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Strategies for Support of Scientific Research

Problems of the Transition Period

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INTELLECTUAL MIGRATIONS AND GLOBAL UNIVERSITIES

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It gives us great strength my holy father that we don't know what we may wish to achieve. From this deep vagueness of our intentions a wonderful freedom arises.

--*Jean Anouilh*[1]

What are the features of science that may distinguish an environment in which a research system will grow and thrive? What is specific to the present era? What accounts for the success of science in America? In this essay I seek to sketch some answers to these questions. The point of departure is the contention of physicist Cesare Marchetti that science is a system of communication for the control of complexity.[2] From this point I revisit three of the canons of the sociology of science, established in large degree by Derek de Solla Price. Science functions as a single cognitive formation. Science is not democratic. Person-to-person contact is the catalyst for scientific creation. These lead to speculations that a discontinuity in the organization of science could be near and that the U.S. research enterprise works because it lacks a design. The discontinuity may be marked by scientists on the move and the emergence of global universities, likely of U.S. origins.

1. Science is a system of communication for the control of complexity.

As Marchetti states, the ability to control complexity is effectively the central parameter of the dynamics of evolution. "In the beginning was the word." So John began his Gospel about 1900 years ago. Today it is said, less poetically, that life is communication. Living objects are essentially communicating systems. They communicate internally to keep their parts operating together. They send signals into the external world, and sense and decode the ones coming from it. Control of complexity permits domination of ever more challenging, and larger, niches.

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[1]. Jean Anouilh, Becket, ou l'honneur de Dieu.

[2]. Marchetti, Cesare, "On the Role of Science in the Post-industrial Society: 'Logos' - the Empire Builder", Technological Forecasting and Social Change, v. 24 (1983) pp. 197-206.

Science is the human language for the exploration of the external world with the highest potential for control of complexity.[3] When messages can be kept free from errors, they can be long, and consequently complex, without losing their power and significance. By checking the interaction between the world of structures created in language and the world of structures examined by experiment and practice, science is the most rigorous method we have for generation of messages of high integrity.
Not coincidentally, it is the language with syntax by Darwin. Mutation is the combinatorial activity of our brains that generates the exploration of possible systems. Experiments are the protocols for selection, filtering for the feasible. Marchetti calls science an informational amoeba that gradually and stochastically explores the phase-space around it.

2. Science functions as a single cognitive formation.

Historian of science Derek de Solla Price described science as a conspiracy to structure a pooling of many people so that the totality of knowledge can grow more rapidly than any individual can move on his or her own.[4] Throughout history, the allegiance of scientists has been more to their group than to the institutions that support them. Of course, there is often an affection for the nodes in the circuit of science that provide support for the so-called invisible college.[5]

A clear demonstration of the dual citizenship of the members of the scientific enterprise is in the discovery of the first 50 elements of the periodic table (~~Table~~ 1). (Fig. 1) The searching chemists spread from Uppsala to Edinburgh, from Transylvania to Castile (Table 1) and into the New World. Their network functioned as one multinational entity as effectively 200 years ago as any today.

In every generation less favored regions experience a brain drain, as the British named the phenomenon when they first faced it in the 1950s.[6] The former USSR may be the

[3]. In this connection it is interesting to note the establishment of the Santa Fe Institute (SFI) in New Mexico whose theme is "the sciences of complexity."

[4]. Derek J. de Solla Price, *Little Science, Big Science...and Beyond*, (New York, Columbia, 1986) p. 159.

[5]. On the diversity and extent of circuits, see Daryl E. Chubin, Sociology of Sciences: An Annotated Bibliography on Invisible Colleges, (New York, Garland, 1983).

[6]. For more recent episodes, see Bruce L. R. Smith, "The Brain Drain Reemergent: Foreign Medical Graduates in American Medical Schools", Minerva v. 17 (Winter 1079), pp. 494 ff; Charles V. Kidd, "The Movement of Younger Scientists into and out of the United States from 1967 to 1980: Some Aspects of the International Movement of Scientific Knowledge", Minerva v. 21 (Winter 1983), pp. 387-409.

Table 1. Place and time of discovery of some chemical elements. The notion of the periodic table of elements, dating to a German chemist in 1780, helped to systematize and accelerate the search. Source: Desmond, Kevin, The Harwin Chronology of Inventions Innovations Discoveries, (London, Constable, 1987).

Element	Country	Year
Cobalt	Sweden	1694
Boron	France	1702
Arsenic	Sweden	1733
Nickel	Sweden	1751
Hydrogen	England	1766
Fluorine	Sweden	1771
Nitrogen	Scotland	1772
Manganese	Sweden	1774
Chlorine	Sweden	1774
Barium	Sweden	1774
Oxygen	England	1774
Molybdenum	Sweden	1778
Tellurium	Austria-Hungary	1782
Tungsten	Spain	1783
Uranium	Germany	1789
Zirconium	Germany	1789
Zinc	France	1790
Titanium	England	1791
Strontium	Scotland	1793
Chromium	France	1797

leading loser in the 1990s. Intellectual migrations are frustrating for the nation that needs to feel it participates in the advancement of science and needs science for its own advancement. Scientists may move from where they are most desperately needed for near-term economic and social progress. Their flows and concentrations may significantly structure international order. Physicist Abdus Salam argues that creation, mastery, and utilisation of modern science and technology are basically what distinguishes the poor nations of the South from the rich North.[7]

But, there is nothing new in the propensity of scientists to move. The migration of scientists is as old as science. As the often exiled Yugoslav physicist Stevan Dedijer highlighted, Daedalus invented the flying machine to accept a new appointment in Sicily.[8] For about 50 years beginning about 1930 the United States was the only significant destination for migrant scientists.[9] It is important to note that the United States was an attractive destination even at the nadir of a depression. Now the destinations are somewhat more diverse, as shown in Table 2, which reports the movement of students. Students have always been a sensitive indicator of academic quality, whether in the time of Socrates, Abelard, Niels Bohr, or today.

It is new that almost every country is helping to expand the world scientific community by domestic efforts to detect and develop its own potential scientists. Many nations will be disappointed with the results, at least from the point of view of credit for notable contributions to the global pool of knowledge. They may benefit from general enhancement of skills, reduction in superstitious beliefs, and other changes associated with diffusion of mathematics and science.

However, the predictable national policy interventions are likely to be secondary factors in scientific geography. The main impulse to ride the circuit comes from inside the individual, judging by the fact that personal and family funds provide almost two-thirds of foreign student funds used in the United States (Table 3). The incentives provided by institutional sponsors that send students and the attractions offered by host institutions each provide less than 20 percent of support. If borders are even a little open, scientists will flow through to serve themselves and Minerva.

It is interesting to view the tenet of the scientific community in favor of the free movement of scientists in light of the reality of the global cognitive formation. Support for such movement may stem less from moral values than functional necessity that the

[7]. Abdus Salam, "Notes on science, technology and science education in the development of the South", Minerva v. 29 (Spring 1991) pp. 90-108.

[8]. Dedijer, Stevan, "Why did Daedalus leave?" Science v. 133 (1961) pp. 2047-2052.

[9]. Donald Fleming and Bernard Bailyn (eds.) documented The Intellectual Migration: Europe and America 1930-1960 (Cambridge, Harvard, 1969).

Table 2. Foreign student enrollment in leading host countries, 1987. Source: Zikopoulos, Marianthi (ed.), "Open Doors 1989/1990: Report on International Educational Exchange" (New York, Institute for International Education, 1991) p. 5. Most data are from Unesco Statistical Yearbooks.

Host country	Foreign enrollment
United States	356,187
France	123,978
Germany, F.R. (1986)	81,724
United Kingdom (1985)	53,964
Italy (1983)	28,068
Canada	27,119
Lebanon (1984)	25,515
Belgium	22,555
Saudi Arabia (1986)	17,971
Austria	16,174
Australia (1985)	16,075
Japan (1986)	14,971
Switzerland	13,925
Syria (1986)	12,309
Egypt (1986)	11,025
Sweden (1984)	10,401
Germany, D.R.	10,351
Vatican City	9,882
Turkey	8,350
Netherlands (1986)	7,873
50 leading countries	948,833

Table 3. Foreign students in U.S. by primary source of funds, 1989/90. Source: Zikopolous, *op. cit.* p. 38.

Source of funds	%	number
Personal & family	63.7	246,250
U.S. college/university	18.2	70,310
Home government/university	6.7	25,910
U.S. private sponsor	3.1	11,750
U.S. government	2.2	8,700
Foreign private sponsor	2.2	8,550
Current employment	2.1	8,260
International organization	0.6	2,460
Other	1.2	4,660

Fig. 7

scientific community expresses as a constitutional principle. Scientists are not unique in their collective identification, but they are unusually disciplined and solid in maintaining it.

3. Science is not democratic.

If science were perfectly democratic, there would tend to be a rather uniform population density of scientists everywhere. But as Price pointed out, scientists tend to congregate in fields, institutions, countries, and even the use of certain journals.[10] The growth of cities in a country provides a useful model for the growth of blocks within science. There is a strict hierarchy of blocks of decreasing size, with a Pareto-like distribution, unchanged since it was first extensively documented by the sociologist George Kingsley Zipf half a century ago.[11] Even today's mobile, allegedly independent students line up with military precision (~~Table~~ 2). Counting dollars rather than brains, a study by the Congressional Office of Technology Assessment (OTA) reports that 53 percent of federal research and development (R&D) funding in the United States goes to 10 percent of the states, and 40 percent of federal academic R&D funding to fewer than 10 percent of the nation's universities.[12] Price noted that science displays in several ways a tendency to crystalize, in the sense that big things grow at the expense of small things that constitute a sort of mother liquor. Large fields seem to absorb the personnel and subject matter of little ones.

The same steep hierarchy is true at the level of the individual investigator. Biologist and demographer Alfred Lotka in 1926 identified an inverse square law for scientific productivity, as manifested in authorship of papers.[13] In the cases he examined, Lotka found that 50 percent of the work is done by 10 percent of the people, and that about 3 percent of the people in a field are highly prolific, major contributors. Science is an elite activity built around the creativity and competence of a very small fraction of the population of scientists. The OTA study reports that at Stanford University 5 percent of the faculty bring in 50 percent of the research dollars, one measure of ability.[14]

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10. Price, *op. cit.*, "Galton Revisited", pp. 30-55.

11. Vilfredo Pareto, Cours d'economie politique, 2 (1897) pp. 299-345; George K. Zipf, Human Behavior and the Principle of Least Effort (Cambridge, Addison-Wesley, 1949).

12. Office of Technology Assessment, "Federally Funded Research: Decisions for a Decade" (Washington DC, US Government Printing Office, 1991) p. 7.

13. Alfred J. Lotka, "The frequency distribution of scientific productivity", *Journal of the Washington Academy of Sciences*, v. 16 (1926) p. 317.

14. OTA *op. cit.*, p. 26.

In the 1950s physicist (and controversial social theorist) William Shockley was concerned with productivity of research scientists and investigated the output of 88 research staff members of the Brookhaven National Laboratory.[15] He found the distribution function of the number of papers published was log normal, having a long tail. He associated long tails with successful completion of numerous independent subtasks, with the failure of any one sufficient to cause the failure of the primary project. The publication of a scientific paper is an example of such a task.[16] Physicists Elliott Montroll and Michael Shlesinger generalized Shockley's analysis, showing that the central limit theorem is applicable to the characterization of the probability distribution of successes in a population seeking to complete a required complex task, and that the full distribution may be log-normal with a transition to an inverse-power Pareto tail.[17] In any case, science is wagged by a long and powerful tail.

4. Person-to-person contact is the catalyst for scientific creation.

Policy for science is often discussed in terms of research equipment, buildings, money, the formal set of institutions, human resources, and programs and plans. Other factors mentioned include salaries, material standard of living, status in the scientific community as well as larger society, ease of obtaining means for research, and contextual factors such as political turbulence. They all certainly matter, and need to be assessed in relation to the different communities that constitute science itself (and society).

Nothing matters for science so much as facilitation of human contact, both through physical juxtaposition and telecommunications. It is important to remember that we communicate person-to-person, not paper-to-paper. Price, geographer Torsten Hagerstrand, management scientist Henry Mintzberg, and others have shown that many of those at the top of the information hierarchy scarcely read at all but take most input

[15]. William H. Shockley, Proceedings of the Institute of Radio Engineers, v. 45 (1957) pp. 279-290.

[16]. Shockley explained that to publish a paper one must 1) have the ability to select an appropriate problem for investigation; 2) have competence to work on it; 3) be capable of recognizing a worthwhile result; 4) be able to choose an appropriate stopping point in the research and start to prepare the manuscript; 5) have the ability to present the results and conclusions adequately; 6) be able to profit from the criticism of those who share an interest in the work; 7) have the determination to complete and submit a manuscript for publication; and 8) respond positively to referees' criticism.

[17]. Elliott W. Montroll and Michael F. Shlesinger, "On 1/*f* noise and other distributions with long tails", Proceedings of the National Academy of Sciences USA, v. 79 (1982) pp. 3380-3383.

in other ways, namely, orally and socially.[18] The number of telephones in a society is one of the best predictors of scientific influence and productivity (~~Table~~ 3). Fig. 3

Thus, one key is to establish small, select groups of the maximum size that can be handled by interpersonal relationships and see that these individuals interact. A group can be concentrated or scattered. Often, the game is to set up a circuit of institutional nodes where invitations are provided to come work for a short time. Then, one returns home. Within a few months or years, everyone see everyone else. The allegiance is more to the network than to the nodes.

Oral communication and participation in meetings where new work is made known are an absolute necessity. How many published papers per year do researchers truly read? As many as one hundred? Fields in the natural sciences move with an immediacy such that 80 percent of references come from work published in the previous five years. It is thus simply not possible to be a current and effective part of the network only by reading published works, especially because published work is already 2-3 years old.

It is also important to appreciate that transportation and communication are complementary goods, in fact chained in tandem. They are not substitutes. The more one travels, the more one sends messages, and vice versa. Physical movement is a requirement for establishing territoriality, which exists in science as in all other endeavors of the human animal. Writing is another territorial act. The main motive in publication in science is the same as for all other graffitti, the leaving of marks to indicate presence, priority, and possession.

It is probably unnecessary for the nodes of the network to be located in places as attractive as Woods Hole, Aspen, Naples, or Laxenburg. Science is a fundamentally social activity, and people will go where the action is, which in practice means where the most creative individuals are. A certain affluence is required to enable interactions. However, the key is more convenience than luxury.

The most prolific individuals, whether renaissance painters or modern physicists, have sought to increase their own productivity by leading teams that can accomplish more than the individuals could singly. Rather than an external requirement for larger scale efforts, the fundamental cause of the growth in the number of centers is the increasing number

[18]. Torsten Hagerstrand, Innovation Diffusion as a Spatial Process (Chicago, University of Chicago, 1967); Lance B. Kurke and Howard E. Aldrich, "Mintzberg was right!: A replication and extension of *The Nature of Managerial Work*", Management Science, 29 (1983) pp. 975-984; Henry Mintzberg, The Nature of Managerial Work (New York, Harper and Row, 1972); Price, *op. cit.*

of creative individuals.[19] As first suggested by Price, the competitive grants system needs to be evaluated as a flexible and efficient system for talented individuals to purchase co-authors.

At the lower end of the scale of scientific productivity, the needs are different. One question is how to keep the large body of average scientists and associated technical workers reasonably close to the leaders. Such scientists typically stabilize in governmental and industrial laboratories and to some extent traditional university departments. They function most happily in an atmosphere of controllability, orderliness, and predictability. They carry on indispensable tasks of instruction, and the data collection, measurement and monitoring, computation, and tidying, firming, and filling that eventually make impressive a body of knowledge.

Another question is how to scan the overall community to minimize waste of talent. As Michael Thompson and co-workers have pointed out, it is important that the system is open for messages from critical groups operating at the periphery as well as from the large cadres at the center.[20]

History suggests that sustaining institutional and cultural pluralism, the winning strategy for science, is exceedingly difficult.[21] Retaining readily recognized, top talent is a quite different matter from retaining the broad base of the hierarchy or the dissonant and dissident. As Thompson et al. indicate, providing freedom for the ego-focused networks of the mandarins of science to self-organize clashes with the need for procedures that permit bureaucracies to operate and the egalitarianism that encourages growth of exploratory, unprivileged groups. In turn, broad public support (or at least acceptance) is required, if the three main forms of social organization in science--the mandarins, the cadre, and the rebels at the gates--are to be allowed a dynamic and creative interaction.

19. I have not been able to find quantitative evidence of the changes in the distribution of the size of groups employed in scholarly and research endeavors. There has always been "big science," but in previous eras large numbers of skilled workers were employed as scribes and copiests and in computational and experimental tasks that have been mechanized, "freeing" people for modern forms of the same work.

20. M. Thompson, R. Ellis, and A. Wildavsky, Cultural Theory (Boulder, Westview, 1990).

21. To the extent that the scientific polity is pluralistic and encourges freedom of inquiry, it is of course democratic in a deep sense. In terms of distribution of talent, wealth, achievment, and status, it is not.

5. A discontinuity in the organization of science could be near.

By several measures, the growth of the world scientific enterprise has been at a nearly exponential rate since World War II. The literature has been doubling every 15 years or so, with papers now accumulating at a rate of more than half a million per year. Price conjectured that the costs of science would increase as the square of the number of scientists. This has not come to pass, but there has been a substantial escalation of costs.[22]

There have been other great expansions of systems of education and research. The Medieval universities were founded and grew between about 950-1450. There was a Renaissance pulse centered about 1600. It appears unlikely that the system can continue to grow as fast as it has recently. As atmospheric scientist Robert M. White has pointed out, science has been procreating like the Sorcerer's Apprentice.[23] The number of employed doctoral scientists and engineers in the United States increased from 285,000 in 1977 to 419,000 in 1987, the latest year of available data.[24]

It may be that American and world science are entering a phase of saturation of certain kinds of institutions, including universities and other research centers as well as journals. Fig. 4
In 1986 Frederick Seitz wrote that "Our [American] universities have in a very real sense

22. Price, *op. cit.*, p. 82. The 1991 OTA study reports (p. 21) that the cost of producing a published paper or performing a given scientific measurement acutally decreased by some indicators. With less than double the annual investment since 1965, more than double the number of papers were published in 1988, and more than double the number of Ph. D. scientists are employed in the academic sector. However, OTA also finds that total expenditures on individual components of grants rose over inflation 1958-1988, though not nearly at the rate of total federal expenditures for research. Instead, growth in the *size* of the research workforce supported by the federal government seems to account for the largest increase in federal research expenditures. The largest component increases of research project budgets were for salaries and indirect costs.

23. Robert M. White, "Science, Engineering, and the Sorcerer's Apprentice", in M.O. Meredith, S.D. Nelson, and A.H. Teich, (eds.), Science and Technology Policy Yearbook (Washington DC, American Association for the Advancement of Science, 1991) pp. 155-167.

24. John Jankowski, "National Patterns of R&D Resources: 1990" NSF 90-316 (Washington DC: National Science Foundation, 1990).

achieved what might be called saturation."[25] Susan Cozzens and others have called attention to "the research system in transition," emphasizing the possibility of "steady state science" without growth.[26] As industries near saturation, there are usually bloody competitions, violent fluctuations, and reorganization. In what respects should the product and organizational life cycle of science and academia be radically different from banking or electric power or other industries?

There are numerous indicators that the world economy is again in a "season of saturations."[27] During the last great saturation in the 1930s, a new order was established in world science, with leadership shifting from Europe to America. Saturation brings death and disappearance for some, but more importantly it signals the beginning of a period for new and exciting tactics in which organizations operate with quite new ground rules in order to survive and grow again.[28]

My guess is that in the next decade or two the reorganization of science and higher education will be dramatic at the national level and the international as well. There will be bankruptcies, condensation, mergers, and acquisitions, perhaps culminating in a move toward integration in the form of regional and global universities, at least for an elite fraction of the population of institutions. Companies such as IBM already operate their research as an integrated network, though the labs are distributed from Tokyo to Zurich to New York and California. We will begin to see more formal international alliances between leading research institutions, designed to accomodate the realities of the invisible colleges that already exist. There can be an international "Ivy League" as well as individual multinational universities. American universities, uncontrolled by ministries of education and already used to the heat of the marketplace, seem most prepared to seize opportunities for globalization.

25. Frederick Seitz, "Some Personal Observations on the Aftermath of the Disturbances", Minerva v. 24 (Spring 1986), p. 130.

26. S.E. Cozzens, P. Healey, A. Rip, and J. Ziman, (eds.), The Research System in Transition (Dordrecht, Kluwer, 1990).

27. See Arnulf Grubler, "Diffusion: Long-term patterns and discontinuities", pp. 451-482, and Nebojsa Nakicenovic, "Diffusion of pervasive systems: A case of transport infrastructures", pp. 483-510, in Nakicenovic and Grubler (eds.), Diffusion of Technologies and Social Behavior (Berlin, Springer, 1991).

28. Price, *op. cit.*, pp. 24-29.

Adjustments will be required by hosting and sponsoring governments. Correspondingly, the universities will have to come to grips more directly with the tensions between world science and national sovereignty, as many private firms already have.[29]

While the focus is on relationships and the pecking order at the top of science and how these may change, one wonders about the rest. Many communities or countries are only in a position similar to that of developing countries in world commodity markets. They can export raw and semi-finished goods, that is, talented individuals ranging from those who are young and undetected to those who are starting to advertise their promise. But, a broad restructuring may offer some new openings on the scientific bandwagon.[30]

6. The U.S. research enterprise works because it lacks a design.

The most successful scientific effort in history by far has occurred in the United States during the past few decades. One has to ask why. To offer a speculation, I return to the initial comments about the nature of the scientific enterprise.

Science is a system developed on the basis of very strong rules, but no objectives. It is open-ended, lacking in the grand design of, say, Catholicism or Marxism. As in evolution itself, new ideas are introduced by mutation, that is to say, they are of stochastic origin. Montroll and Kurt Shuler noted that the word "*re*search" connotes an activity that does not yield its sought goal upon one's first attempt to achieve it.[31] Research is endowed with a random component. The proper description of research must characterize the stochastic process that generates the random component, and the best homes for research will permit or even foster it.[32]

29. One case already is the Massachusetts Institute of Technology. See "The International Relationships of MIT in a Technologically Competitive World", Report of the Faculty Study Group, E. Skolnikoff, chair (Cambridge, MIT, 1991) 41pp.

30. Carolta Perez and Luc Soete, "Catching up in technology: entry barriers and windows of opportunity", in G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete, (eds.), Technical Change and Economic Theory (London, Pinter, 1988) pp. 458-479.

31. Elliott W. Montroll and Kurt E. Shuler, "Dynamics of technological evolution: Random walk model for the research enterprise", Proceedings of the National Academy of Sciences USA, v. 76 (1979) pp. 6030-6034.

32. Classic discussions of whether science of various kinds at various scales can be planned include Michael Polanyi, "The republic of science: Its political and economic theory", Minerva, v. 1 (Autumn 1962) pp. 54-73; Alvin M. Weinberg, "Criteria for scientific choice", Minerva v. 1 (Winter 1963) pp.

Societies with strong and comprehensively expressed objectives may not be able to sustain science, or technology. The Islamic world was the cutting edge of science until past 1000 AD. Then it rejected the windmill and the printing press.

The genius for science of the American system may be that it lacks long-term goals and objectives.[33] This absence of objectives in the United States is, of course, not limited to science. So, the key to success in this country may not lie in a scientific tradition per se, but rather in the prevalence of a more general social Darwinist, entrepreneurial, market-oriented culture.[34] This culture is justly criticized for myopia. However, myopia may in the long run be a trait that is conducive for the evolution of science. Or, said with more sympathy, the cultural conduciveness of America to science is that it supports a heterogeneity of preferences, competencies, and expectations.

Acknowledgement: The author is grateful to Alexander Bearn, William Carey, Rudolf Czelnai, Arnulf Gruebler, Alexander Keynan, Cesare Marchetti, and Walter Rosenblith for helpful discussions and suggestions.

159-171; Alvin M. Weinberg, "Values in science: unity as a criterion for scientific choice", Minerva v. 22 (Spring 1984), pp. 1-12; and Harvey Brooks, "Can science be planned?", in The Government of Science (Cambridge, MIT Press, 1968), chapter 3, pp. 54-80.

33. Anyone who doubts the absence of design should read Bruce L. R. Smith, American Science Policy Since World War II (Washington DC, Brookings, 1990).

34. The culture of course also includes values about individual and social welfare that constructively shape and drive goals. Simple wealth matters, too.

FIGURE CAPTIONS

Figure 1. The fraction of the stable elements discovered. There were 50 elements to be discovered, and they were found as one coherent process. Source: Marchetti, *op. cit.*

Figure 2. Foreign student enrollment in leading host countries plotted as a rank-size (Zipf) distribution. Data are for 1987 unless otherwise indicated. Source of data: see Table 2.

Figure 3. Citations and telephones in diverse nations. The causal path would appear to be that those who talk are cited. After Braun T. and Schubert A., "Scientometric versus socio-economic indicators: scatter plots for 51 countries, 1978-1980", *Scientometrics* 13 (1988) pp. 3-9. SUN is Soviet Union, CHE Switzerland, ESP Spain, etc.

Figure 4. Logistic growth of U.S. universities. Saturation, defined as the time when the population fills more than 90% of the potential calculated ecological niche, has occurred. Creating the Academy was a slow process, requiring about 130 years to go from 10% to 90% saturation. 100% saturation, a state rarely attained and never sustained, is estimated at 545 universities, while 537 claimed to exist in the late 1980s. Source of data: *Webster's Ninth New Collegiate Dictionary* (Springfield, Mass., Merriam, 1987), pp. 1519-1533.

FIGURE 1

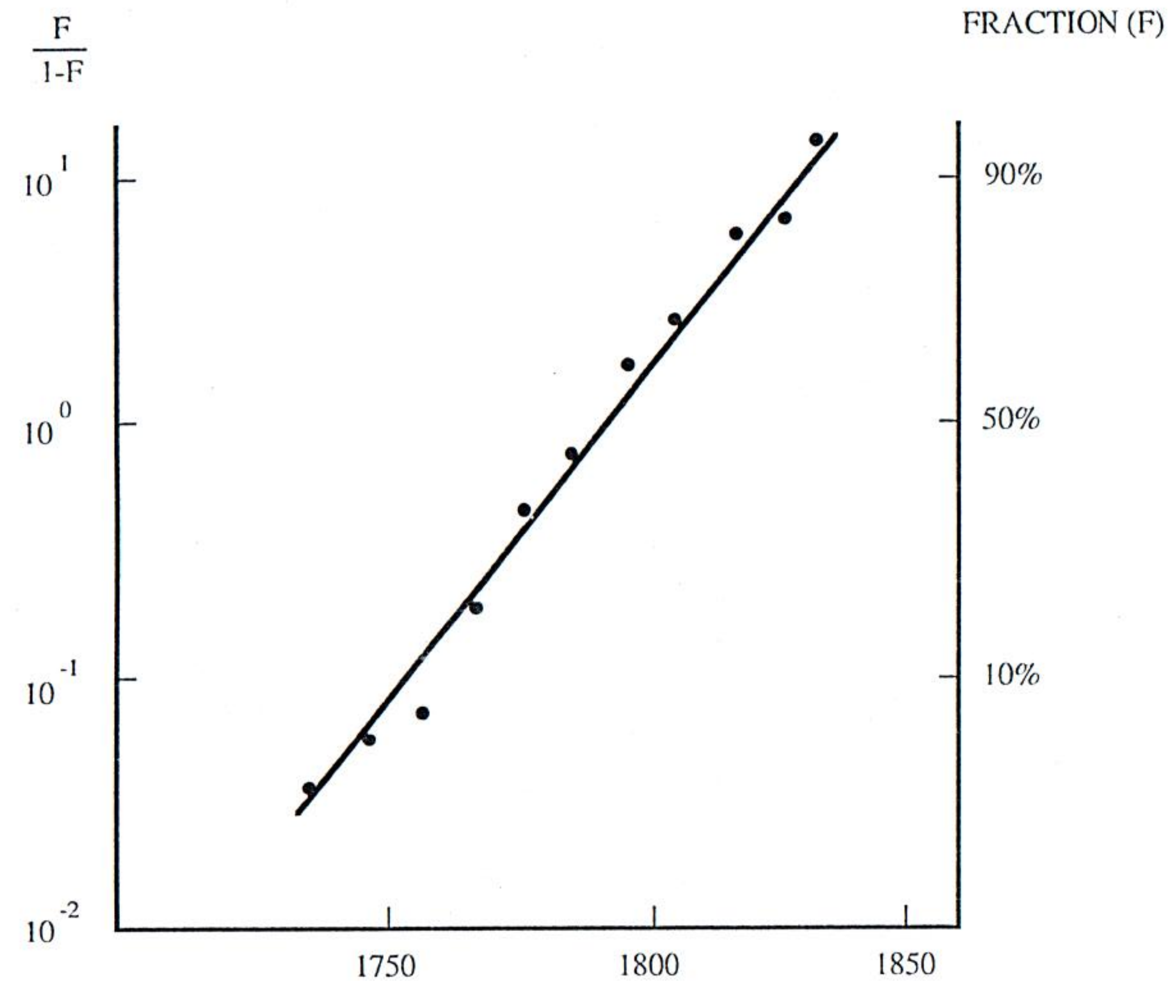
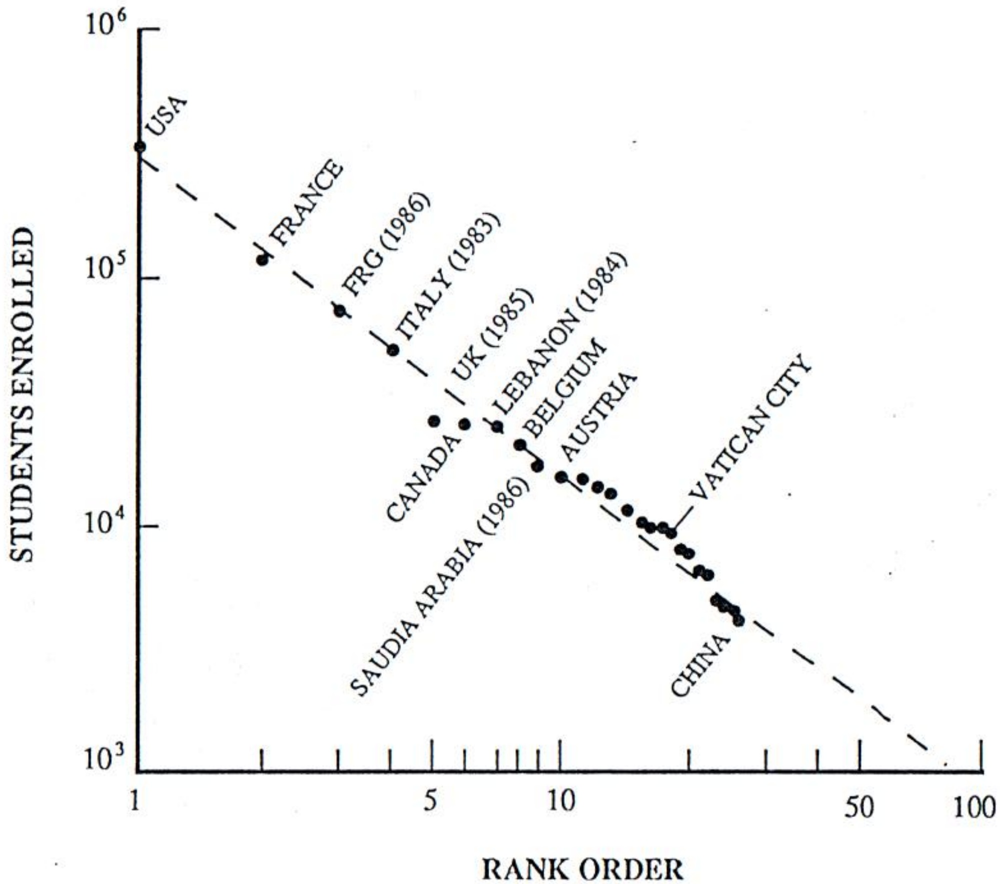
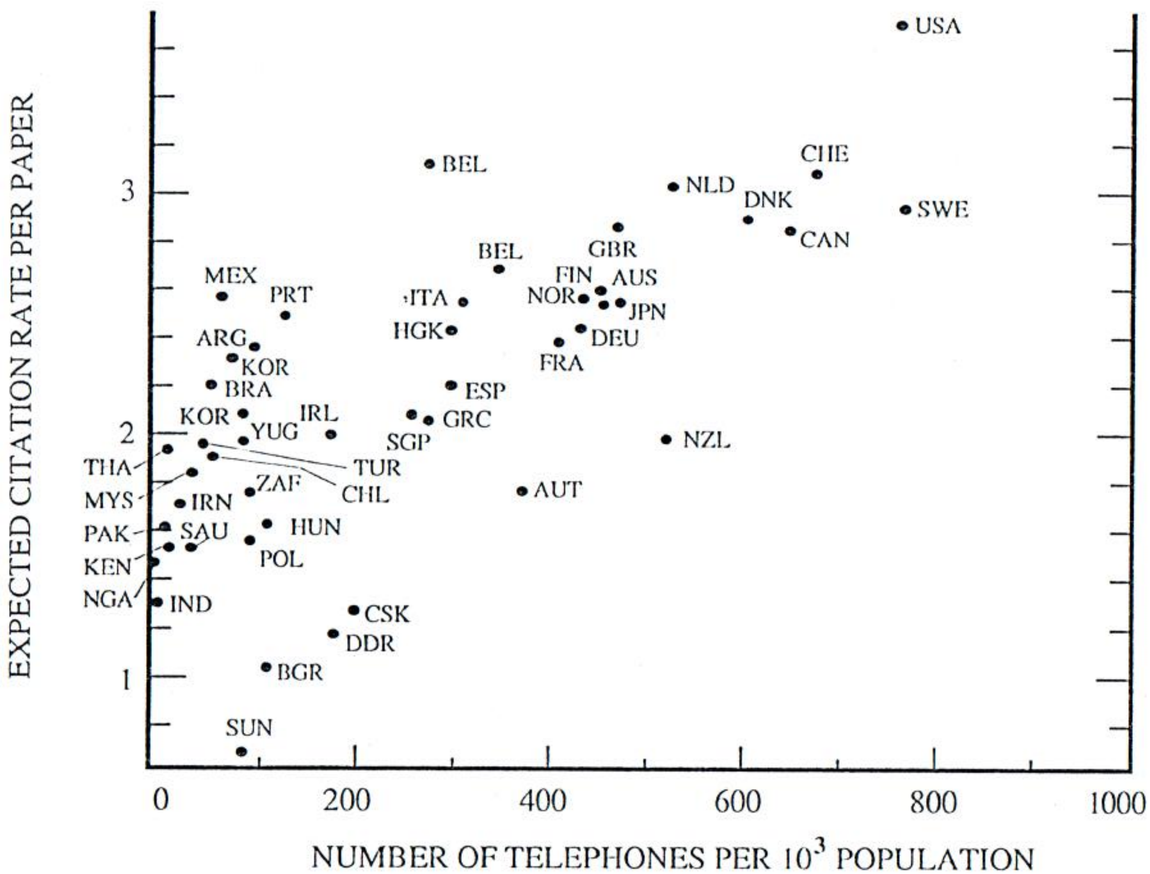


FIGURE 2



STUDENTS ENROLLED
10^6
10^5
10^4
10^3
USA
FRANCE
FRG (1986)
ITALY (1983)
UK (1985)
CANADA
LEBANON (1984)
BELGIUM
AUSTRIA
SAUDIA ARABIA (1986)
VATICAN CITY
CHINA
1
5
10
50
100
RANK ORDER

FIGURE 3


USA
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ARG
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BRA
ESP
KOR
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GRC
YUG
SGP
NZL
THA
TUR
ZAF
CHL
AUT
MYS
IRN
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SAU
HUN
POL
KEN
NGA
IND
CSK
DDR
BGR
SUN
3
2
1
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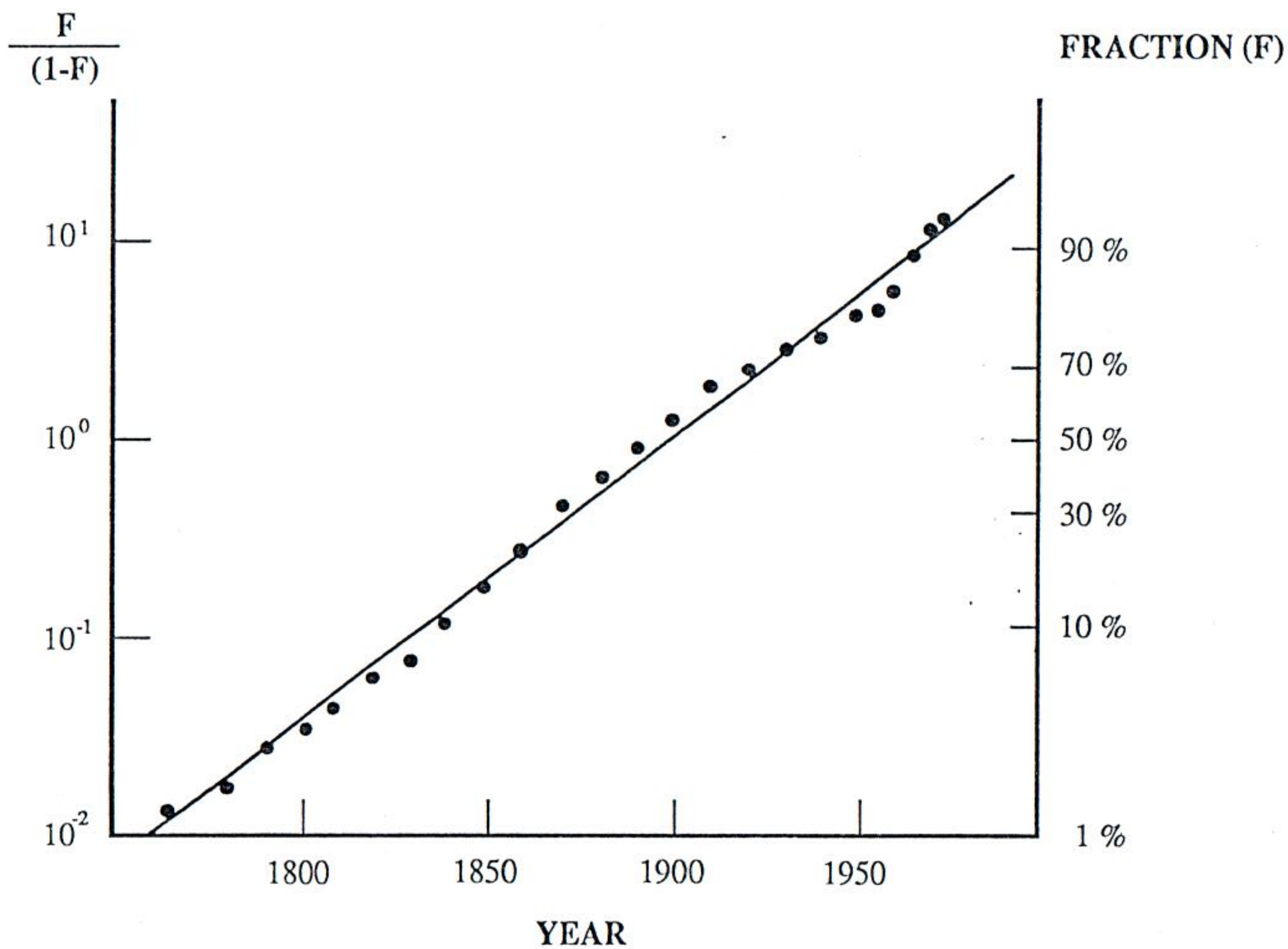
200
400
600
800
1000
EXPECTED CITATION RATE PER PAPER
NUMBER OF TELEPHONES PER 10^3 POPULATION

FIGURE 4



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FRACTION (F)
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YEAR

Hungarian Academy of Sciences - National Science Foundation

Strategies for Support of Scientific Research

Problems of the Transition Period

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