how economics shapes science

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HOW ECONOMICS SHAPES SCIENCE

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For Bill, always for Bill

Preface

THIS IS A BOOK that explores what economics has to do with science. The book also explores how science affects the economy, especially economic growth. Because much of public research occurs at universities and medical schools, especially in the United States, much of the book's focus is on how research is conducted and supported at universities. It is also about the consequences for universities of having the research enterprise—at least in the United States—so fully embedded in the university.

This is not to say that economics has a monopoly when it comes to factors that affect science or in providing a lens for examining science. Other disciplines—and their foci—contribute considerably to the study of science. Sociology, for example, contributes a great deal to the understanding of how science is organized and the reward structure of science. It is also not to say that science is the only factor that contributes to economic growth. Politics and values, for example, clearly play important roles.

Despite the title, the book draws on research and insights from several disciplines. Indeed, one of the factors that led me to study science was the opportunity to indulge my interest in and penchant for reading outside my—sometimes overly narrow—discipline of economics.

Some of the discussion in the book is highly descriptive, summarizing what is known about the various players and factors that influence research behavior and outcomes. This descriptive nature is by design. Throughout my thirty-plus years of studying science, I have been amazed at the number of people who venture to write about science and science policy without understanding the environment in which research takes place. One of my goals in writing this book is to lay out the scientific landscape in what I hope to be a somewhat engaging manner, so that those who wish to continue the study of the economics of science (and I am happy to say there are a growing number) can approach it with a more solid footing. I also hope to offer, from time to time, questions that warrant further research. I do not mean by this that I see myself as the first to examine these issues, and I certainly don't see myself as the most proficient. Far from it: my work—and that of other scholars in the field—owes an enormous debt to the luminaries who began the field a generation (or half a generation) before I began doing research in the area. They include Kenneth Arrow, Paul David, Zvi Griliches, Robert K. Merton, Richard Nelson, and Nathan Rosenberg.

But I did not only—or primarily—write the book for my peers or their students. I also wrote it for the considerable community that works at public research institutions, be they in the United States, China, Europe, or Japan. I also wrote it for policy makers, as well as for members of the general public who share an interest in the workings of public institutions and the study of science. It is my hope that a greater understanding of how economics shapes science can lead to more effective science policy and a better use of resources in the research enterprise.

Abbreviations

AAMC	Associations of American Medical Colleges
AAU	American Association of Universities
ANR	L'Agence nationale de la recherche (France)
APS	Advanced Photon Source, Argonne National Laboratory
ARRA	American Recovery and Reinvestment Act
AUTM	Association of University Technology Managers
BLS	Bureau of Labor Statistics
CERN	European Organization for Nuclear Research
CIS	Community Innovation Surveys (Europe)
CMS	Compact Muon Selanoid (at CERN)
CPS	Current Population Survey
CNRS	Centre national de la recherche scientifique (National Center for Scientific Research, France)
DARPA	Defense Advanced Research Projects Agency (U.S.)
DGF	Direct government funds
DOD	Department of Defense (U.S.)
DOE	Department of Energy (U.S.)
E-ELT	European Extremely Large Telescope
ERC	European Research Council
FIRB	Fund for Investing in Fundamental Research (Italy)
GMT	Giant Magellan Telescope
GRE	Graduate Record Examination
GUF	General university funds
H-1B visa	A nonimmigrant visa that allows U.S. employers to hire noncitizens on a temporary basis in occupations requiring specialized knowledge

hESC	The human embryonic stem cell policy implemented under President George W. Bush in 2001
HGP	Human Genome Project
HHMI	Howard Hughes Medical Institute
ITER	International Thermonuclear Experimental Reactor
LHC	Large Hadron Collider (at CERN)
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NIGMS	National Institutes of General Medical Science
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NRSA	National Research Service Awards
NSCG	National Survey of College Graduates (Census administered; overseen by NSF)
NSF	National Science Foundation
OECD	Organization for Economic Co-operation and Development
OWL	Overwhelmingly Large Telescope
PSI	Protein Structure Initiative (NIH)
R&D	Research and development
RAE	Research Assessment Exercise (U.K.)
REF	Research Excellence Framework (to replace the Research Assessment Exercise, U.K.)
R01	Research project grant awarded by NIH, it is the agency's oldest grant mechanism used by the NIH to support research; generally investigator initiated.
S&E	Science and engineering
SDR	Survey of Doctorate Recipients (NSF-collected data)
SDSS	Sloan Digital Sky Survey
SED	Survey of Earned Doctorates (NSF-collected data)
SEPPS	National S&E PhD & Postdoc Survey
SER-CAT	Southeast Regional Collaborative Access Team
SKA	Square Kilometer Array
SMSA	Standard Metropolitan Statistical Area
Study Section	Scientific review groups at NIH, primarily made up of nongovernment experts
TMT	30-meter telescope
TTO	Technology Transfer Office

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CHAPTER ONE

What Does Economics Have To Do with Science?

THIS IS A BOOK about how economics shapes science as practiced at public research organizations. In the United States these are primarily universities and medical schools. But in Europe and Asia a considerable amount of public research is conducted at research institutes. The book's focus reflects the strong role that public research organizations play in creating knowledge. In the United States, for example, approximately 75 percent of all articles published in scientific journals are written by scientists and engineers working at universities and medical schools.[1] Of equal importance, almost 60 percent of basic research is conducted at universities and medical schools.[2]

What does economics have to do with science? Plenty, it turns out. Economics, after all, is the study of incentives and costs, of how scarce resources are allocated across competing wants and needs. Science costs money and incentives play a key role in science. At the extreme end of the cost spectrum is the Large Hadron Collider (LHC), which came on line (for the second time) in the fall of 2009 and cost approximately $8 billion (U.S.).[3] But there are numerous other examples. The personnel costs of a typical university lab with eight researchers is about $350,000 after fringe benefits but before taking into account the cost of the principal investigator's time or indirect costs.[4] Public research organizations routinely spend large sums of money building and maintaining research facilities and large sums of money on start-up packages for faculty hired to work in the new facilities. In recent years, these packages have become sufficiently large that a university routinely spends four to five times as much on the package as on the faculty member's annual salary.[5] Even mice, the ubiquitous research animal, can cost a substantial amount to buy and keep. Custom-made mice, designed with a predisposition to a specific disease or problem, such as diabetes, Alzheimer's disease, or obesity, can cost in the neighborhood of $3,500. The daily cost of keeping a mouse is around $0.18. Sounds cheap—until one realizes that some researchers keep a sufficient number of animals that the annual budget for mouse upkeep can be in excess of $200,000.[6]

The amount of money spent on scientific research in the public sector is substantial. The United States spends between 0.3 and 0.4 percent of its gross domestic product (GDP) on research and development at universities and medical schools. This represented almost $55 billion dollars in 2009 or approximately $170 per person.[7] While most other countries spend a smaller percent of GDP, several countries, including Sweden, Finland, Denmark, and Canada, spend a considerably higher percentage of their GDP on research and development at universities and medical schools.[8]

Costs

Costs affect the way research is conducted. Costs were a major factor in Europe's decision to settle for building the Exceedingly Large Telescope (E-ELT) rather than the Overwhelmingly Large Telescope (OWL)—with its much larger mirror—as originally planned.[9] Costs can derail large projects or at best delay them. Original plans called for the multi-billion-euro fusion reactor ITER to begin operation in 2016. Now the earliest that ITER can become operational is in 2018—and if it does become operational at that time, it will be a stripped-down version; additional components will be needed for power-producing plasmas.[10] Along the way, the costs of constructing ITER keep rising. New cost calculations made public in the spring of 2010, for example, suggest that Europe's contribution will be 2.7 times greater than the amount originally estimated; that of the United States will be about 2.2 times greater.[11]

Costs play a role in determining whether researchers work with male mice or female mice (females, it turns out, can be more expensive), whether principal investigators staff their labs with postdoctoral fellows (postdocs) or graduate students, and why faculty prefer to staff labs with "temporary" workers, be they graduate students, postdocs, or staff scientists, rather than with permanent staff. High electricity costs dictate that the LHC not run in the winter but rather during the rest of the year when electricity is considerably less expensive.[12] Costs are a major factor in determining what equipment at a university will be "core" and shared across labs rather than belonging to a specific lab. Costs—and the desire to minimize risk—have played a major role in the decision of universities to substitute non-tenure-track faculty for tenure-track faculty.

Costs affect the pace of discovery. When the human genome project began in 1990, it cost more than $10.00 to sequence a base pair. Sequencing costs fell rapidly, hitting less than a penny a base pair by 2007. That is now ancient history: since then, new generations of sequencing technology have been developed that have lowered the cost dramatically. Before this book sees the light of day, it is possible that the Archon X Prize for Genomics will be awarded to the first group to "build a device and use it to sequence 100 human genomes within 10 days or less . . . at a recurring cost of no more than $10,000 per genome."[13]

Incentives

Universities respond to incentives. In the early 2000s, universities went on an unprecedented building spree, developing new research facilities in the biomedical sciences. Within less than five years, construction and renovation costs for biomedical research facilities accelerated from $348 million annually to $1.1 billion annually at U.S. medical schools. (All figures are in 1990-adjusted dollars.)[14] The reason: the budget for the National Institutes of Health, the major funder of research in the biomedical sciences, doubled between 1998 and 2003, opening a panoply of what universities perceived to be new opportunities to expand their research efforts and, in the process, enhance their reputation. It was not the first time that U.S. medical schools responded to financial incentives. The substantial expansion of medical colleges over the past 40 years is widely attributed to the adoption of Medicare and Medicaid in 1965, which provided university medical schools with a new source of revenue.

Scientists and engineers respond to incentives as well. Money, despite statements to the contrary, is not unimportant. Actions speak louder than words. Scientists routinely move to take more lucrative-paying positions. A number of public universities have lost faculty in recent years because private universities, especially before the financial collapse of 2008, could often offer much more lucrative packages than their public sisters. Indeed, in the 2009–2010 academic year, only one public institution (UCLA) was among the top twenty research universities in terms of salaries paid to full professors—and it held the 20th position, paying $43,000 less than top-paying Harvard. Phones began to ring at Berkeley in 2009 soon after the California system imposed a substantial pay cut on its faculty. Full professors at Berkeley already earned about 25 percent less than their peers at Harvard and Columbia. Now they would earn even less.[15]

Scientists respond to incentives in choosing where to submit articles for publications. The number of articles submitted to the journal *Science,* for example, is significantly related to whether the scientist's home country offers a bonus or other monetary reward for publishing in the journal.[16] In some instances, the bonuses can be quite large—on the order of 20 to 30 percent of the scientist's base salary.

Financial incentives encourage university faculty to start new companies based on their research. In recent years, a number of scientists have made substantial sums of money by forming start-up companies or by receiving royalties from universities licensing patents on which they are an inventor. David Sinclair, a Harvard professor and founder of Sirtris Pharmaceuticals, received more than $3.4 million for the shares he held in Sirtris when Glaxo acquired the company in 2008. Robert Tjian received millions in 2004 when Tularik, the company he cofounded when he was a faculty member at the University of California–Berkeley, was sold to Amgen for $1.3 billion. Stephen Hsu, a professor of physics at the University of Oregon, received a substantial amount when Symantec paid $26 million in cash in 2003 for one of two software companies he had founded. László Z. Bitó, whose work led to the invention of the drug Xalantan for the treatment of glaucoma, has earned several million a year from the patent that Columbia University held on the drug. The patent is due to expire in 2011.[17] In 2005, three researchers at Emory University divided more than $200 million when Emory sold its royalty interest in emtricitabine, used in the treatment of human immunodeficiency virus (HIV), to Gilead Sciences and Royalty Pharma. Although rare, events such as these occur with sufficient frequency that, on the campus of almost every research university in the United States, two or three faculty members have become wealthy as a result of their research.

Neither do scientists, especially highly productive scientists, receive a pauper's pay. Full professors at the top of their game employed at private research universities in math earned an annualized salary of $180,000 a year in 2006 in the United States. Comparably ranked full professors at public universities earned $150,000. Those in the biological sciences earned $277,700 at private research universities; those at public universities earned $200,000.[18] It is no wonder that the United States has been a magnet for highly productive European scientists. Not only has there been