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An Overview of Science and Cents: Exploring the Economics of Biotechnology

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This article provides an overview of the conference "Science and Cents: Exploring the Economics of Biotechnology," hosted by the Federal Reserve Bank of Dallas in April 2002. The conference brought together distinguished experts who spoke about economic and scientific issues surrounding biotechnology. In this article, John Duca and Mine Yücel summarize the presentations made at the conference. Topics covered include funding, location, and legal issues confronting the biotech industry. The interdisciplinary nature of biotech research, along with recent advances and future applications, is also discussed.

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The recent rapid pace of discovery in life sciences raises a host of economic issues. Advances in biotechnology will likely affect the well-being of people throughout the world for many years to come. While we can only speculate on the specific form of advances that will be made, we can address many of the economic questions raised by developments in the life sciences. What potential economic benefits does biotechnology offer? How is the emergence of the biotech industry similar to the infancy of now-established industries? Where do biotech firms locate? How will biotech research be financed and what are the funding hurdles? What legal and regulatory issues will confront the industry?

To address these and other important questions surrounding the development of biotechnology, the Federal Reserve Bank of Dallas hosted the conference "Science and Cents: Exploring the Economics of Biotechnology" on April 19, 2002. The conference brought together distinguished experts who spoke about economic and scientific issues surrounding biotechnology.

This article highlights the main points and summarizes the presentations made at the conference. Conference presentations can be viewed at www.dallasfed.org/htm/dallas/events/archive/02biotech.html.

The first session provided an economic perspective on the biotech revolution, with one speaker discussing how this revolution compares with other periods of major technological change and another quantifying some of the benefits from the pharmaceutical sector, the most established biotech-related industry. Another session examined the difficulties biotech firms encounter in capturing the economic value from expensive and lengthy research. Reflecting the changing nature of research in the life sciences, two speakers discussed how and why two important sources of financing—venture capital and public funding—have evolved in recent decades. Two presentations described the nature of advances in the life sciences, with one providing an overview of basic biotech research and the other focusing on likely areas of future discoveries. The final session focused on the factors driving the location of biotech research and what regions can do to foster such activity. Throughout this overview, we use the term biotechnology in a broad sense, as "the application of the principles of engineering and technology to the life sciences" (*American Heritage Dictionary*). The technical terms used in this article are defined in the glossary. We conclude with a discussion of the broad economic implications of biotechnology.

AN ECONOMIC PERSPECTIVE ON THE BIOTECH REVOLUTION

In providing an economic perspective on whether biotech advances will kindle a new industrial revolution, the opening speaker, Professor Michael Darby of the University of California at Los Angeles (UCLA), drew on his paper to be published in 2003 in *Economic Inquiry* (Darby and Zucker, forthcoming). He emphasized that biotech research appears to represent a major, metamorphic revolution in which new industries are created, rather than incremental progress that perfects existing products. As with earlier metamorphic revolutions, a lack of data and history hampers our ability to gauge biotech's importance.

Another characteristic of metamorphic revolutions is that many new firms enter an emerging industry that has few or no incumbents, but just a fraction of these new firms succeed and thrive. With the biotech sector still in its formative stage, the number of biotech firms will probably rise before

declining during the shake-out phase that often occurs in the development of an industry. Nevertheless, as Darby stressed, many of the economic benefits to society accrue during the consolidation and maturation stages of an industry's life cycle.

Darby also noted that biotech research is hard to imitate and has a natural excludability, in that innovators have a profound advantage over imitators in creating successful applications from the research. In particular, success in biotech is highly correlated with links to star scientists at universities, and these links are empirically the most important factors affecting the probability of success. For this reason, Darby stressed that drawing top scientific talent and expanding university research are critical to increasing biotech activity in areas like Texas.

Columbia University Professor Frank Lichtenberg reviewed some of the limited evidence on biotech's promise from studies of the economic benefits of drugs, arguably the most established biotech-related industry (Lichtenberg 2002). These benefits include lower overall medical costs, higher productivity, and increased longevity. Recently, much attention has been paid to rising drug costs. But, as French economist Frédéric Bastiat emphasized long ago, economists should consider what is unseen, not just what is seen.

For example, with respect to medical costs, what is seen—the $18 increase in the cost of new drugs per person—is more than offset by what is unseen—a $129 estimated decline in net, nondrug medical costs.[1] These savings stem mainly from more effective new drugs eliminating or shortening hospital stays.

In addition to these cost savings, there are gains from boosting worker productivity. In particular, Lichtenberg's econometric studies estimate that for every $34 employers and employees spend on prescriptions, the cost of sick days falls by roughly $40. Additional gains of $112 arise because pharmaceuticals improve the on-the-job performance of those already working and enable the disabled to enter the workforce. Together, these estimates imply that $34 spent on prescriptions boosts output by roughly $152.

Another major benefit from pharmaceuticals is increased life expectancy. For example, between 1979 and 1997, the United States spent an average of $13 billion a year to develop new drugs that collectively boosted longevity by nearly five months, according to research. As Lichtenberg noted, by some economic yardsticks, this increase in life expectancy is worth about $120 billion a year. Other data linking pharmaceutical advances to longevity include time-series evidence of a positive correlation between new drug approvals and life expectancy and between HIV drug approvals and reductions in HIV-related deaths. Lichtenberg cited the latter as evidence for the positive impact of the Orphan Drug Act of 1983, which reduced the hurdles for developing treatments or cures for certain classes of diseases.

Of course, these findings about the benefits of pharmaceuticals are based on past experience, and there is no guarantee that future advances will pay off as handsomely. Nevertheless, the track record for new pharmaceuticals is impressive and should be considered when evaluating policy proposals that affect the incentives for innovation. This caution also

[1] In his paper, Lichtenberg (2002) mentions $71 in net, nondrug medical cost savings. In his more up-to-date conference presentation, he cited a larger $129 figure from revised estimates.

applies to other biotech-related industries, especially in light of the key role that highly risky research plays in biotech advances, as illustrated by other conference speakers.

LEGAL AND REGULATORY ISSUES

The speakers in this session offered perspective on the legal and regulatory issues surrounding biotechnology. Duke University Professor Henry Grabowski emphasized that two of the biggest hurdles for drug research are high risk and high costs (Grabowski 2002). Professor Rebecca Eisenberg of the University of Michigan stressed the importance of patent strategies to capture the returns to R&D in biotech (Eisenberg 2002).

The High-Risk and High-Cost Hurdles to R&D

Grabowski noted that only 22 percent of drugs that enter clinical trials eventually receive FDA approval. Furthermore, even among approved drugs there are few winners, as evidenced by three facts. First, only one-third of approved pharmaceuticals cover out-of-pocket expenses, which are not adjusted for risk or time. Second, the 20 percent of new drugs with the highest revenues as a group outsell the remaining 80 percent combined. Third, earnings at large pharmaceutical companies are mainly from a few drugs, in some cases just one or two.

Another important hurdle for drug research is that R&D costs are high and are rising quickly. Grabowski estimated that it costs about $400 million, on average, in out-of-pocket expenses to develop a new drug. In addition, along with the high risks, there is a lengthy ten- to twelve-year gestation period to develop a drug. Adjusting out-of-pocket costs for risk and time, Grabowski and his fellow researchers estimate that it costs roughly $800 million to develop a new drug.

He also noted that R&D costs have generally increased more rapidly than inflation. Older data show that clinical costs rose 12 percent faster than inflation during the 1980s, after exceeding inflation by 6 percent per year in the 1970s. Despite a slowing of nonclinical cost increases, overall R&D cost increases outpaced overall inflation by roughly 7.5 percentage points per year in the 1980s, after outpacing inflation by 7 percent per year in the 1970s. Incomplete data indicate that this pattern likely continued in the 1990s. Especially noteworthy is the doubling of the length of clinical trials from 33 months in the 1980s to 67 months today.

In light of the high and rising costs of biotech R&D, inventors need to capture enough of the economic returns to make their investment worthwhile. In general, biotech firms defend their intellectual property through formal patents and an evolving set of legal strategies.

Devising appropriate patent protections is a balancing act. Because R&D costs and risks are high, patents need to be long enough for firms to recoup their risk-adjusted R&D costs without unduly dissuading patent holders or their potential competitors from conducting more research. Grabowski pointed out that patents provide outsiders with information about new discoveries that, in turn, spurs more research. As Grabowski emphasized, patents are the most important factor affecting R&D decisions, according to surveys of biotech firms.

The economics of developing new drugs differs from that of developing generic versions of existing drugs. First, the out-of-pocket costs of developing a generic are only $1 million to $2 million, far below the $400 million for developing a new drug. Second, the clinical success rate for

generics is 90 to 100 percent, four to five times that of new drugs. Finally, it takes only one to two years to develop a generic versus ten to twelve years for a new drug.

Capturing the Returns to Research

Another impediment to capturing the returns to biotech R&D is that earlier established patent practices may not be suitable for the fast-changing biotech landscape because it takes a while for the law to catch up with science. As Eisenberg stressed, the rapid development of biotech science has led to a rapid evolution in patent strategies. Today, the value of an innovation is not in the direct production of therapeutic or diagnostic products but in the use of that invention in research and product development. Moreover, it is not obvious how to use patents to capture the value of these research technologies. For this reason, many innovators pursue reach-through strategies to claim a share of the value of future products. These strategies entail innovators and their start-up firms (upstream firms) reaching into future revenues from the end products that are developed using their inventions. Not surprisingly, the established pharmaceutical and biotech firms (downstream firms) strongly oppose these strategies.

Eisenberg listed three main strategies for capturing the value of research in biotech: reach-through licensing, reach-through remedy, and reach-through claiming. *Reach-through licensing* refers to a patent holder restricting access to a patented research-enabling technology to users that agree, as a term of the license, to share a portion of the revenue or profits from future products.

A *reach-through remedy* is an ex post damage award for infringement that is measured as a reach-through royalty on sales of products developed through unlicensed use of a research tool. Under this strategy, researchers who use an innovation without permission are only liable for reach-through royalties if their research yields a successful product.

Reach-through claiming is an approach that depends more on patents. In this case, patents are issued that are broad enough to cover future discoveries enabled by prior inventions. If the patent covers future products, there is no need to get the user to agree to pay royalties for future products. The primary obstacle to reach-through claiming arises from the disclosure requirements of patent law. The patent-seeker must supply information about the structure of products covered by the claim and not just their function. In addition, a successful patent application must demonstrate that the invention is necessary to the successful development of the products in question. Providing such a description is sometimes impossible because the innovator does not know beforehand what particular molecular structures will be developed using the patented invention.

Eisenberg discussed the pros and cons of reach-through strategies. One argument against such strategies is that they overcompensate those who rest on their laurels at the expense of those who carry the research forward. A second objection is that such strategies give innovators too much control over future research, which could inhibit innovation. Another argument is that although there have been many path-breaking discoveries in biotech, government funding has paid for them, through such agencies as the National Institutes of Health (NIH). Hence, reach-through strategies are not needed to motivate and reward this basic research.

The arguments in favor of reach-through strategies contrast sharply with this last objection. One position favoring reach-through practices is that they enable researchers to capture the value that their discov-

eries contribute to future research. It is argued that upstream research is riskier and less likely to have high stand-alone value than downstream research, which is more closely related to marketable products. In the past three decades the pharmaceutical business has been very profitable, while other biotech-related industries have mostly been unprofitable. Proponents of reach-through strategies maintain that this pattern occurs because biotech innovators cannot recapture the value that their inventions have contributed to the pharmaceutical industry.

Eisenberg argued that reach-through strategies help with the valuation and financing of biotech research and tools. In the absence of reach-through agreements, firms using innovations would pay up-front fees for using inventions. Such pay-as-you-go practices would suit pharmaceutical firms well because they have plenty of cash and would rather pay a relatively small amount up front. However, reach-through agreements allow upstream and downstream biotech firms and universities to form joint ventures, sharing risks without draining cash at the research stage.

Eisenberg concluded by observing that patent law has a tradition of limiting protection to actual accomplishments and future variations that arise from work that is routine and predictable. She believes this is a sensible limitation that guides patent examiners away from acceding to patent claims that would unreasonably cover future research. Eisenberg believes there are good reasons for permitting prior innovators to capture a fair share of the value their discoveries contribute to subsequent downstream innovation. Nevertheless, she is generally more comfortable with strategies in which licenses are negotiated in the market than with strategies negotiated in the course of patent prosecution.

FUNDING BIOTECH RESEARCH

Funding expensive research that has highly risky returns is another hurdle for biotech. Aside from pharmaceutical research, which is often done by established companies, much biotech research is conducted by new firms partly funded by venture capitalists and other private equity investors. Much of their applied research is based on basic or generic research that is either publicly funded or conducted at publicly funded universities and other institutions. For some perspective on the relative importance of funding sources, note that in 1999, NIH outlays (including non-R&D expenses) amounted to $13.8 billion, while private R&D outlays on health research totaled $11 billion. The latter figure excludes research at universities but includes expenditures by large pharmaceutical firms and much of the $2.2 billion in venture capital invested that year. Given that future biotech research is likely to branch out beyond old-style pharmaceutical R&D, the session on funding biotech research focused on the roles played by venture capital and the public sector.

Venture Capital: Its Role and Prospects

Timothy Howe, founding partner of a venture capital firm, emphasized several points about the role of venture capitalists (Howe 2002). First, biotech venture capital firms combine managerial with scientific talent in picking, funding, advising, and even managing biotech start-ups. By performing these roles, venture firms enable scientists in start-ups to focus on inventing. A second point is that most venture firms directly invest in young companies, without intermediaries. Third, the distribution of returns is highly skewed, with few big winners.

Another important aspect of venture capital firms it that they have an incentive to diversify their investments across different solutions to medical problems, which can be found not only in biotechnology but also in medical devices and service firms. Finally, the rising share of GDP devoted to health and the related aging of the baby boom generation offers big incentives for venture capital firms to enter the medical arena. Howe stressed that the population age 55 and older is projected to grow at a pace five times that of younger cohorts. This is important because the older group spends much more on health; for example, people 55 and over spend an average of three times more days per year in the hospital than do younger people.

Howe discussed two general opportunities for venture capital. The first concerns a shift in the type of science funded. Venture firms focused on funding conventional drug development in the 1980s and genomics in the 1990s. Looking ahead, venture firms are likely to fund projects in proteomics, the study of how human genes produce proteins that act upon the body. As Howe stressed, the human genome project has identified over 35,000 genes that have a role in producing proteins, but current drugs work on only 400 proteins. Although much more complicated than genomics, proteomics offers the benefits of customizing drugs. Proteomic advances would enable physicians to tailor treatments to a patient's genetic makeup, appropriately affecting the body's output of proteins and thereby reducing toxic side effects.

Howe sees the other big opportunity in the maturation of the oldest, most established biotech-related industry, pharmaceuticals, from a vertically integrated industry to a horizontally organized one. Building upon insights from Andrew Grove's (1996) book, *Only the Paranoid Survive*, Howe likened the drug industry to the computer industry of twenty years ago, which was dominated by big, vertically integrated firms like IBM, DEC, Sperry-Univac, and Wang. Two decades ago, each of those firms did it all—manufacturing chips and computers, designing application systems and software, and selling and distributing products. Since then, as Grove points out, the computer industry has been transformed into a horizontally integrated industry with a few big players dominating each particular segment. For example, leaders have arisen within particular segments of the computer industry, including Intel in chips, Dell and the newly merged Hewlett-Packard and Compaq in personal computers, and Microsoft in operating systems and software. Similarly, Howe sees the pharmaceutical industry becoming dominated by a few major players in distinct horizontal segments, such as research and target discovery, clinical testing, and distribution.

The Public-Sector Role in Funding Biotech Research

Another important source of funding for biotech research is government. Wake Forest University Professor Michael Lawlor emphasized that the benefits resulting from certain types of research warrant some form of public subsidy (Lawlor 2002). The returns to R&D have historically exceeded those on other investments. At the macroeconomic level, U.S. growth has arisen more from innovation than directly from growth in the capital stock or labor force. But if the returns were so large, why hasn't there been more investment, which would drive the returns down to normal? One reason is that there are high-risk premiums on biotechnology investments because there are few winners. Another is that the economic value generated by inventors' discoveries spills over to others. Indeed, most microeconomic studies find that inventors recoup only a part of the economic value of their research.

Lawlor discussed three public policy options for addressing underinvestment, along with the drawbacks of each. An industrial policy, which invests directly in the research and production of goods, poses challenges associated with state enterprises operating in a dynamic area. Tax credits sound appealing, but it is hard to prevent firms from reclassifying other expenses as R&D, thereby diluting the effectiveness of a tax cut. The final option is direct funding of R&D, but this runs the risk of project selection being politicized or not accountable enough.

According to Lawlor, a complex, direct-funding approach has evolved in this country, helping make the United States the world leader in biotech research. He noted that the public role in R&D surged during World War II when the federal government boosted its direct funding of research, with projects ranging from developing the atomic bomb to perfecting the mass production of penicillin. After the war, federal funding for health research focused on basic research, driven by curiosity and Cold War concern. This effort was linked to security and politics and was less directed at applied research having commercial applications.

During the early years of the Cold War, NIH funding expanded greatly. NIH is a hybrid institution whose social mission is set and funded from the top but whose operations are largely decentralized. Congress sets NIH's budget, but scientists choose which research projects to fund in a careful peer-review process. This allows for accountability, flexibility, and competition.

Lawlor stressed that in recent decades, public funding of R&D has evolved in response to the increased complexity of research, which is more interdisciplinary and which has blurred the lines between basic and applied research. In particular, new technologies are now often applied in many fields and are therefore referred to as *generic technologies*.

Recognizing these trends and seeking to encourage the transfer of federally funded research to the private sector, Congress passed legislation in the mid-1980s that created cooperative research and development agreements (CRADAs). These CRADAs allow federally funded laboratories to establish profitable research links with commercial firms that draw on lab research findings. In addition, in 1996 the Department of Commerce instituted the advanced technology program, which directly funds research into developing new generic processes for high-tech industries. This program has been instrumental in speeding up and reducing the financial risk of research in stem cells, regenerating human tissue, and treating diabetes.

THE INTERDISCIPLINARY NATURE OF BIOTECH RESEARCH

Given the importance of scientific breakthroughs to the development of biotech industries, two of the conference presentations focused on the complex, interdisciplinary nature of biotechnology research. Rice University President Malcolm Gillis focused on the critical roles nanotechnology and bioinformatics will likely play in advances in biotech (Gillis 2002). Tom Caskey, head of a biotech venture capital fund, stressed how innovations from several areas of science are being used in the new field of proteomics (Caskey 2002).

The Future of New Technologies Related to Biotechnology

As Gillis noted, development of the biotech industry will fuel growth in dozens of other industries and thereby foster overall economic growth. He predicted that biotech will grow ever faster as applications extend beyond pharmaceuticals and agriculture to nutrition, energy production, tissue engi-

neering, and gene therapy. Moreover, technology-driven progress rarely results from a single invention or a single set of technologies. Instead, rapid growth is generally caused by the interplay of a collection of discoveries in different fields over a long period. Biotech progress is propelled by a synthesis of new technologies, not only from the biosciences but also from other sciences, such as information technology and nanotechnology.

In discussing biotech and infotech, Gillis noted that mathematical, statistical, and computer methods are indispensable to analyzing biological, biochemical, and biophysical data. The techniques developed in this field of bioinformatics weave together biology and information science. Computational physiology is one of several bioinformatics subfields moving ahead at high speed. One example of a product in computational physiology is the virtual heart, which required the translation of thousands of mathematical equations and data points into a computer simulation of a heart.

Another subfield is computational cancer research, which deals with an overwhelming number of possible combinations and permutations of cancer-causing mutations, a problem bioinformatics is well suited to handle. Yet another subfield is pharmacogenomics, which combines computational sciences with biochemistry and pharmacology and offers the potential for customizing drugs to the genetic makeup of individuals and developing new insights into disease prevention.

Gillis also described the growing research in the interface between biotechnology and nanotechnology. Nanotechnology is the application of findings of nanoscale science, which deals with objects as small as a nanometer (one-billionth of a meter). To provide perspective, Gillis noted that a typical thumb is 30 million nanometers wide.

Biomedical applications of nanotech were given a large boost when Rice University researchers discovered two geodesic-shaped and very stable nanoparticles: carbon 60 (also called Buckyball after Buckminster Fuller, an inventor, philosopher, and architect who experimented with geodesic shapes) and carbon 70 (another so-called Fullerene). The surfaces of the nanoparticles are extremely suitable for attaching therapeutic compounds. The particles can then deliver the drugs to specifically targeted sites in the body. For example, the particle's shape facilitates easy binding with HIV-infected cells.

Another example of a nanoparticle is a gold nanoshell (a gold surface adhered to a silica core). Rice University and M.D. Anderson Hospital are working together on the diagnosis and treatment of cancer using gold nanoshells. Because of their small size, nanoshells pass easily through the circulatory system, which can deliver them to individual tumors. Physicians can then direct infrared light onto the tumors, which heats the nanoshells as high as 55 degrees C (131 degrees F), enough to destroy the cancer cells but leave healthy cells intact.

Gillis also spoke of developments in the design and use of nanomaterials for biomedical engineering. The most notable of these is tissue engineering, which focuses on the development of biological substitutes to restore, maintain, or improve tissue function. Examples include bone and organ replacement and the development of blood substitutes. These innovations require several types of new technology. In particular, nanotechnology is used to create the tissue analogs to grow skin, bone, and organs. Engineering and computational skills are needed to construct the mathematical models and create images used in the bioscientists' work.

Gillis forecasted that biotech would be the principal arena for an ongoing, far-reaching synthesis in science and engineering. He noted that

the interplay between bio-, nano-, and information technology will have a striking impact on health maintenance, diagnosis, and treatment. He predicted that biotech will provide an array of products and services to fuel sharp increases in living standards in the twenty-first century.

The Convergence of New Technologies in Biotechnology Research

Caskey discussed the convergence of new technologies that enable a new industrial approach to health products. He noted that many different technologies in chemistry and biology are being combined to develop new therapeutics. For example, recombinant DNA technology and genome sequencing have helped researchers understand the structure of the HIV virus and have aided work on developing vaccines and treatments for HIV. More broadly, advances in recombinant DNA technology, the study of cell growth, proteomics, and bioinformatics contribute to the development of proteins that can be used to treat or prevent disease. Drawing on huge accumulated databases about protein structure and behavior, scientists can now predict how proteins will function. Such research has led to the development of replacement proteins, such as insulin and interferon, and of inhibitory proteins, such as monoclonal antibodies. The study of human genetics and the discovery of disease–gene associations have also benefited research into drugs for Alzheimer's disease.

Caskey also briefly discussed the financial drivers of the biotech industry, pointing out that the NIH and large pharmaceutical firms are the main source of funds, with a small amount coming from venture capital. He then spoke of some developments in Texas and shared his ideas about what is needed to foster biotech in the state. These include increasing the number of new firms, improving the recruitment of pharmaceutical and large biotech firms to the region, and enabling in-state and out-of-state firms to consolidate. Achieving these goals requires improving business plans and management, recruiting more biotech talent, bolstering venture capital funding, and improving state and regional incentives, Caskey concluded.

THE LOCAL DETERMINANTS OF BIOTECH

The last session of the conference concentrated on the local determinants of biotechnology. Dennis Stone, vice president for technology development at the University of Texas Southwestern Medical Center in Dallas (UTSW), focused on biotech activity in the Dallas/Fort Worth metro area. UCLA Professor Lynne Zucker discussed what factors have affected the location of biotech firms across the United States.

The University's Role in Biotech Development in D/FW

Stone emphasized the role of the university in the biotech industry, focusing on developments in the Dallas/Fort Worth metro area. Unlike the information technology industries, biotech depends on the university as a technology source. Stone illustrated the scope of the University of Texas' biotech presence, using life science research expenditures and patent data (Stone 2002). In 2000, Texas was third in the nation in life science research expenditures, with an outlay of $1.3 billion, including $750 million in expenditures at the University of Texas. Moreover, the University of Texas system was fifth in the nation in the number of patents generated during 2001.

Stone then discussed the Biotechnology Initiative, a joint effort of the city of Dallas, the Dallas Plan, UTSW, and STARTech Early Ventures, a business accelerator, to foster the industry's growth in Dallas. The initia-

tive's mission is to translate UTSW discoveries into platform technologies for Dallas-based biotech companies and to recruit biotech and pharmaceutical companies to Dallas. UTSW's role is to be the source of platform technologies, staff, and expertise and to serve as a resource for materials and ongoing developmental and clinical work.

To better support commercialization, UTSW created the Office of Technology Development (OTD) in 1998. Since its formation, the OTD has launched three start-ups, doubled its staff and more than quadrupled its licensing revenues. The OTD was also recognized by the Texas Legislature in 2001 as a leading technology development center.

Stone noted that Dallas has very few biotech companies because of barriers to entry facing start-ups. In his opinion, the main barriers include the lack of biotech entrepreneurs, the lack of local venture capitalists, the academic culture of local faculty, and the fact that UTSW cannot form companies. By default, the OTD's main option is to license the technology to existing entities. UTSW has also joined forces with STARTech to overcome some of these barriers. STARTech helps with company formation by identifying management and finding the venture capitalists and seed capital necessary to start a company.

The OTD's criteria for backing a start-up are quite stringent. First, the firm must have broad platforms that enable multiple discoveries or product pathways. Second, the foreseeable market size for the line of products must exceed $1 billion per year. Third, the time to market must be less than five years. Finally, the inventor must be a suitable partner for the company. Some of the successful start-up companies in the pipeline are Origami, Chia, Signal Biotechnology, Light Biology, and Eliance (since bought by Microgenics).

In closing, Stone stressed that fostering the growth of seed capital, venture capital, and biotech space will enable the biotech industry to flourish in Dallas. In addition, Stone saw a need to increase the flexibility of firms to operate with a public institution such as UTSW and to bolster cooperation among North Dallas stakeholders.

Commercializing Knowledge: University Science and Firm Performance

The last speaker of the conference, Zucker began with a glimpse of Texas' science base. Using several gauges, she compared how Texas stacks up against other high-tech states. She showed that except for the quality of patents, Texas was near the national average and 20 percent below the high-tech-state average for a variety of measures of scientific prowess.

Zucker stressed that the biotechnology industry has few big winners and many losers, as only 10 percent of biotech start-ups grew into reasonably large firms. To gauge the strength of local biotech activity, Zucker, in research done with Darby and Armstrong (Zucker, Darby, and Armstrong 2002), included not only technological indicators, such as patents, products marketed or in development, and firm size, but also financial indicators covering financing (initial public offerings, venture capital, mergers, and acquisitions) and income (revenues, sales, licensing, and profits). The science base of a state was very important in determining the success of biotech firms. Using data through the early 1990s, she showed that the most successful firms were clustered in the Northeast and on the West Coast and that Texas was not on the map for any of these indicators. However, another speaker, Tom Caskey, stressed that the state's ranking may not be as low today, pointing out that Zucker's data were roughly a

decade old and that Texas biotech activity has increased dramatically in recent years.[2]

Zucker's research shows that basic university science is integral to successful commercialization of scientific discoveries. Intellectual capital flourishes around the best universities, but outstanding scientists play a role over and above the presence of the universities and government research funding. Firms working with star scientists are much more likely to be successful, controlling for other factors. Star scientists who collaborate with outside firms provide the intellectual human capital that defines the firm's core technology and largely determines the company's success. For example, the Zucker, Darby, and Armstrong (2002) study finds that five articles coauthored by academic stars and the firm's scientists are correlated, on average, with about five more products in development, 3.5 more products on the market, and 860 more employees. Their research also shows that local venture capital is very important to the industry's growth, increasing R&D productivity and fueling firms' expansion.

Zucker concluded by noting that Texas' biotech success would be driven by the number and quality of top research university bioscientists, especially those with ties to firms, and stressed the need for more investment in Texas' scientific base.

THE BROAD ECONOMIC IMPLICATIONS OF BIOTECHNOLOGY

Several broad implications arise from the conference presentations. One is that if past technological revolutions are any guide, more research is needed to develop gauges of biotech activity. Also, the benefits of biotech advances are likely to be felt long after the inevitable shakeout periods that will cull the ranks of biotech firms. In addition, at a time when health care premiums are growing rapidly and drug cost increases are getting a lot of press, we should remember that the benefits of new drugs have historically outweighed their higher costs. That's why Lichtenberg emphasizes that restricting drug benefits or drug prices to hold down medical costs could backfire.

Another broad implication is that while policymakers should spur basic and generic research, they should ensure that incentives are appropriate for markets to perform efficiently. With respect to funding, it is encouraging that NIH's 2003 budget is twice what it was for 1998. But interventions in the form of price controls or forcing biotech firms to relinquish property rights could reduce the incentives for innovation. The risky nature of biotech research was a theme common to several conference speakers, including Darby, Grabowski, Howe, and Zucker. Given the high cost and risks of biotech research, emerging industries need a few big winners to justify investing in many new ideas. And as Eisenberg stressed, patent and royalty laws need to catch up to the technology so the markets can perform better.

Another set of implications concerns the interdisciplinary nature of biotech research, which encompasses a broad scientific base and which may greatly affect other areas and industries. Current biotech science draws on advances in chemistry, biology, computational methods, and medicine to develop new therapeutics. The knowledge and expertise from these different areas is being utilized in the hopes of developing major scientific

[2] Consistent with Caskey's view, *Science Watch* ranked UTSW among the top ten universities in four of six categories of biomedical research in 2002 (*Science Watch* 2002).

breakthroughs to better understand different diseases and to ultimately discover new treatments and methods of prevention. Looking ahead, the interplay between advances in biotechnology, informatics, and nanotechnology could extend biotech applications to a wide array of products and services inconceivable only a short time ago and greatly improve the quality of life and bolster economic growth. But to succeed, biotech firms must draw on specialists from different areas, foster technical collaboration among these scientists and credibly communicate their findings to regulatory agencies, customers, and investors.

The conference presentations also have implications for investors. Direct implications include recognizing that there are high risks of having large portfolio stakes in individual biotech firms, as reflected in the very low success rate of biotech firms or new drugs (Darby and Zucker 2002; Grabowski 2002; Howe 2002; and Zucker, Darby, and Armstrong 2002). In addition, excluding pharmaceutical makers, biotech stock indexes had very high valuations in April 2002, suggesting that this sector may have been overvalued at the time of the conference. Given the difficulties in capturing the value of inventions (Eisenberg 2002, Grabowski 2002, Howe 2002, and Lawlor 2002), investors should consider the risk that innovations could benefit end users more than inventors.

Perhaps the biggest implications for investors arise from biotech's indirect effect on benefit costs and customer bases for all sorts of companies. In particular, biotech research could increase longevity beyond most projections, a possibility Lichtenberg's research suggests. As a result, firms with large defined-benefit pension obligations could face greater risks, as would the Social Security retirement system. The aging of the population poses serious risks for medical expenses, as Howe emphasized. On the other hand, medical advances might help control the projected jump in Medicare benefits, which are expected to produce bigger budget shortfalls than the looming Social Security problem (see Rettenmaier and Saving 1999).

In addition, spending patterns could shift by more than expected if longevity increases more rapidly than projected, particularly if medical advances reduce disabilities and improve the quality—as well as the quantity—of life.

The conference presentations also had implications for local government policies aimed at fostering biotech activity. The recipe for success in biotech seems to be a strong scientific base built around top-rated academic institutions. These provide groundbreaking research and draw star scientists to the region. The second important element is the ability to commercialize the innovations coming out of the research institutions. To become a major player in biotech, Texas needs to continue to develop its strong research base but also needs increased venture capital to commercialize innovations from the state's research institutions.

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Glossary of Biotech Terms

Advanced Technology Program: Technology program instituted in 1990 by the Department of Commerce to directly fund research into developing new generic processes for high-tech industries.

Bioinformatics: The use of computers in solving information problems in the life sciences; mainly, it involves the creation of extensive electronic databases on genomes, protein sequences, and so forth. Secondarily, it involves techniques such as the three-dimensional modeling of biomolecules and biologic systems.

Biotechnology: "The use of microorganisms, such as bacteria or yeasts, or biological substances, such as enzymes, to perform specific industrial or manufacturing processes," and more broadly, "the application of the principles of engineering and technology to the life sciences," *American Heritage Dictionary*.

Clinical trials: The phase of research and development in which a product's effectiveness and safety are tested.

Cooperative Research and Development Agreement (CRADA): An agreement under which federally funded laboratories establish profitable research links with commercial firms that draw upon lab research findings.

Genomics: The scientific discipline that systematically investigates the set of chromosomes and genes of an organism.

Gestation period: In the context of biotechnology, the period during which a product is being researched and developed, not including the development of prior technologies used in the research.

Incremental progress: The type of technological progress in which an existing product is perfected or the process of making that product is perfected.

Inhibitor: A substance that suppresses or slows a chemical reaction.

Insulin: A hormone that regulates the metabolism of glucose, fats, and proteins.

Interferon: A protein that helps the body fight off viral infections.

Monoclonal antibody: An antibody that recognizes only one type of virus or bacterium.

Nanotechnology: The application of findings of nanoscale science, which deals with objects as small as a nanometer (one billionth of a meter).

Nonclinical costs: The R&D costs incurred in addition to the costs of clinically testing a product.

Proteomics: The use of quantitative protein-level measurements of how genes behave and affect the body.

Recombinant DNA: A combination of DNA molecules of different origin that are joined together using recombinant DNA techniques. Recombinant DNA is a fragment of DNA incorporated artificially into the DNA molecule of a suitable vector so that it can express itself many times. This way, a large quantity of the DNA in question can be obtained.

Stem cells: Cells that can develop into many different types of tissue and could be the key to a number of therapeutic breakthroughs in the field of medicine and research.

Venture capital: Private equity capital invested in a new or fresh enterprise.