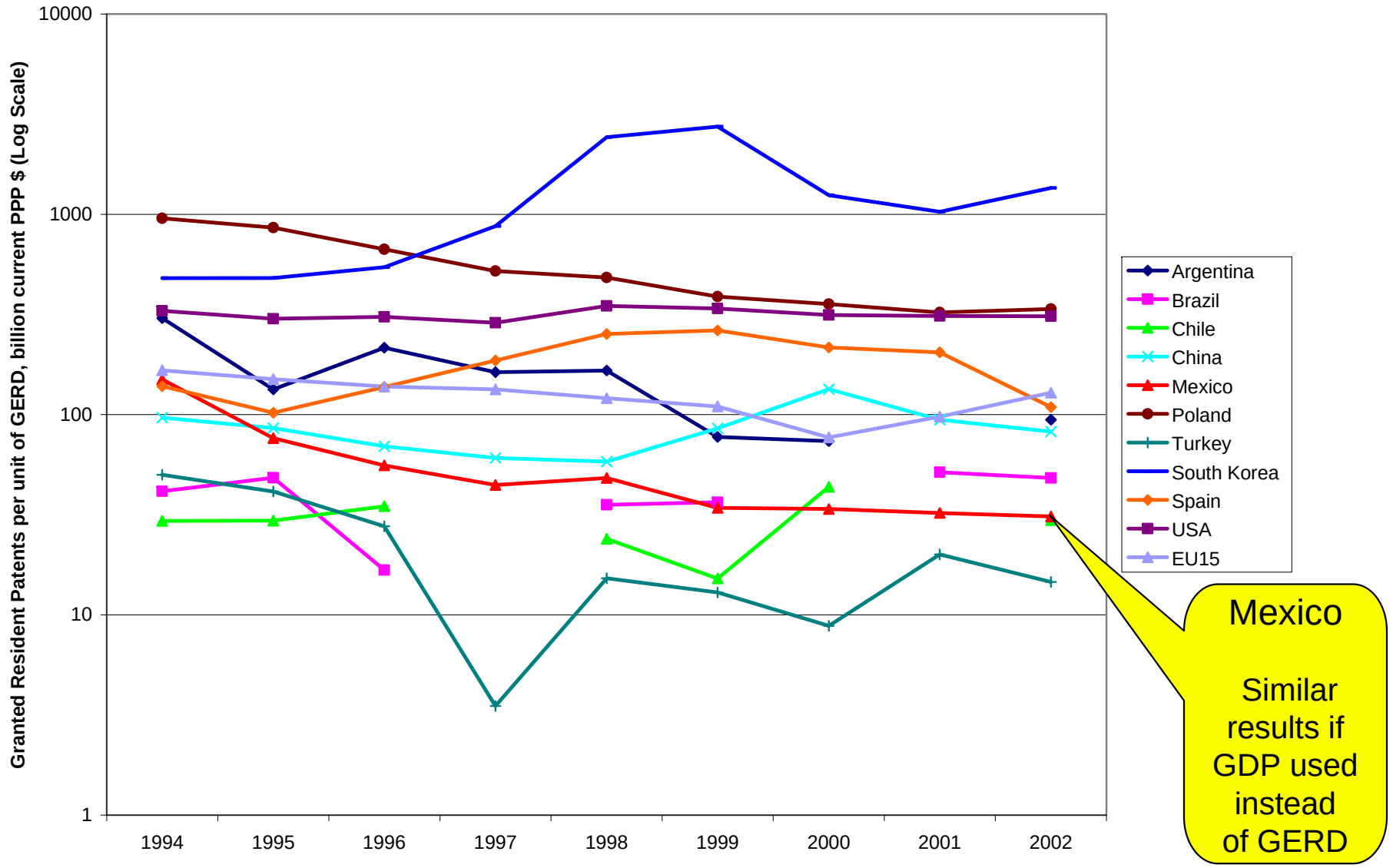


Graph measures world share for each nation included in benchmark, either in GERD or Citations

- Mexico improved its small presence in global science, both in investment and impact
- But still invests relatively more than it creates an impact – as measured by citations - though in line with most other equivalent nations such as Brazil

Granted Resident Patents per unit of GERD (billions)

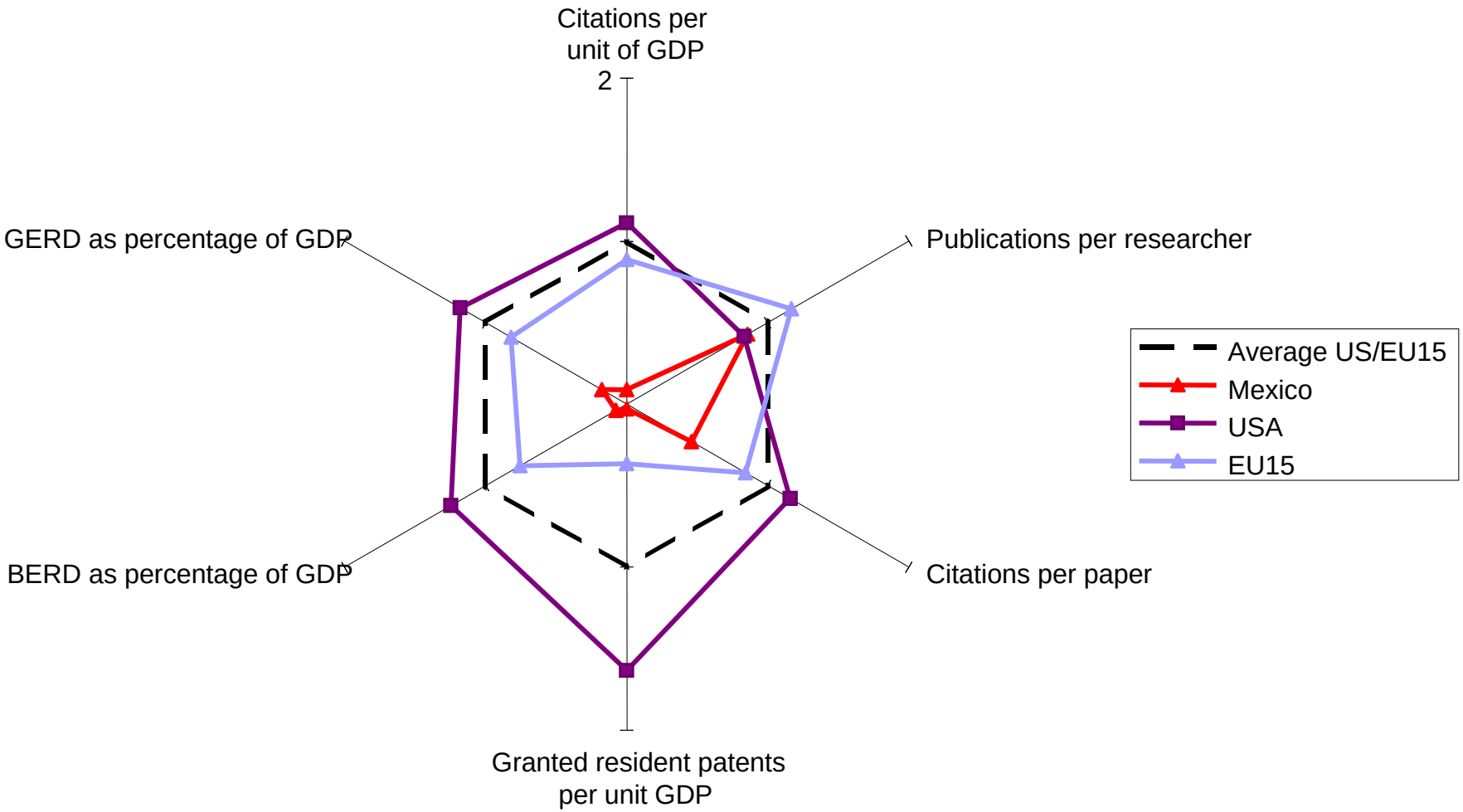
GERD: Gross Domestic Product



- Invention coming from science and technology investments does not seem to be a priority in Mexico, which ranks among the lowest in the group
- Moreover, Mexico dropped dramatically in this in indicator - by over 50% since 1994!

Inputs vs. Outputs, Mexico vs. the US/EU average 98-02

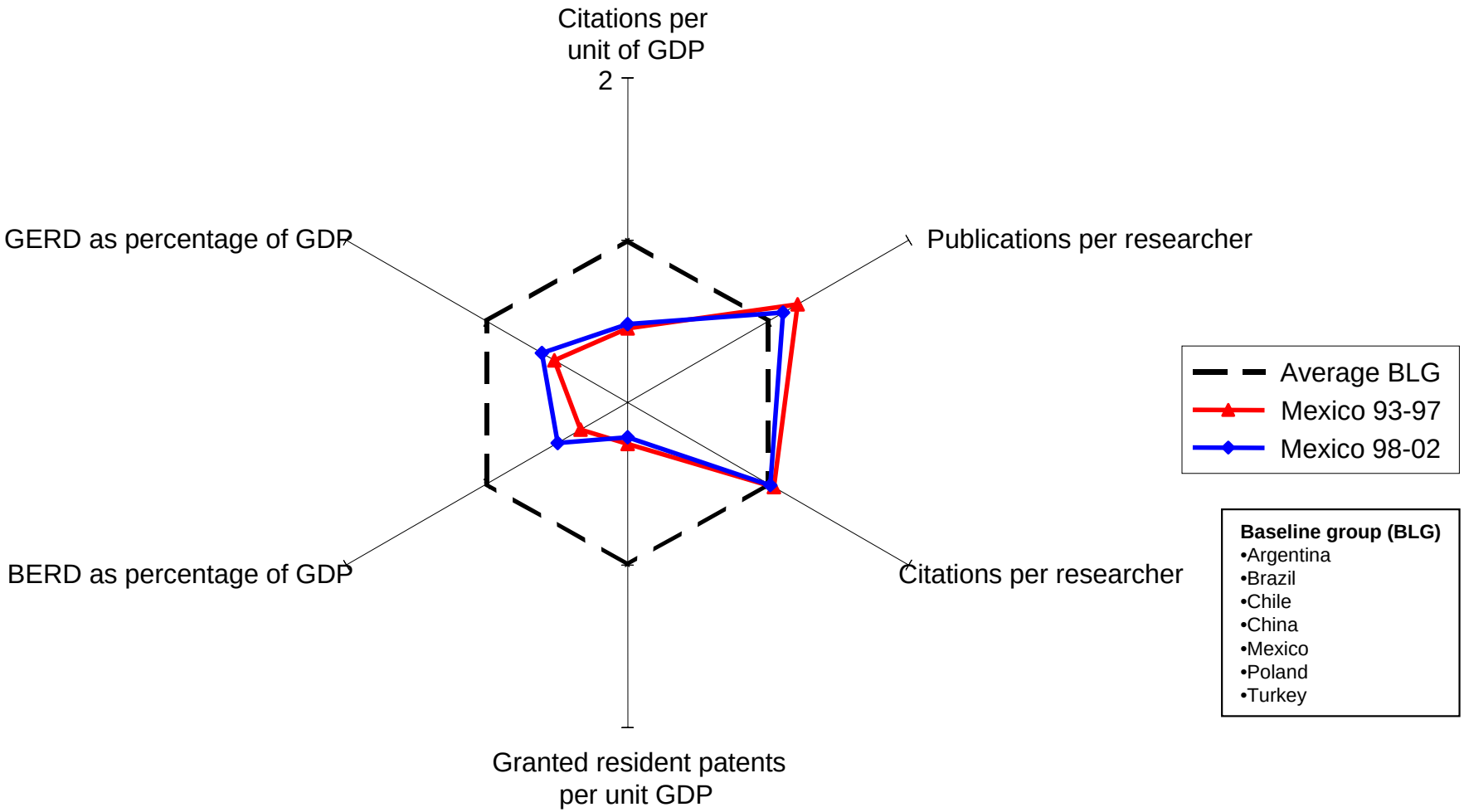
GERD: Gross Expenditure on Research and Development;
BERD: Business Expenditure on Research and Development; GDP: Gross Domestic Product



- When looking at various indicators together – we easily see how far Mexico is from the lead nations in virtually any of the critical input or output indicators
- Important exceptions are publications per researcher and, to some extent, citations per paper

Inputs vs. Outputs, Mexico vs. the baseline group over time

GERD: Gross Expenditure on Research and Development; BERD: Business Expenditure on Research and Development; GDP: Gross Domestic Product



- A similar perspective to the US/U emerges when comparing Mexico to equivalent nations on the various indicators, although less pronounced
- Mexico is actually above average in publications per researcher and citations per researcher

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What we observe:

- Mexico improved its modest presence in global science, both in investment and impact, but still invests relatively more than it creates an impact
- Invention coming from science and technology investments is very low in Mexico and the situation has worsened over the last decade
- When looking at input and output indicators together – we easily see how far Mexico is from the other nations in virtually all indicators
- But perspective is different in publications per researcher and citations per paper, where Mexico has a very reasonable performance, above many peers

What we conclude:

- The Mexican S&T system has a very small international output and impact, which result from little investment and limited human resources in R&D
- But individual researchers are productive and have a reasonable impact
- Growing the system could lead to quick and large boom in Mexican S&T output and impact – if researcher productivity is maintained
- Mexico must also work to foster innovation, which appears to be very weak

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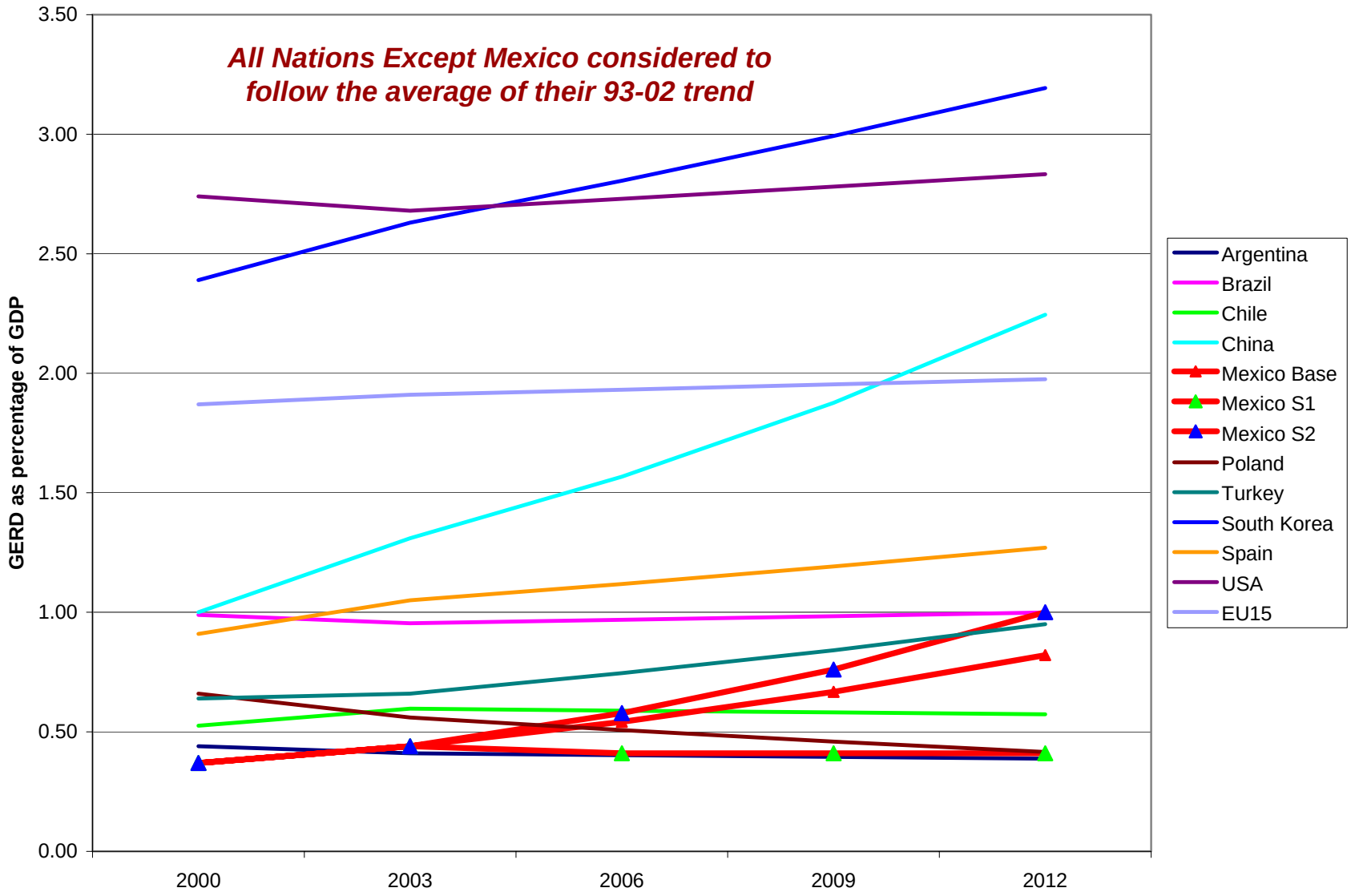
Scenarios for Country GERD as Percentage of GDP

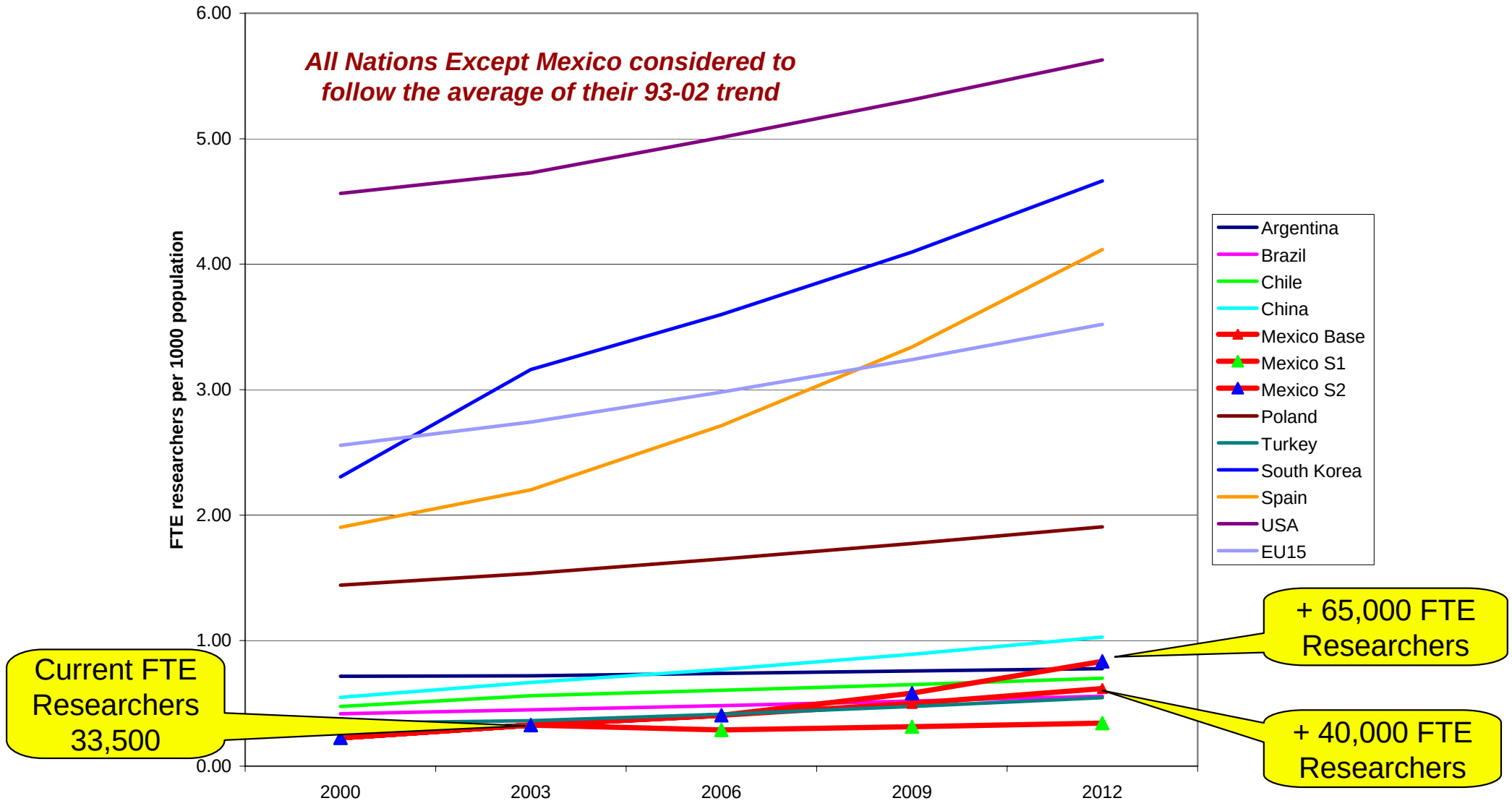
GERD: Gross Expenditures in Research & Development; GDP: Gross Domestic Product



- Pessimistic scenario (S1): Mexico continues investing constantly 0.41% of GDP on R&D
- Base scenario: GERD percentage grows at same rate as 93-02 period, reaches 0.8%
- Optimistic scenario (S2): By 2012 Mexico is investing 1% of GDP on R&D

Scenarios for FTE Researchers per 1000 Population

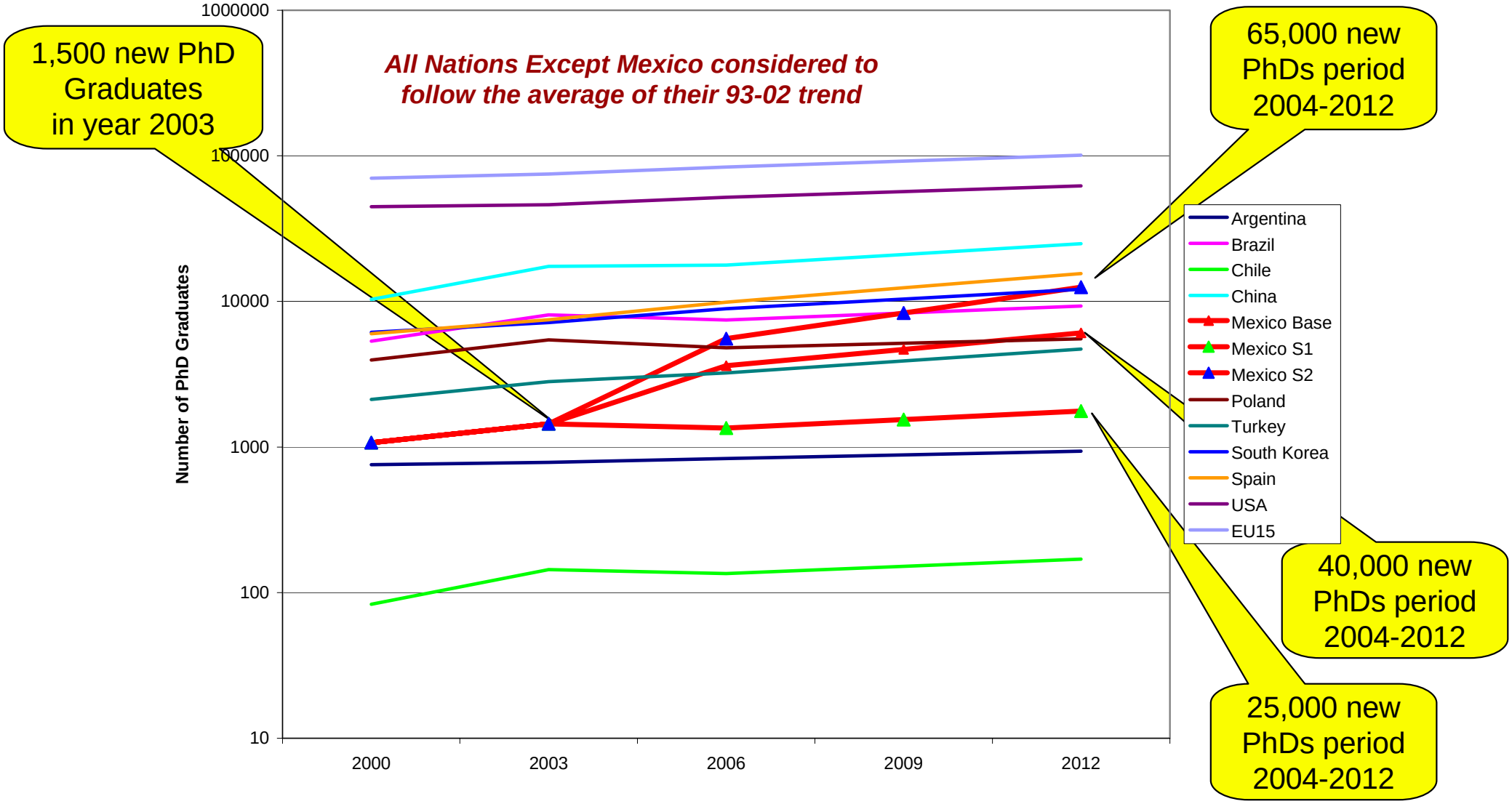
FTE: Full Time Equivalent; Values assume prior GERD Scenarios and current GERD per FTE Researcher



- S1 scenario: Mexico stagnates, remaining at the bottom of the group of nations analyzed
- Base case: Mexico evolves slightly and overturns Brazil and Turkey
- S2 scenario: Mexico ranks second in mid-to-low group, further overturning Chile & Argentina

Scenarios for Number of Future PhD Graduates

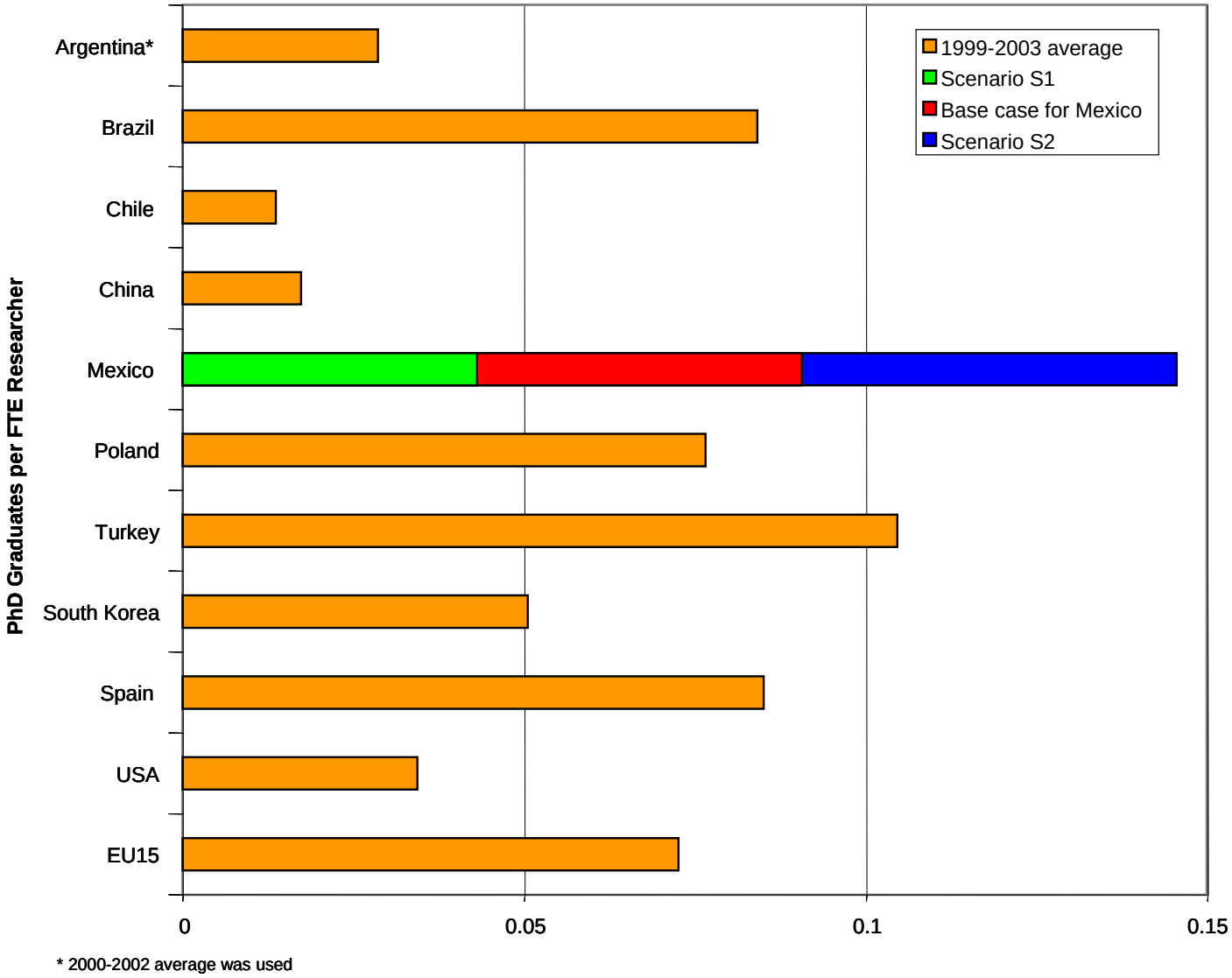
Indicative values: assume prior scenarios for FTE Res. per pop; all PhDs become researchers; no foreign PhDs[32]



- Even with a strong growth, Mexico will still be lagging many benchmark nations
- Base and S2 Scenarios require at least doubling or tripling total FTE researchers in Mexico
- Growth poses difficult challenges to the ability of S&T system to generate and absorb people

Scenarios for PhD Graduates per FTE Researcher

Indicative values: assume prior scenarios for new res. required; all PhDs become researchers; no foreign PhDs



* 2000-2002 average was used

- Productivity of Mexican S&T system in generation of new PhDs has to increase significantly to respond to desired growth in number of Researchers – or rely on training abroad
- Estimates suggest system will not be able to train all required PhDs – levels are too high

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What we observe:

- If Mexican S&T stagnates (Scenario S1), Mexico will further trail all benchmark economies considered in the study
- Under the base case and scenario S2, Mexico could become a mid-to-high performer in the group
- Base and S2 Scenarios require doubling or tripling FTE researchers

What we conclude:

- Changing the current level of development for Mexican S&T system requires significant financial resources and human capital training
- National system not be able to train required levels of human capital and it will be critical to send people abroad to be educated
- Even if such high levels of human capital training are acheived, growing the system in jobs and facilities will be extremely challenging

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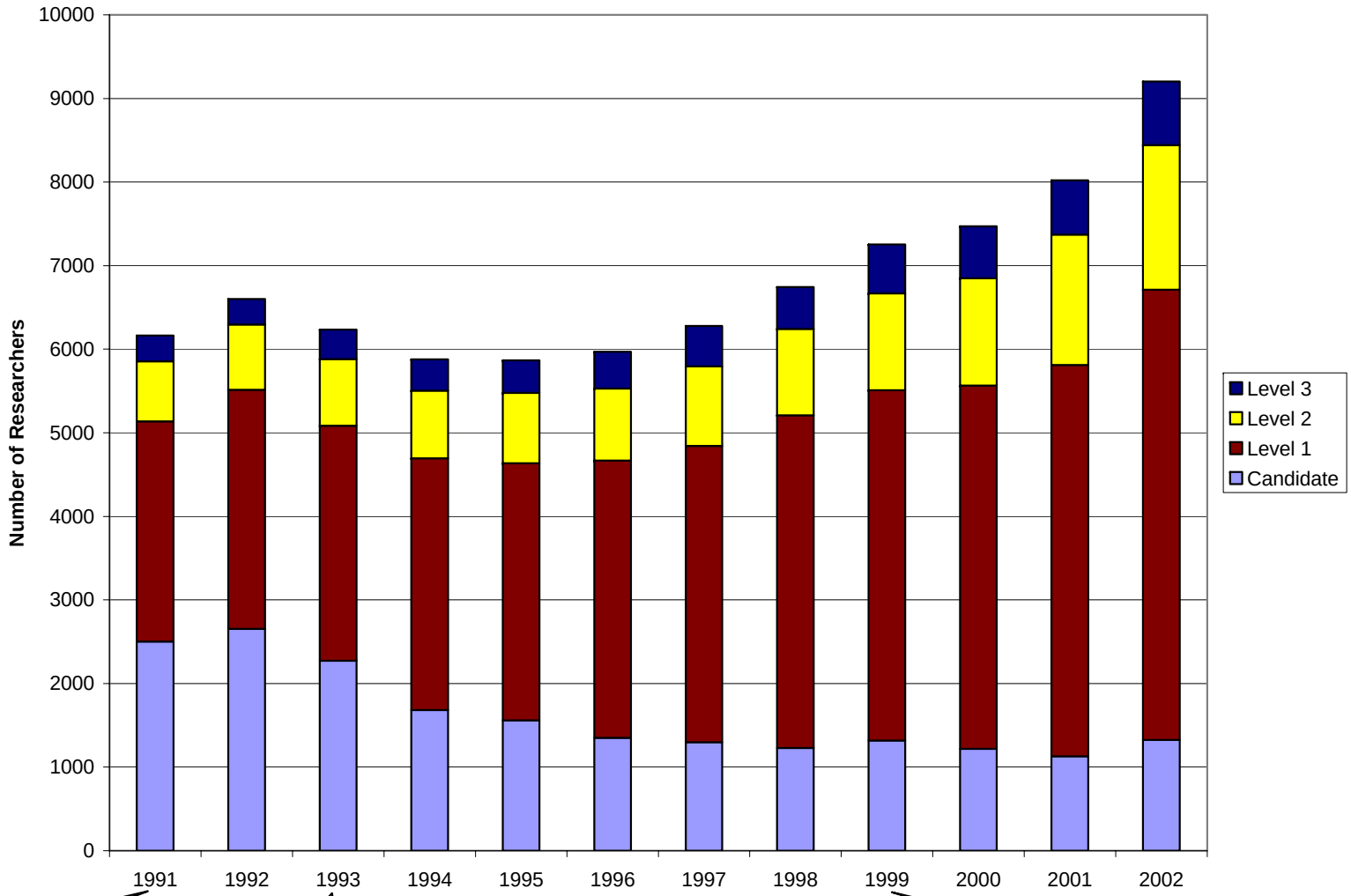
Evolution of SNI - The Mexican System of Researchers



PACIME World Bank Loan for S&T

Changes in SNI Requirements

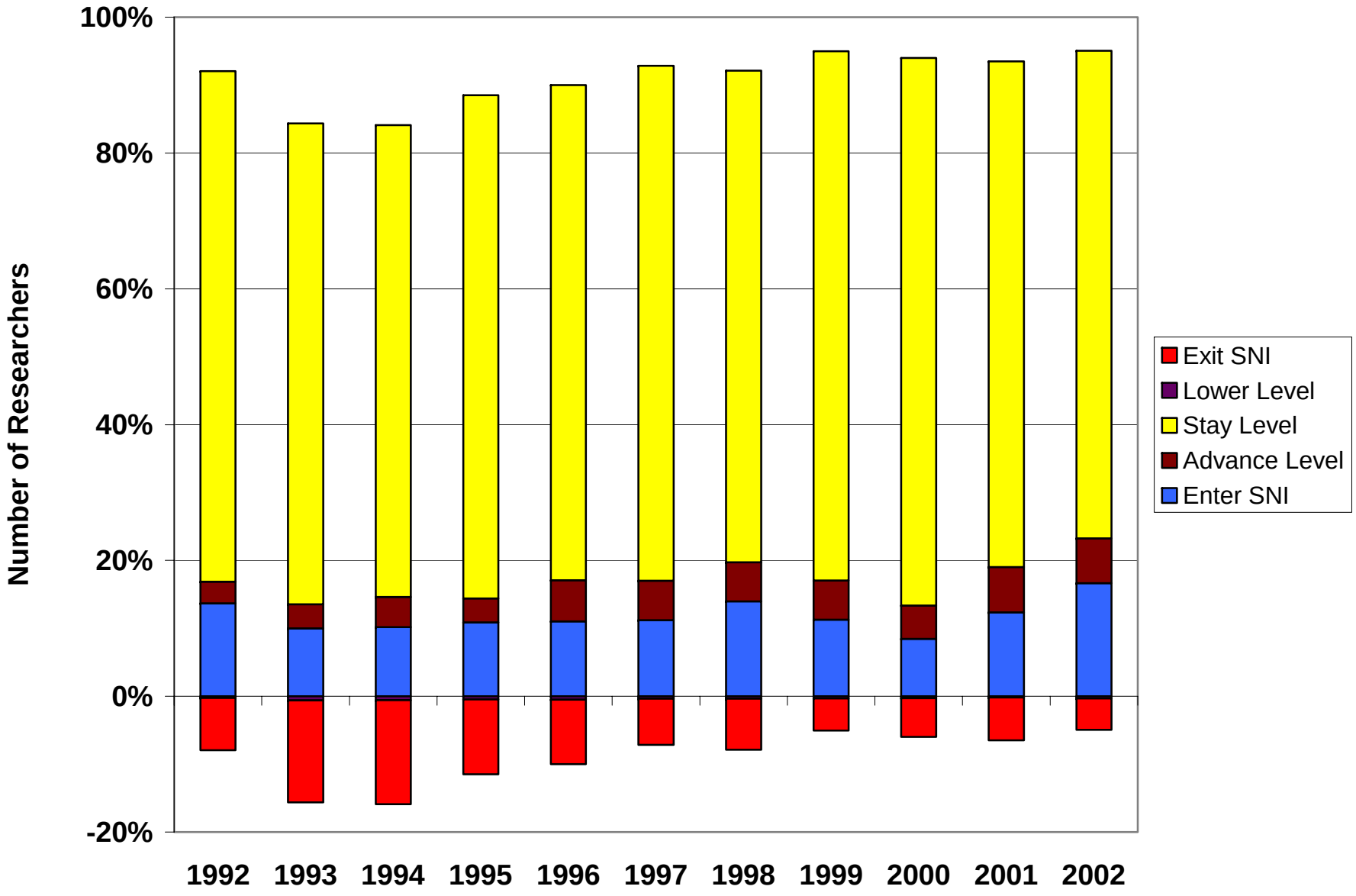
PhD required for all SNI

PCI - New World Bank Loan

Ley de Fomento

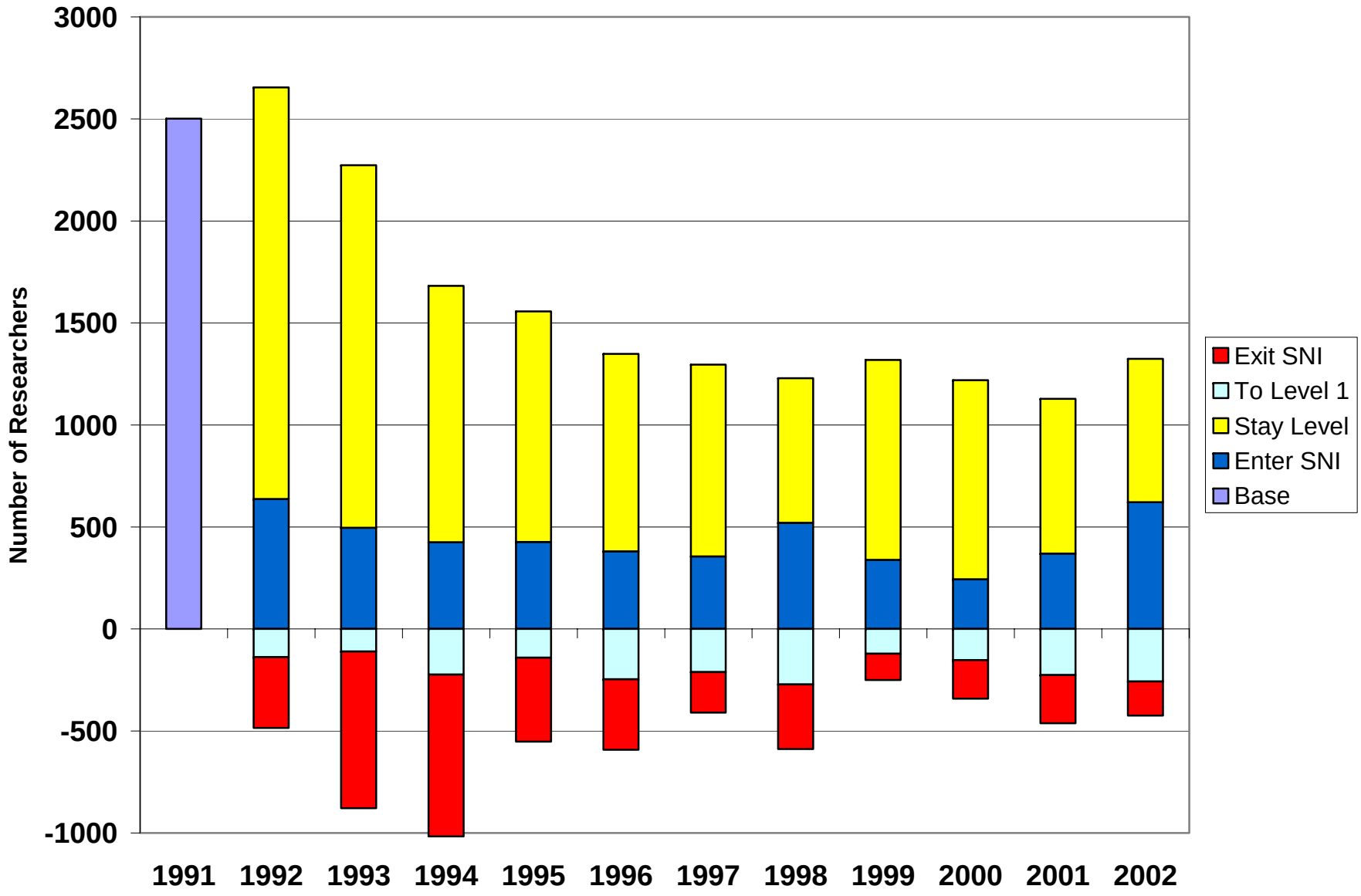
- From 1991 to 2002, the number of Researchers in SNI increased by 2600, almost 40%
- During the period, Candidates were reduced from 40% of the system to only 14%
- Level 1 increased from 43% to 59%, Level 2 from 12% to 19% and Level 3 from 5% to 8%

Researcher Movement in SNI Across All Levels



- After some turbulence in early ninities – especially in exit, SNI has become rather stable
- Entry averages 13% of system size and Exit 10% (6% since mid '90s) leading to SNI growth
- Advancement to next levels is around 6% of the system with virtually no regression

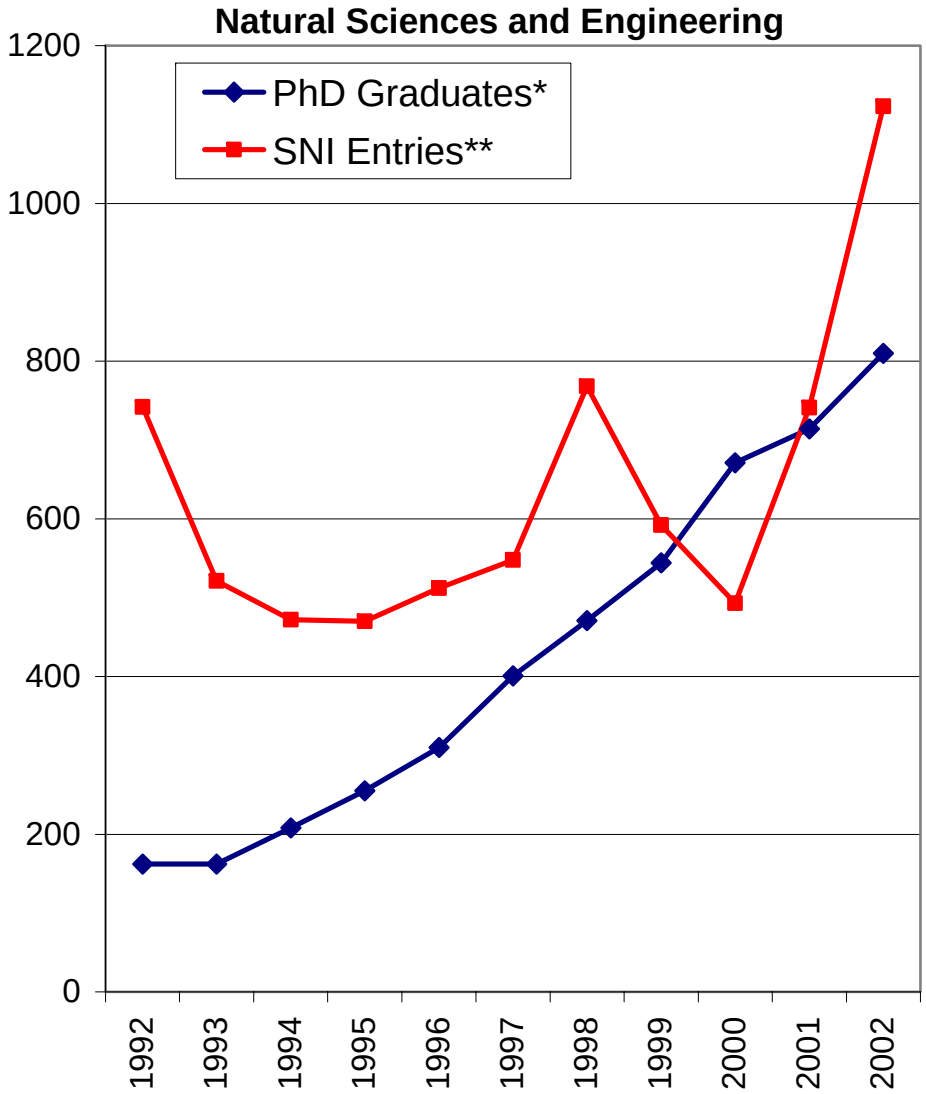
Researcher Movement in SNI Candidate Level

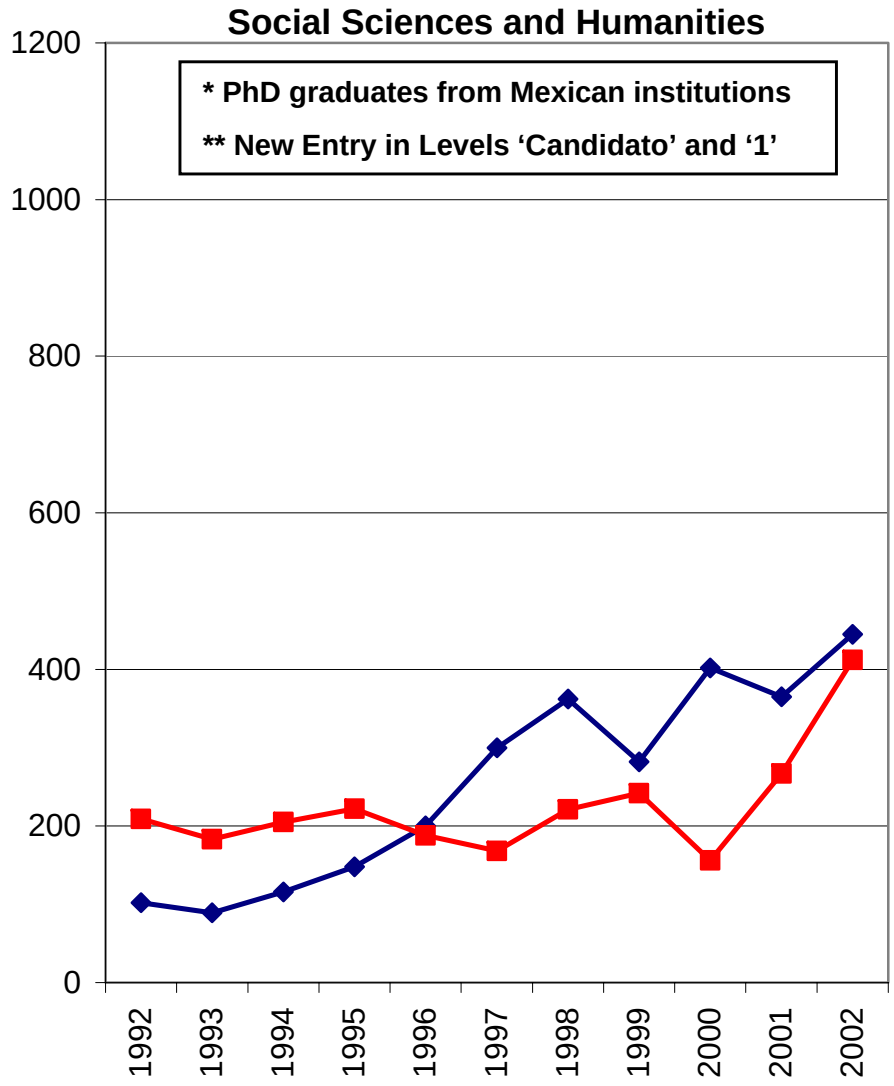


- Turbulence in SNI is mostly driven by Candidate Level – especially in early nineties
- While Exit from SNI at Candidate level seems to be shrinking, there is significant variation in Entry and Advancement to Level 1 of SNI

PhD Generation and Entry in SNI

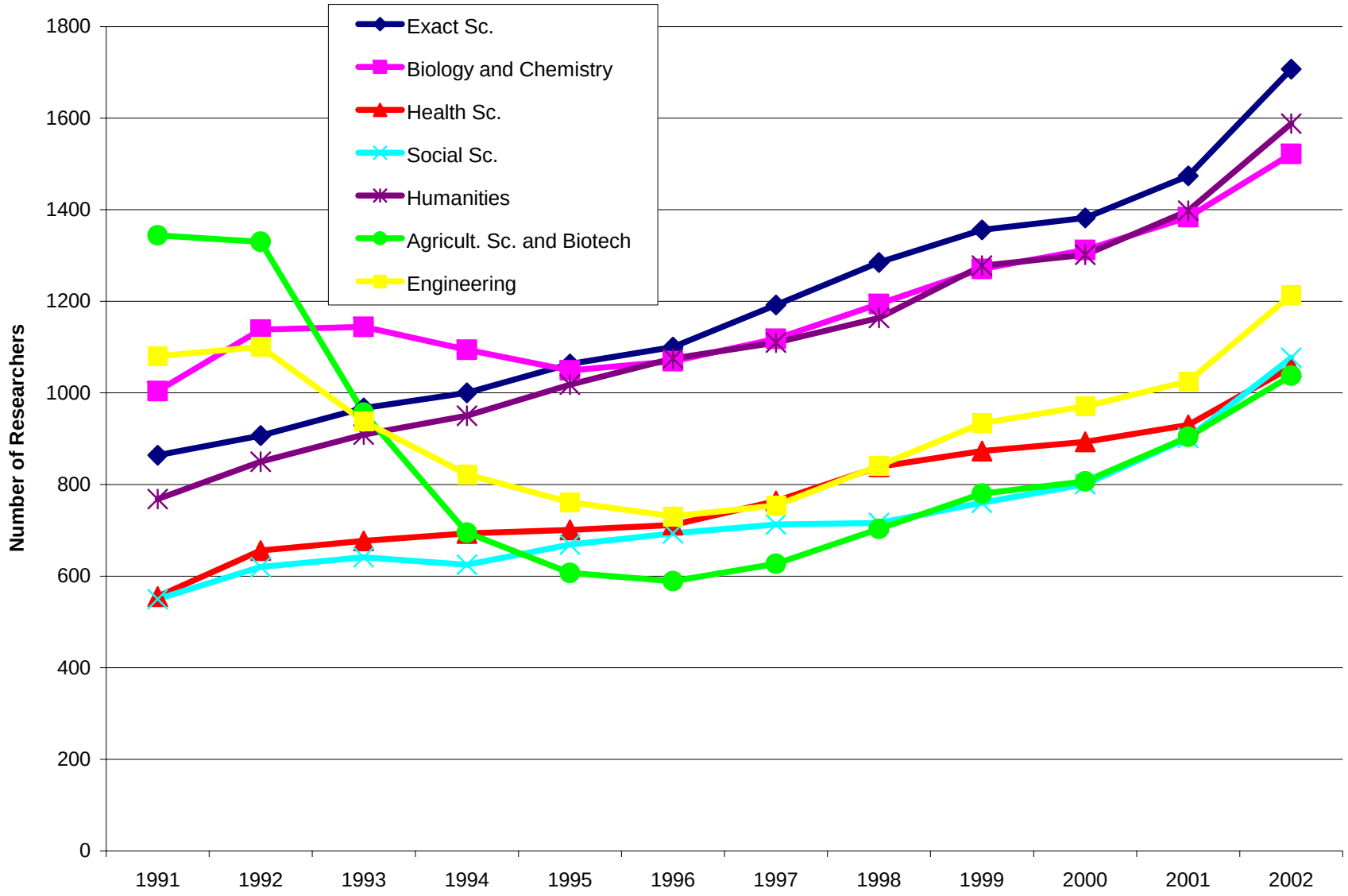
Sources: Conacyt; Encuesta de Graduados de Doctorado, 2002 y 2005.





- Most researchers that have entered SNI in the last decade do not come from Mexican Institutions. This gap is particularly important in Natural Sciences and Engineering
- A steady progress in rates of PhD graduates in Mexican institutions is reducing this gap

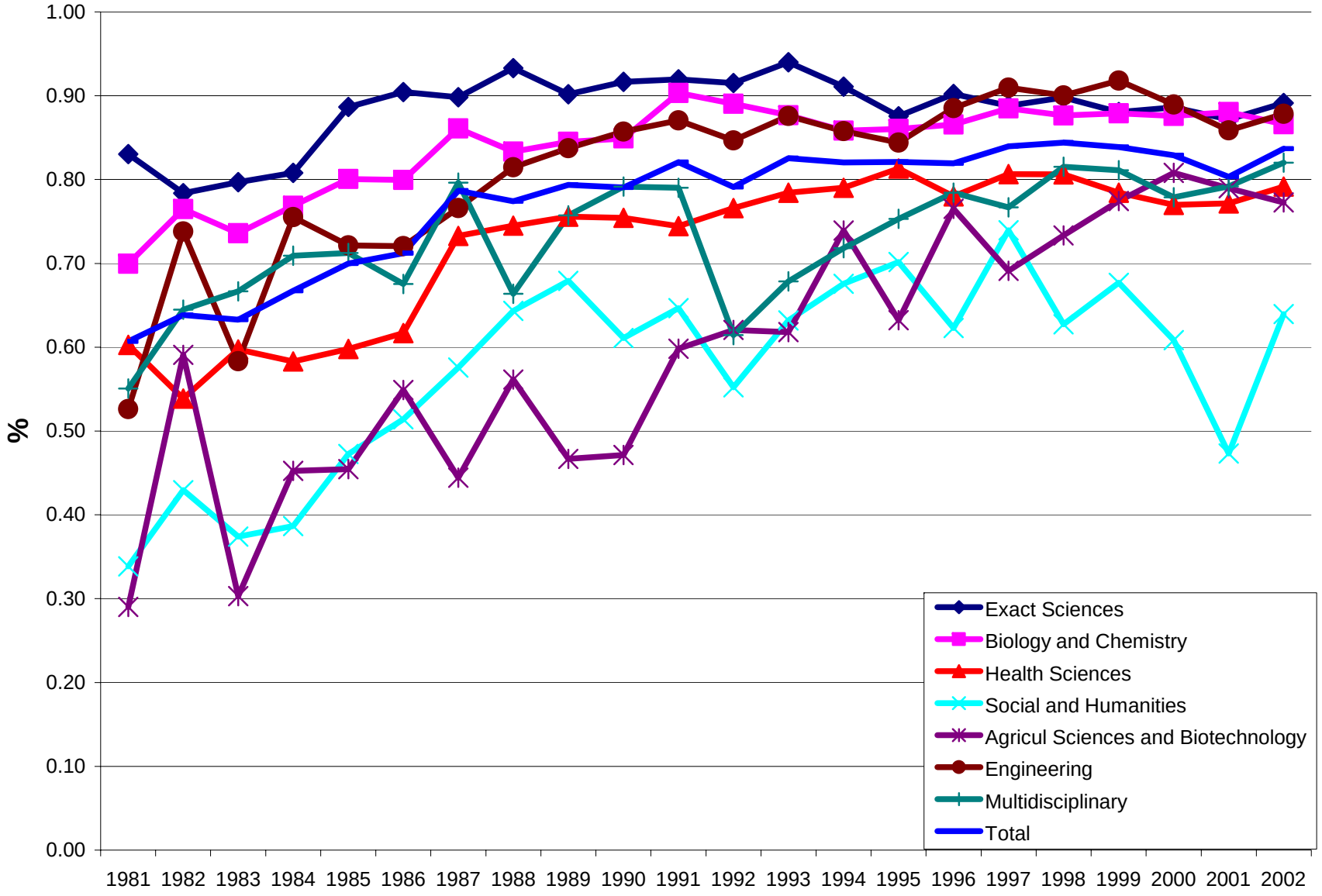
Number of SNI Researchers by Area of Knowledge



Investigadores vigentes

- Number of SNI researchers grew in all areas except Agricultural Sciences and Biotechnology
- Smallest growth in Engineering; largest in Humanities, Exact Sciences and Social Sciences
- In the middle of the nineties several areas declined before catching up

Mexican Publications by SNI Researchers by Area of Knowledge



- SNI researchers represent the overwhelming majority of scientific output of Mexico
- Relevance of SNI researchers to scientific output grew from 67% to 85% of total papers
- Despite important growth, social sciences and humanities contribute the least among areas

Mexican Science in a Global Context – An Assessment

2. Characterizing the productivity of SNI researchers
   - The profile and relevance of SNI researchers
   - Productivity of SNI researchers
   - Costs and Outcomes for SNI researchers

What we observe:

- Number of SNI Researchers increased by 40% from ‘91 to ‘02
- System grew in all areas except Agricultural Science & Biotech
- Growth particularly important in Humanities and Exact Sciences
- After some turbulence in early nineties, SNI became stable with Entry averaging 13% of system size and Exit 6%
- SNI represents the overwhelming majority of scientific output of Mexico – share grew from 60% to 85% of total publications

What we conclude:

- SNI is growing system representing active participants in Mexico S&T
- SNI functioning appears quite stable in the upper ranks of the system, with some turbulence at Candidate level
- Exact Sciences, Humanities and Biology & Chemistry dominate SNI
- Most past SNI entrants not trained in Mexico, but situation changing recently

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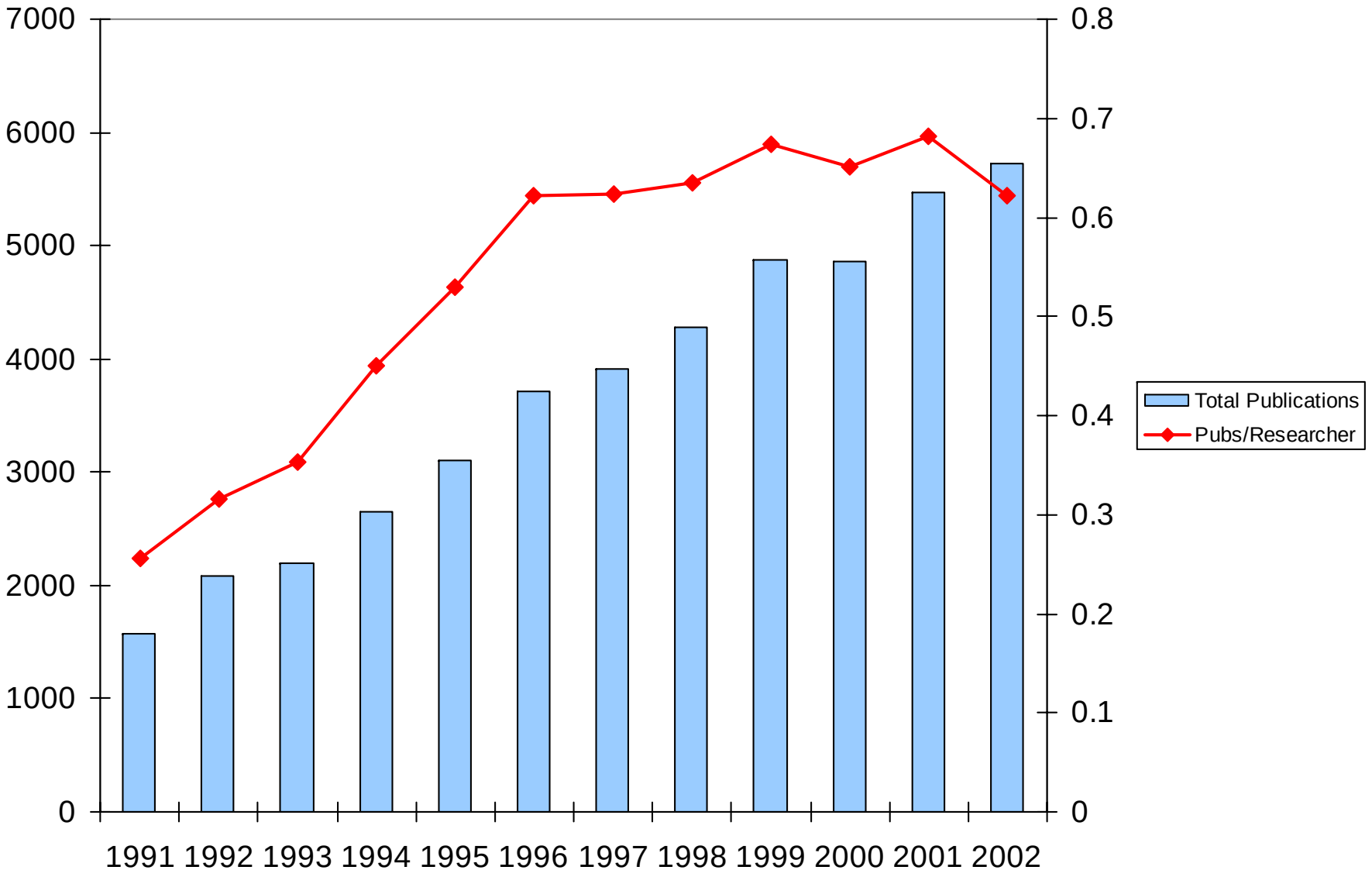
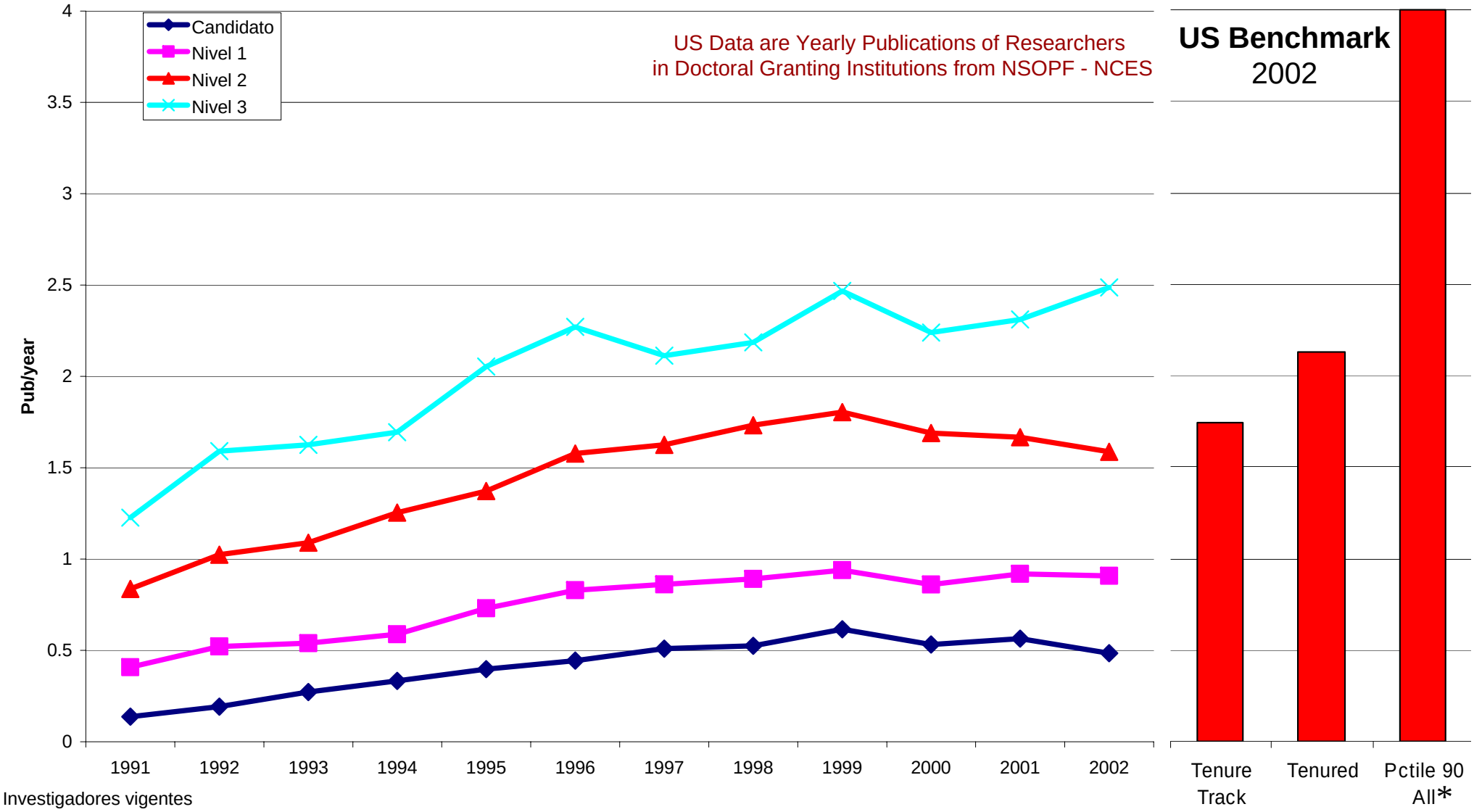
SNI Publications in ISI



Note: pubs/researchers is not directly comparable with Pubs/FTE researcher because of time allocation adjustments

- Publications by SNI researchers grew rapidly through nineties, faster than total Mexican pubs
- Productivity measured in publications per researcher grew rapidly throughout the nineties, especially in the early part of the decade, but leveled off after that

Mean of Publications, SNI Researchers by Level – All Areas

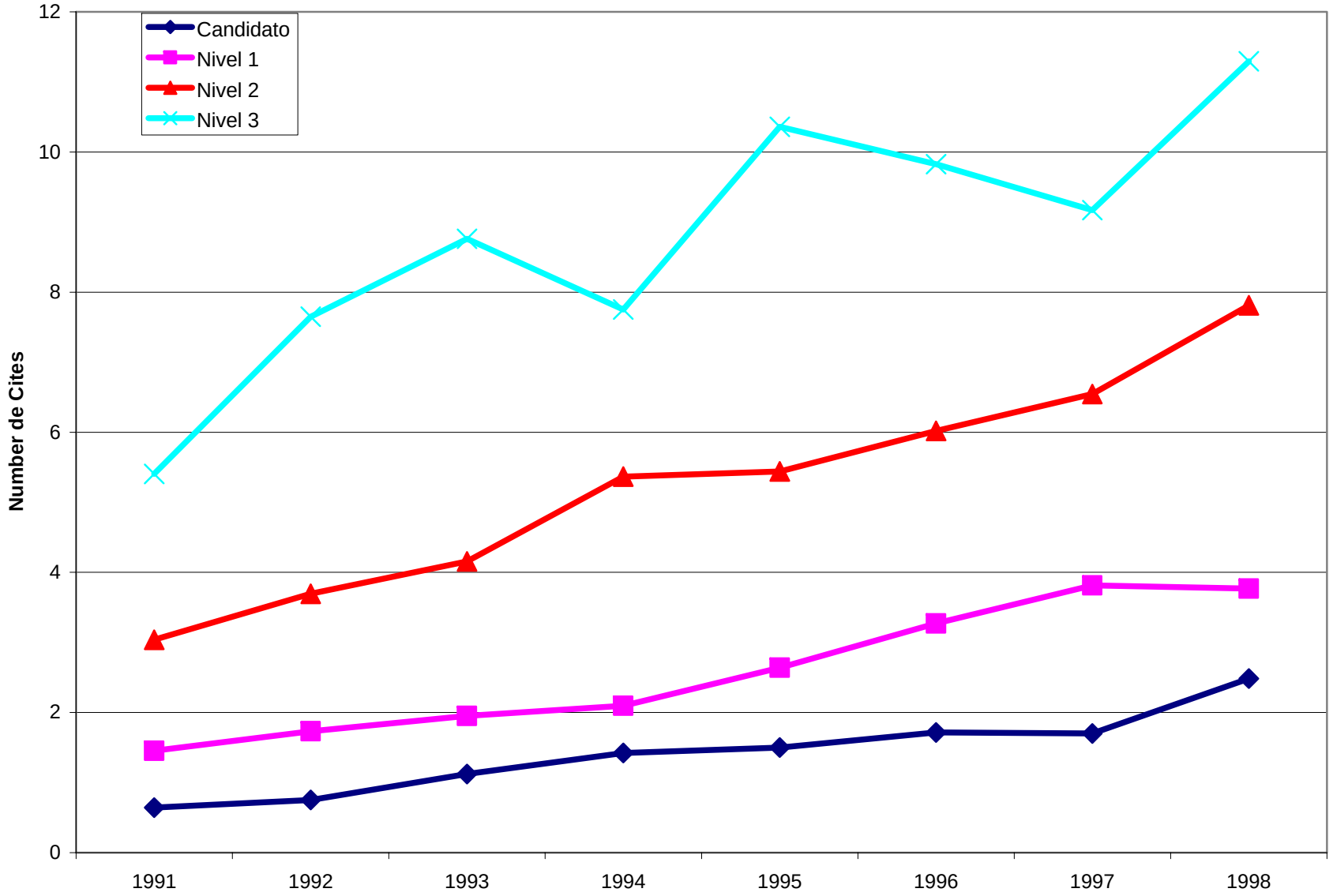


* Percentile 90 of papers published per year for all Researchers in US Doctoral Granting Institutions

- Productivity grows 50% to 60% as one moves climbs levels in per
- Productivity grew at an average of 9% annually in all levels, but mostly until 1999 then leveled
- SNI researcher still behind their US equivalents, especially Level 1, though

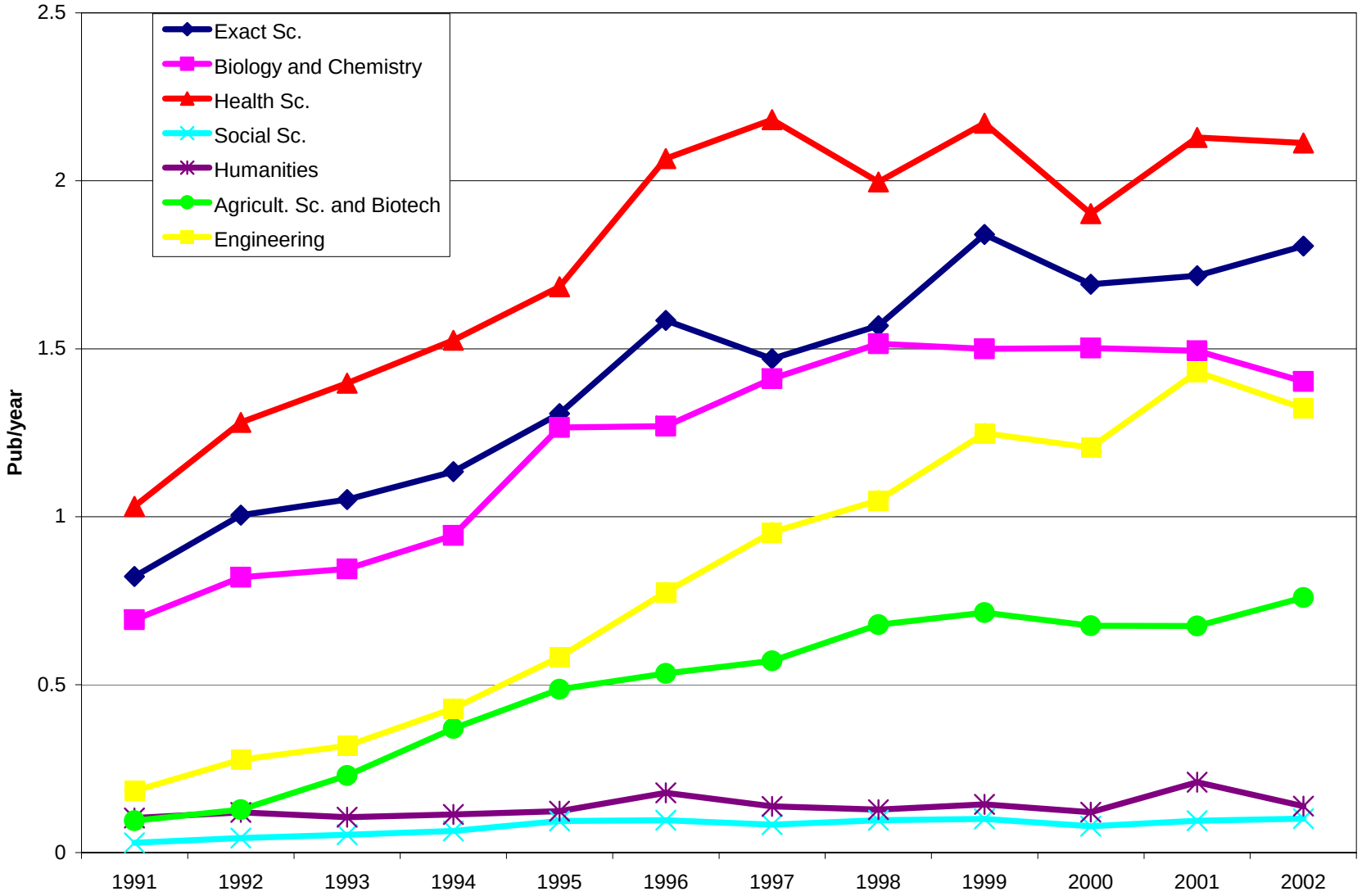
Mean of Citations, SNI Researchers by Level – All Areas

5 Year forward citations for each article generated by a SNI researcher



- There seems to be no trade-off between quantity and quality, at least until 1998, since citations and publications follow the same pattern
- Greatest impact increase is in candidatos, who grew almost 400%, followed by Nivel 1 and 2

Mean of Publications, SNI Researchers by Area of Knowledge

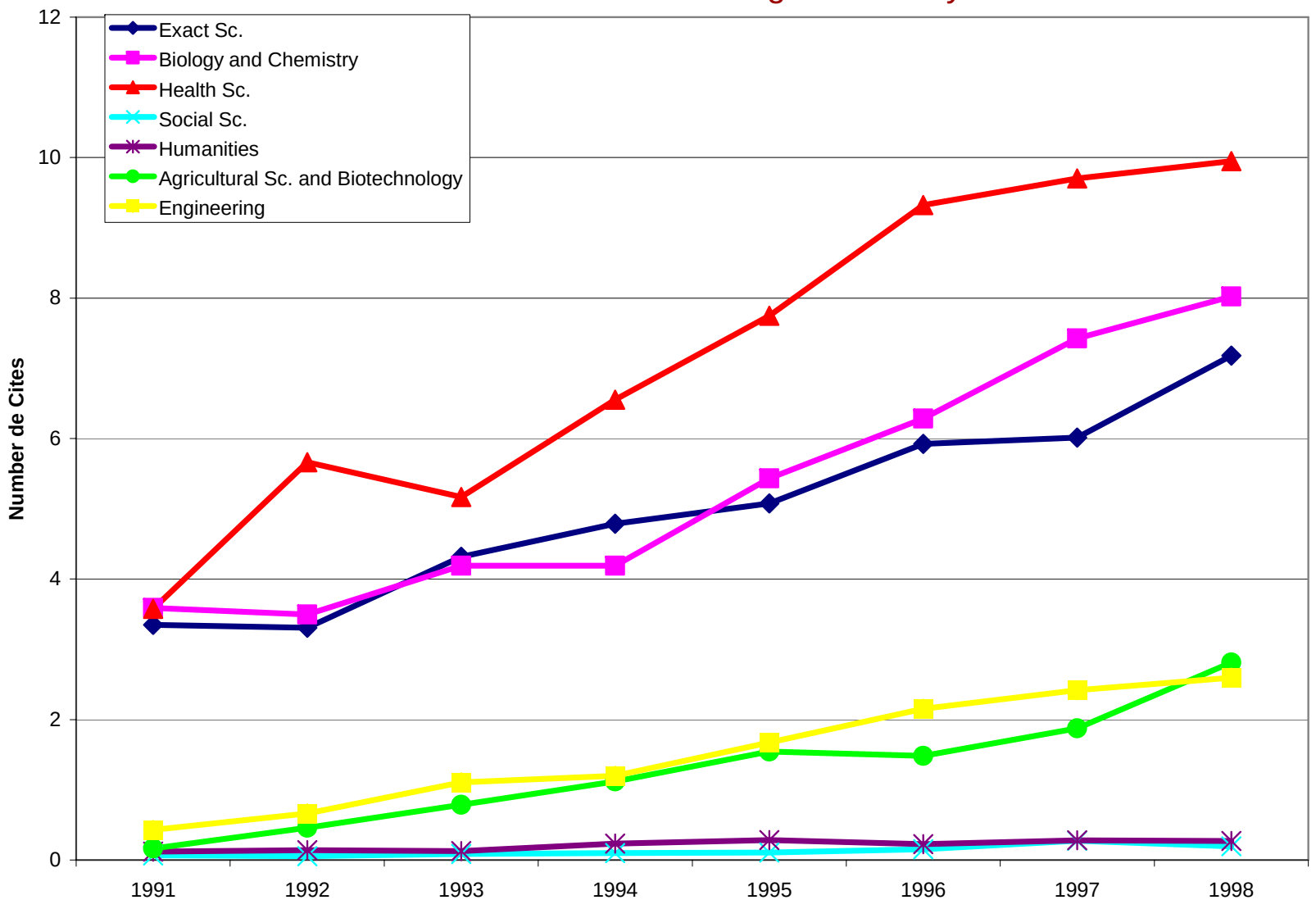


Investigadores vigentes

- Researcher Productivity varies significantly across areas of knowledge – it is area specific!
- Researchers in Health sciences publish the most, while Social and Humanities the least
- Important to note there are outputs other than publications, especially in Social & Humanities
- All areas except Social and Humanities significantly increased their productivity over time

Mean of Citations, SNI Researchers by Area of Knowledge

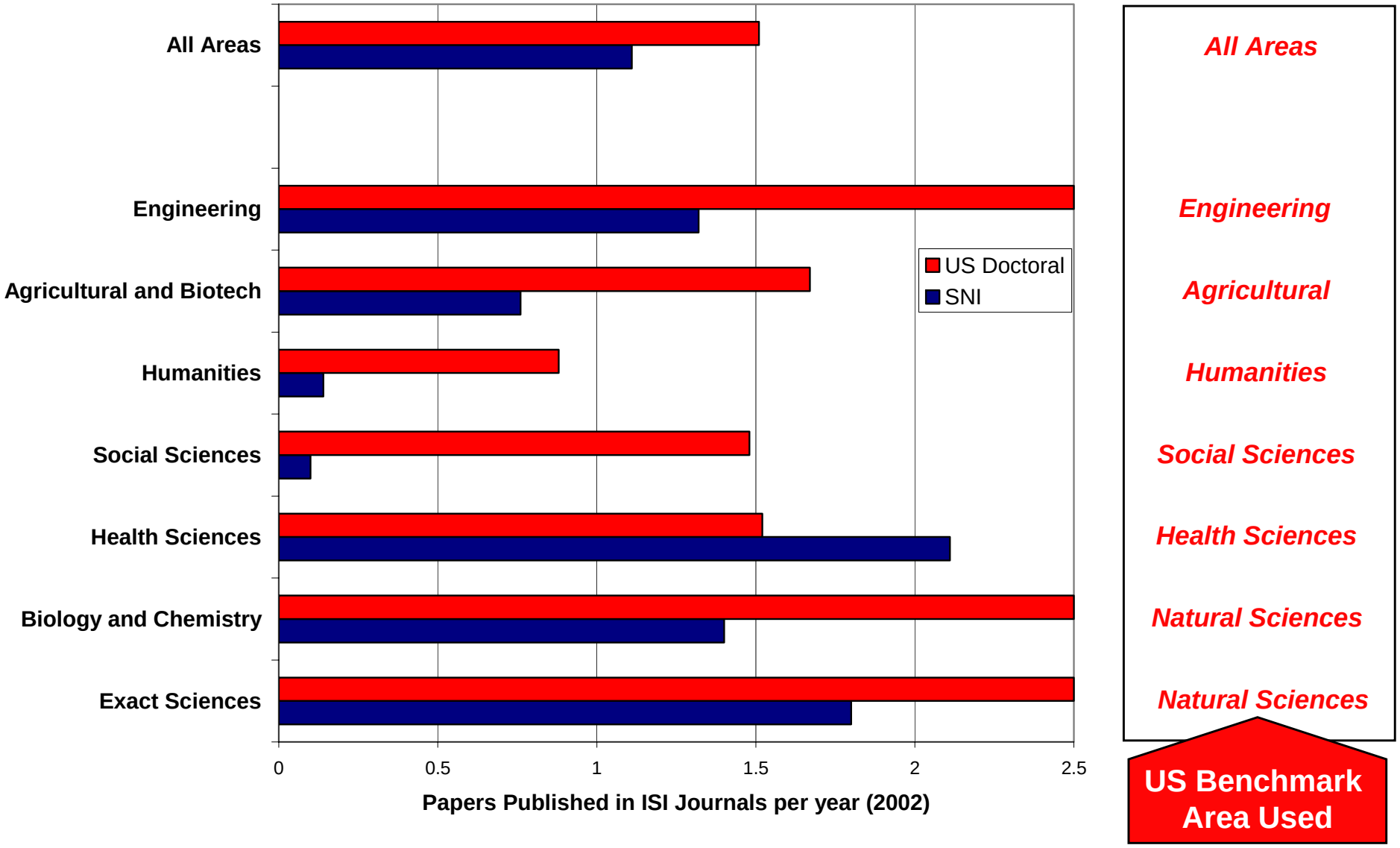
5 Year forward citations for each article generated by a SNI researcher



- The number of citations follows a pattern similar to that of publications for most areas
- Relative position and growth trend relatively lower than publications for Agricultural and Biotech, and much lower in Engineering
- Impact in Humanities and Social Sciences is quite low

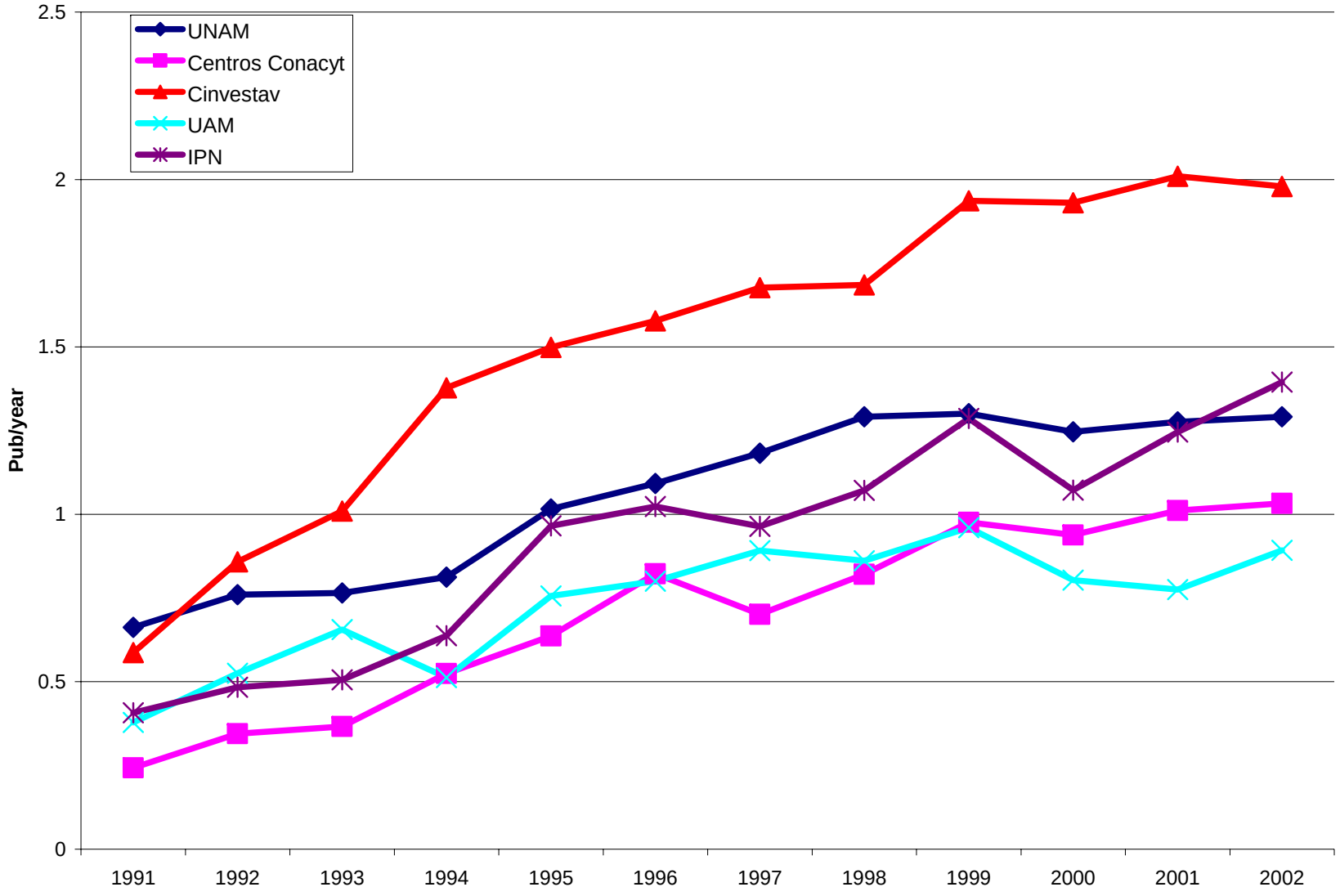
Publications Benchmark Against US Researchers – Per Area

US Data are Yearly Publications of Researchers in Doctoral Granting Institutions. Source: NSOPF, NCES (2002)



- Overall, SNI researchers are 26% below in output compared to their US counterparts
- Largest difference appears to be in Humanities and Social Sciences, with a gap above 90%
- In Health, SNI researchers generate a greater average output than their US counterparts

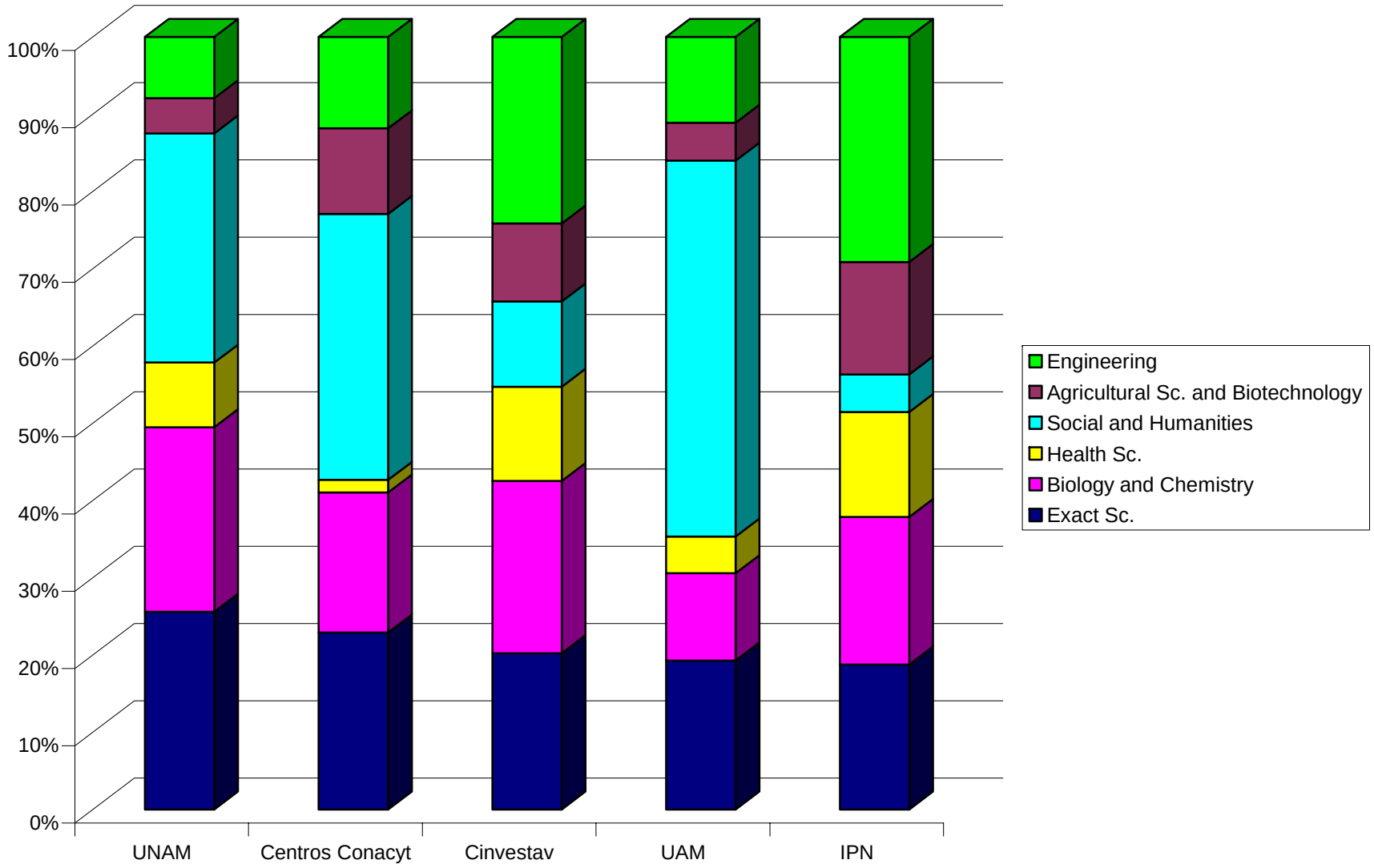
Mean of Publications of SNI Researchers. Selected Institutions



Investigadores vigentes

- SNI researchers in most lead institutions have increased their productivity over time
- There are also important differences in research productivity among institutions, with Cinvestav leading the group and UAM trailing

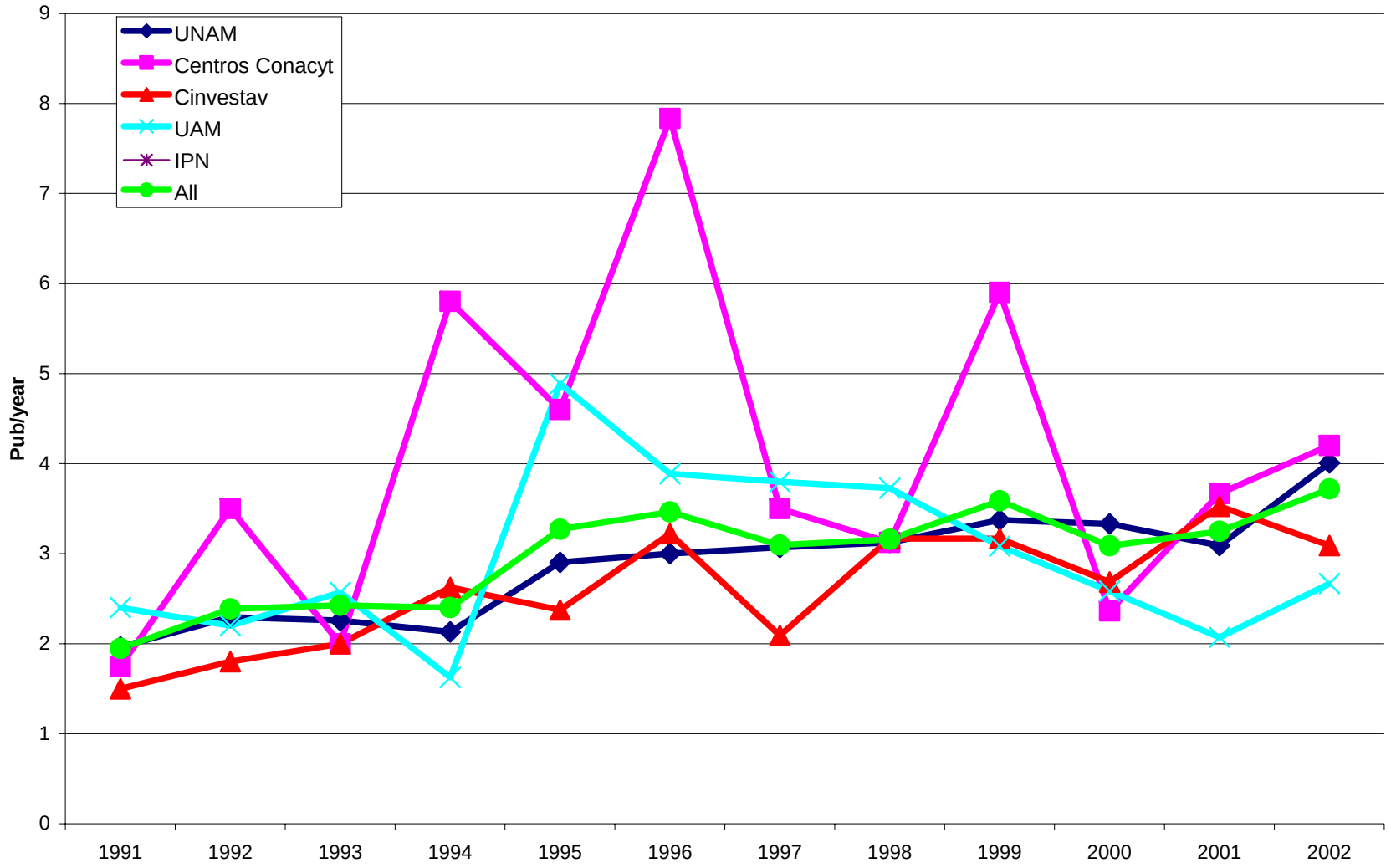
Proportion of SNI Researchers by Area of Knowledge



Investigadores vigentes 2002

- But it is important to recognize that institutions differ in their composition among areas of knowledge – who in turn have very different levels of productivity
- e.g. UAM has very large share of researchers in social and humanities, a low publication area

Mean of Publications of SNI Researchers in Exact Sciences in Level 3



Investigadores vigentes
Note: IPN was not included because during 5 years there was only 1 researchers at this level.

- If comparisons are made per area of knowledge and SNI level, overall levels of productivity for the researchers are much similar
- But there is still some variance across institutions and time

Publishing Dynamics in the Different Areas of Knowledge

Estimates from Regression – Details in Gonzalez-Brambila and Veloso (2006)

Area of knowledge	Researchers productive between: (years old)	The peak in productivity is at age: (years old)
All	30-79	53
Exact Sciences	31-85	56
Bio. & Chem.	27-83	53
Health Sciences	27-78	50
Social and Hum.	36-74	53
Agric. & Biotech.	32-74	53
Engineering	34-72	51

- On average, SNI researchers are productive over a long cycle – from 30 to 79 years old
- Productivity peak happens quite late in their lives, at 53, much later than in previous studies
- This is true for all areas, with Biology and Chemistry displaying the most extreme case

Other results

- Gender
  - There is not a big gender difference in scientific productivity
    - Mexican female scientists are not overrepresented among the non publishers
    - They produce only slightly fewer papers (0.07 paper) than men on average per year
  - Proportion of female scientists varies a lot among areas of knowledge, from Engineering with 12% and Exact Sciences with 15% until Social and Humanities at 38% and Health Sciences with 39%

- Country of PhD
  - Results suggest that there is no significant difference on researcher productivity as a function of the country where the PhD was earned
  - Proportion of researchers in each area of knowledge who got their PhD abroad goes from Biology and Chemistry with 30% and Health Sciences with 32%, to Engineering reaching 69% of the researchers graduating in a foreign country

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What we observe:

- Productivity of SNI researchers grew at an average of 9% annually from 1991 to 1999, but it has leveled off after that
- Productivity varies significantly across areas of knowledge and, as a consequence, also institutions; when comparing area of knowledge and level, institutions display comparable levels of productivity
- On average, SNI researchers are productive from 30 to 79 years old, and reach peak productivity at 53, a very long productive life cycle
- There is no big gender difference in productivity nor is there a significant gap if PhD was earned locally versus abroad

What we conclude:

- SNI has increased its productivity, especially in the mid nineties period of when many Candidates left and the system became leaner
- Productivity improved throughout the system except in social an humanities
- SNI researchers have a very long productive life cycle, beyond what other studies have shown, suggesting that its incentive role is working

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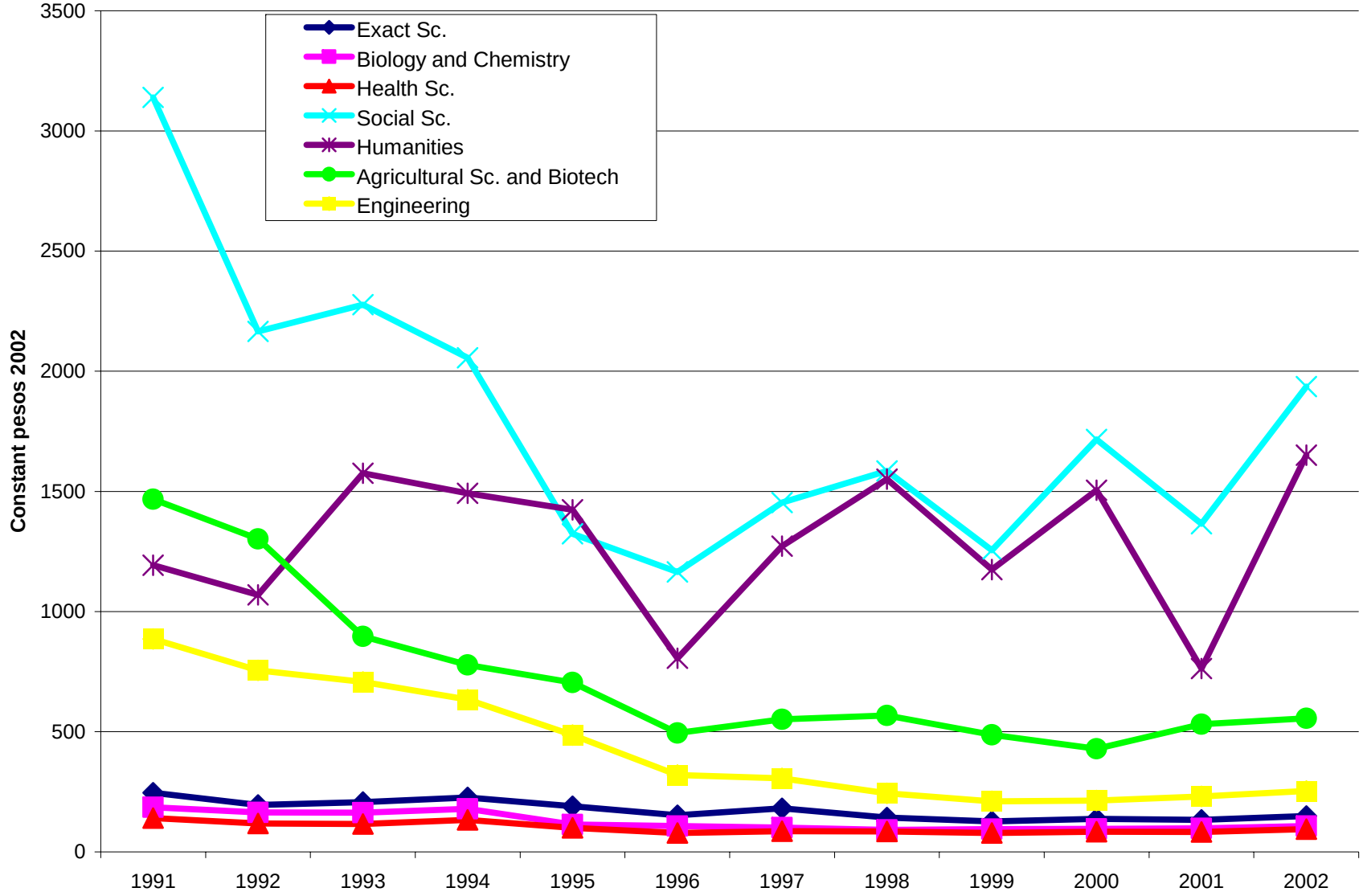
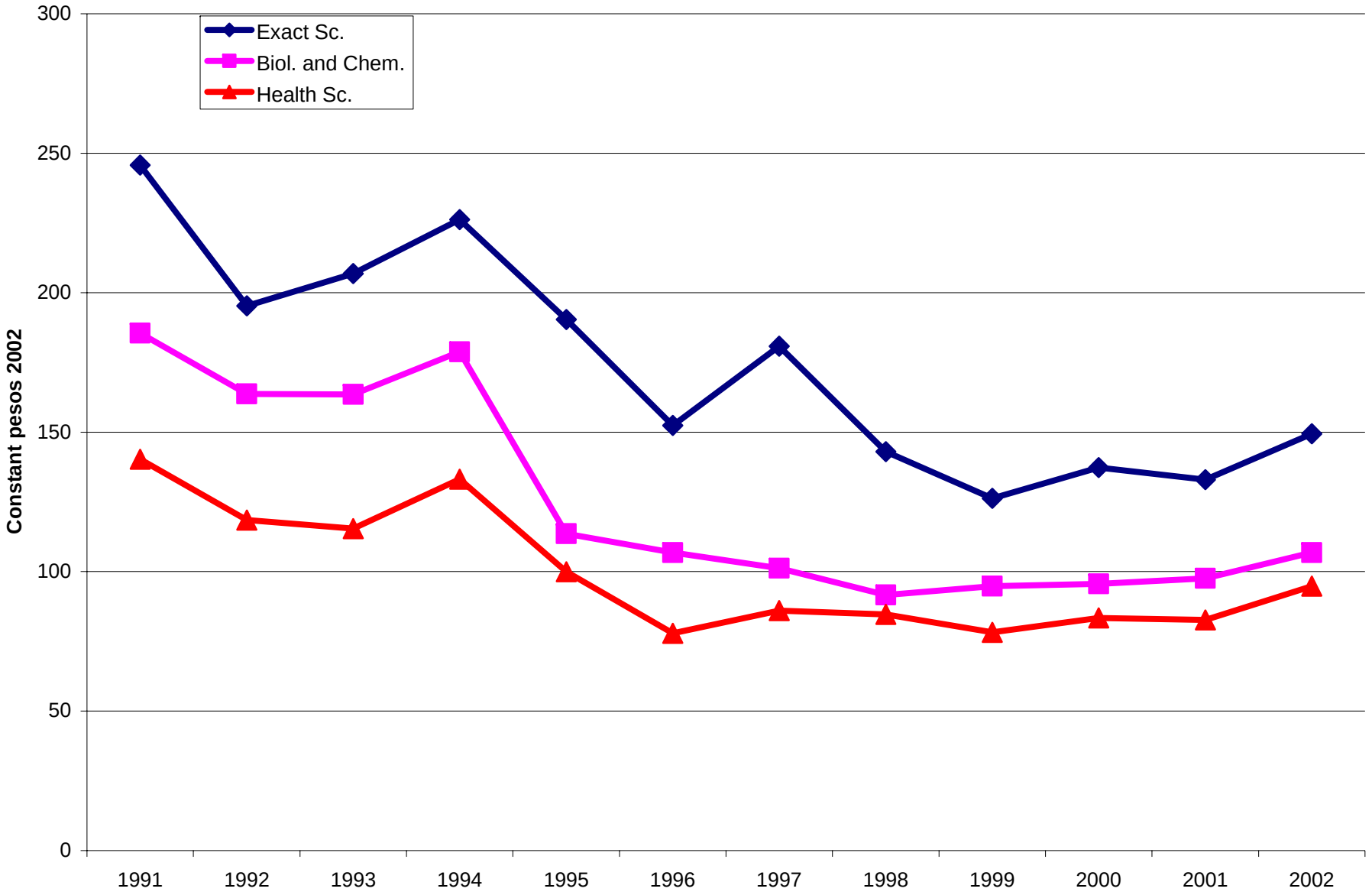
Cost of Publications by Area of Knowledge



SNI Budget per area/pubs per area

- With expanded researcher productivity, unit costs of publications have declined since 1991 in all areas except in Humanities – which, together with Social Sciences have the highest cost
- The most significant declines have been in Engineering as well as Agricultural and Biotech

Cost of Publications – Detail on 3 Areas of Knowledge



SNI's Budget per area/pubs per area

Mexican Science in a Global Context – An Assessment

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What we observe:

- Unit costs of publications by SNI researchers have declined since 1991 in all areas except Humanities and to a less extent Social Sc.
- The most significant declines have been in Engineering as well as Agricultural and Biotech
- The cost of Social and Humanities publications is the highest
- Decline in cost has mostly happened during nineties

What we conclude:

- The incentive system that SNI encompasses seem to be increasing its efficiency in terms of the cost per publication
- But most of the gains happened in the nineties, when productivity increased the most; cost has leveled off since then
- Despite being large areas and with high growth in SNI, Social and Humanities have not increased its productivity and reduced cost

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Conclusions and Implications – International Benchmarking

- Despite some development, Mexican S&T pool is very small
  - Little R&D investment in relation to size – bottom of benchmark nations
  - Small size of research system - commensurate to investment
- S&T system has small international output and impact
  - Results from the little investment in R&D
  - Valid for all areas of knowledge, with gap size depending on area
- **But** system is reasonable on an individual researcher basis
  - Investment per researcher in line with other comparable nations
  - Average researcher is productive and has a very reasonable level of impact – more than most comparable nations
  - But the small size of the system limits international output and impact
  - And other benchmark nations seem to be catching up with Mexico
- Small S&T size likely to be a liability for economic development
- Growing S&T system could lead to quick and large boom in output and impact – if researcher productivity is maintained
- But fast growth is difficult to achieve in terms of training and employing new large pool of researchers – must be rely on international education and carefully plan job creation

Conclusions and Implications – Assessing SNI

- SNI at the heart of the Mexican S&T system
  - SNI has grown to represent overwhelming majority of productive researchers
  - Functioning stable in system upper ranks, with some turbulence at Candidate level
  - SNI researchers have long productive life cycle, beyond shown in other studies
- SNI researchers have increased their productivity
  - Productivity improved throughout the system in most levels and most areas
  - But gap to most productive nation, US, still exist; especially in lower SNI ranks
  - SNI is also increasing its efficiency in terms of cost per publication
  - Most gains happened in mid nineties, period of when many Candidates left SNI
- Social Sciences & Humanities do not follow same path
  - Areas of knowledge have different levels of productivity
  - Social and Humanities grew the furthest and are dominant areas in SNI
  - But Social and Humanities have not increased productivity and reduced cost

- SNI plays strong role as incentive for researchers to continue publishing and has become an increasingly efficient system
- But still gap to fill to reach top international productivity levels
- Expansion of social sciences and humanities areas without corresponding productivity increase is affecting SNI efficiency