

Forces Shaping Philadelphia's Future

Based on a speech made by President Santomero, to PECO Energy, Philadelphia, May 13, 2002

BY ANTHONY M. SANTOMERO

Does Philadelphia have what it takes to expand economic growth and attract more people? It's a challenge, says President Santomero in this quarter's message. The city has many things to recommend it as a location. Nevertheless, it has faced some difficulties in cultivating a role in certain important segments of the economy, and its population has been declining. But good things are also happening. Ultimately, Philadelphia's success — and the success of the surrounding area — depends on the creativity and commitment of its civic and business leaders. If they stay focused on contributing to the city's future, Philadelphia, President Santomero believes, will succeed.

The Philadelphia metropolitan area consists of Philadelphia County and its eight surrounding counties: Bucks, Chester, Delaware, and Montgomery on the Pennsylvania side; and Burlington, Camden, Gloucester, and Salem on the New Jersey side. When business people consider whether to locate here, they think about "here" as the Philadelphia metropolitan area. And research, including research at our own Bank, has shown that the economic fate of an entire region — that is, its major city and its suburbs — is bound together. In a statistical and, more important, in an economic sense, we are all part of one region.

So what are the forces shaping Philadelphia's future, and what shape

are they imparting to it? There are three sets of forces: those affecting the future of the national economy; those influencing the future of metropolitan areas in general; and finally those forging Philadelphia's own unique position among those metropolitan regions.

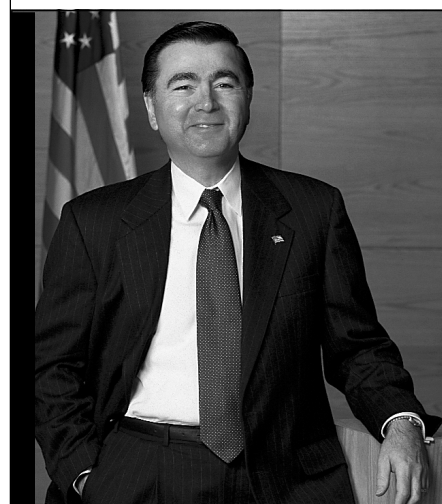
Earlier this year, the Federal Reserve Bank of Philadelphia released a study of the changes in Philadelphia's economic structure; we called it "The Industrial Evolution." * As that title suggests, changes in the economic base of our economy occur gradually — in

evolutionary, rather than revolutionary, style. One implication of this is that the forces shaping Philadelphia's future are to a large extent already in operation and have been for some time.

NATIONAL ECONOMIC TRENDS SHAPE PHILADELPHIA'S FUTURE

One set of forces shaping Philadelphia's future emanates from the national economy. Cyclical swings and secular trends in the national economy have an important impact on the pace and pattern of economic activity here. Over the past several decades, we have seen that impact for both good and bad.

I want to discuss these broader secular trends and their implications for our community. Here, the changing composition of economic activity in the national economy over the past several decades is particularly noteworthy: it affects the ongoing shift in the economy



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* Available on our web site at
www.phil.frb.org/files/reghigh/repcard02.pdf.

of Greater Philadelphia. At both levels, there has been a clear movement away from employment in the manufacturing sector and toward the service sector. In 1980, 54 percent of the people employed in the U.S. worked in the service sector. By 2000, that proportion rose to 65 percent, an increase of 11 percentage points. In Philadelphia, the proportion rose from 57 percent to 71 percent, an increase of 14 percentage points.

The shift away from manufacturing employment and toward service-sector employment is a theme with which we have long been familiar. However, the last couple of decades have represented more than a shift from factory work to fast-food minimum-wage jobs. This has occurred to some extent, to be sure, but a more important and more fundamental trend has been the shift toward the knowledge occupations, that is, occupations typically requiring a bachelor's degree or higher education.

Knowledge occupations span a broad range of activities: from science and education, to professional business services, to computer hardware and software design. Knowledge occupations represent a significant and growing proportion of total employment in the U.S., particularly in metropolitan places, including Philadelphia. Tim Schiller's article later in this issue, "From Laboratory to Market: The Biotechnology Industry in the Third District," discusses the rise of one important industry that employs knowledge workers.

In our study "The Industrial Evolution," we compared patterns of employment and economic activity for the United States and 14 major metropolitan areas. In the U.S., 28 percent of workers were in knowledge occupations as of 1999. The percentage of workers in knowledge occupations exceeded that average in all but one of the 14 metropolitan areas we examined. In Philadelphia, 32 percent of workers

— nearly one-third — were in knowledge occupations. That places Philadelphia sixth among the 14 cities — Los Angeles, Baltimore, and New York had comparable (but slightly higher) percentages; Washington, D.C. and Boston had significantly higher percentages.

Having a substantial percentage of our workforce in knowledge occupations brings Philadelphia some important economic benefits. Knowledge occupations offer significantly higher compensation than other occupations. Keith Sill's article in this issue, "Widening the Wage Gap: The Skill Premium and Technology," discusses the wage differential between skilled and unskilled workers. Also,

THE ROLE OF METROPOLITAN LOCATIONS IN THE ECONOMY SHAPES PHILADELPHIA'S FUTURE

A key question is: Will Philadelphia continue to participate in the expanding knowledge economy? I certainly believe it has that opportunity.

One reason is simply that it is a large metropolitan location. Such places have an important role to play in the knowledge economy. I just mentioned that virtually every one of the metropolitan areas we studied exceeds the national average for the proportion of its workforce in knowledge occupations. Indeed, I would argue that such

The changing composition of economic activity in the national economy over the past several decades is particularly noteworthy: it affects the ongoing shift in the economy of Greater Philadelphia.

knowledge workers traditionally have lower unemployment rates than other workers.

Undoubtedly, Philadelphia's knowledge-based sector has contributed to the relatively rapid growth in real per capita income here since 1980. Philadelphia ranked fourth out of the 14 cities studied in this category, and this, in part, accounts for the relatively small increase in unemployment rates here during the current business cycle.

Equally important, knowledge occupations are projected to be among the most rapidly growing employment categories in this decade. So, to the extent that Philadelphia continues to participate in the national expansion of the knowledge-based economy, it will be a growing place with high average incomes and relatively stable employment.

locations are natural centers of knowledge-based economic activity.

The essence of a large metropolitan region is that it provides a geographic concentration of many people and organizations. This concentration is essential for creating an environment that both knowledge businesses and knowledge workers find attractive. In what way?

Let me start on the business side. The rise of the Internet and other global communications networks has made long-distance communication routine. But physical proximity is still important for some aspects of business. This is particularly true of the business conducted by the people in knowledge occupations. Their work requires frequent face-to-face interaction with counterparts from different organizations: researchers, entrepreneurs,

financiers, engineers, designers, lawyers, accountants, advertisers, and so forth. The physical proximity that a large metropolitan area provides makes such interaction relatively easy and inexpensive. So businesses employing a large proportion of knowledge workers find metropolitan areas relatively attractive locations.

But beyond this, large metropolitan regions have another important attraction. They can be and have been attractive places for knowledge workers to live. The physical proximity provides value to their residents because they offer economies of scale in the provision of social amenities. Because they can draw patrons from a large pool of people, many organizations, both public and private, can offer specialized leisure-time activities on an economically viable scale. Residents can choose from a rich and varied menu of cultural and recreational activities and experiences.

As people's incomes rise, their demand for this variety of leisure-time activities increases. Within this group, knowledge workers are particularly attracted to the quality of life that only a large metropolitan area can offer. In a world that is long on ideas and short on talent, this offers an important draw for knowledge-based businesses to locate and operate in these centers.

Thus, large metropolitan areas offer some fundamental advantages over smaller, nonmetropolitan areas as locations both for knowledge businesses and for knowledge workers.

THE PHILADELPHIA STORY

More distinctively, as Tim Schiller discusses in his article in this issue, Philadelphia has been particularly successful in cultivating an important niche in a dynamic sector of the knowledge economy, centered on life sciences: biotechnology, pharmaceuticals, and health care. Its success in this

category is a testament to the power of the synergies that emerge when specific kinds of knowledge-based organizations come together.

Philadelphia ranks high in research and development spending at its colleges and universities. Much of the research is in the medical field. Research in the life sciences centered at the University of Pennsylvania and elsewhere has provided the kinds of potentially marketable ideas that attract entrepreneurs.

But to bring potentially marketable ideas to market takes venture capital. And while Philadelphia is not in the top tier of regions in the country for overall venture capital investment, it does rank high in venture capital investment in biotech and pharmaceuticals. Such investments have fostered any number of start-up businesses in the area.

Major pharmaceutical firms have had a significant presence here as well. Access to new ideas and new opportunities induced many of them to expand and others to establish a

presence here. Consequently, the pharmaceutical industry is important to our region and has made an important contribution to employment. In fact, the pharmaceutical industry is one segment of the few manufacturing sectors that has been growing in our region.

Perhaps the surest sign that Philadelphia has made it as a center for the life sciences came in a comment made in a local newspaper not long ago. One industry observer was quoted as saying that our area is now so renowned for its life sciences companies that headhunters typically start by looking here to find executives for companies elsewhere.

Nonetheless, the glass is not completely full. Philadelphia has not been as successful in cultivating an important role in some other segments of the knowledge economy: those centered on the physical sciences or computer hardware and software. Research spending in computer science at the area's universities and colleges is relatively low. As a consequence, a relatively small amount of venture



capital is invested in computer software and services here — hence, our area’s relatively low employment in the computing industry, broadly defined.

LOOKING TO THE FUTURE

Looking ahead, an important question is whether Philadelphia can turn its advantage as a metropolitan location into enough of a magnet for the expanding knowledge sector to bring substantial growth to the area.

This is a challenge. Thus far, Philadelphia has not generated growth on par with that of other major metropolitan areas. Of the 14 areas we studied, Philadelphia ranked 12th in population growth from 1990 to 2000. But Philadelphia may very well be stepping up to the challenge. Recent initiatives at both the state and city levels and led by both public and private interests indicate that the region sees the importance of these issues for its future success.

Certainly, Philadelphia has significant potential to expand its economy. For one thing, it can tap the flow of graduates from local colleges and universities to expand its capacity for growth in knowledge-based sectors. Philadelphia has a large college-student population and well-regarded graduate programs. Indeed, the region attracts a substantial number of students from elsewhere in the nation and around the world.

The problem is that so many of our graduates leave the area for positions elsewhere. One survey showed that fewer than 30 percent of the alumni of Penn, Bryn Mawr, Haverford, and Swarthmore live in the city of Philadelphia or the adjoining Pennsylvania counties. We have less data on the many other institutions that surround us, such as Princeton, Rutgers, Lehigh, and Penn State, but this itself suggests their concentrations are even lower.

Knowledge workers are

mobile. They go wherever the job opportunities and quality of life suit them. If our region were to offer more engaging opportunities, more people who earn their degrees in the region should find staying here for their first job highly attractive as well.

Keeping them would permit our region’s advantage in life sciences to expand and broaden into other growing knowledge industries, such as the hard sciences or computer hardware and software, where future growth would be welcomed and some key activities are already under way.

One important ingredient for this expansion is already present. Entrepreneurial networks now exist in

has stepped up its efforts to offer the diverse array of cultural and recreational activities that only a large metropolitan area can support. We now have a revitalized Center City, the Avenue of the Arts, and the First Union Center. Soon we will have two new sports stadiums and the National Constitution Center. There are plenty of other examples, both in the city, its neighborhoods, and its surrounding suburbs.

Debates on the funding, location, and design of some of these facilities are inevitable, but the fundamental fact is that their existence makes Philadelphia a top-tier region. We need this kind of infrastructure not only to attract tourists but also to provide the

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the region. Such groups serve as catalysts for the inception and growth of knowledge-based industries by organizing the diverse resources that the metropolitan areas offer.

In recent years, the Philadelphia region has developed many networks, such as the Greater Philadelphia Venture Group, the Eastern Technology Council, the Entrepreneurs Forum, and the Ben Franklin Technology Center. These types of organizations establish a business-friendly climate and one particularly supportive of the knowledge-based economy.

When it comes to retaining local college graduates — and knowledge workers more generally — one half of the equation is offering interesting job opportunities. The other half is offering an interesting lifestyle.

In recent years, Philadelphia

quality of life that attracts and retains residents and jobs in a knowledge-based economy. We seem to be on the path to exploiting that advantage further.

One serious problem remains. Can the region begin to generate the growth in employment and population that we need to maintain our status as the nation’s fourth largest metropolitan area (ranked by 2000 population)? This is an open question and a clear challenge, which we must address directly.

PHILADELPHIA’S OWN UNIQUE CHARACTERISTICS WILL HELP SHAPE ITS FUTURE

The third set of forces shaping Philadelphia’s future are those unique characteristics shaping its capacity to compete with other metropolitan areas for people and jobs. Whether these features prove a positive or negative

force, they differentiate Philadelphia from other metropolitan areas as a location of choice for businesses or potential residents.

Let me first offer a few words about two such features — taxes and public schools in the city of Philadelphia — then some thoughts on a third — our location.

Those who live or work in the city of Philadelphia bear one of the heaviest local tax burdens in the nation. The business tax burden here is equally onerous, particularly for start-up businesses. This issue has been widely debated, and I will add nothing to that debate here except to say that reducing that burden in a fiscally responsible way would significantly improve the whole region's competitive advantage.

Likewise, the public school system in the city of Philadelphia is not meeting the basic educational needs of its students. It is worth emphasizing, though, that a good public school system would give the city a decisive competitive advantage in attracting both businesses and residents to the region in this knowledge-based economy. Conversely, its failure weighs heavily on our minds and the minds of business leaders considering site relocation. So, our current initiatives in the area of public school education will have a profound effect on the city, on the region, and on the Commonwealth of Pennsylvania, to say nothing of the lives and futures of our children.

The impact of Philadelphia's location on its future is a more complex issue. I consider it both a disadvantage and an advantage in our new world economy. Much has been made of the

fact that economic activity has been gravitating to less densely populated areas, particularly in the South and the West, and away from the densely populated areas in the Northeast and Midwest. That has indeed been the trend, and it works to our disadvantage.

On the other hand, the densely populated Northeast corridor is the center of economic and political activity in the U.S. Philadelphia's location between New York and Washington, D.C. provides people and businesses here with an opportunity to tap into the broader network of activity that the Northeast corridor represents. In essence, Philadelphia's location leverages up its value in the knowledge-based economy by providing access to a broader network of contacts and opportunities.

The advantage of Philadelphia's location plays out in a number of ways. On the business side, Philadelphia's location in the middle of the Northeast corridor allows it to tap into industrial growth along the corridor. The prominence of the pharmaceutical industry in Philadelphia is part of the larger story of the industry's prominence in the larger geographic area. "The nation's medicine chest" runs from New York through the state of Delaware.

On the consumer side, ready access to cultural activities and entertainment in New York and Washington complement the menu offered to Philadelphia residents in their own city, heightening the attractiveness of our region as a place to live and work.


As we look to the future, I think the challenge presented by our location is to maintain the energetic

business climate and high quality of life that make Philadelphia a significant and desirable base of operations from which one can plug into the entire network of the Northeast corridor.

CONCLUSION

I began by saying there are three sets of forces shaping Philadelphia's future: those affecting the future of the national economy; those influencing the future role of metropolitan areas; and those forging Philadelphia's own unique position among those metropolitan areas. The last of these is really a question of how we respond to the forces of change that affect our environment.

Large metropolitan areas have some fundamental advantages that can place them at the forefront of our knowledge-driven economy. Philadelphia has had particular success in establishing itself in an important segment of the knowledge economy, and it seems to be developing the capacity to broaden its role. The question is whether the potential will be realized. Will the business leaders of the community show the creativity and take the risks necessary to move ahead? Will civic leaders build the basic infrastructure, manage the budgets, and provide the basic education on which this economy can thrive?

If business and civic leaders throughout the region stay focused on contributing to Philadelphia's future, I believe we will succeed. 

From Laboratory to Market:

The Biotechnology Industry in the Third District

BY TIMOTHY SCHILLER

Basic biotechnology has been around a long time. Bakers have used yeast for centuries, and smallpox vaccination was introduced in the 18th century, long before the details of cell structure were known. However, recent events, such as the human genome project, have firmly anchored biotechnology and its applications in the public's mind and imagination. Here, Tim Schiller briefly describes major biotechnology products, reviews estimates of the industry's size and scope, and outlines where the industry is most active in the United States, especially in the Third District states of Pennsylvania, New Jersey, and Delaware.

Biotechnology uses living organisms at the cellular or molecular level for medical, agricultural, or industrial purposes. The publication of the human genome sequence in 2001 brought biotechnology dramatically before the public as a leading-edge scientific endeavor. Although biotechnology has only relatively recently

gained widespread public interest, basic biotechnology is thousands of years old.

This article briefly describes major biotechnology products currently in use or under development and their applications; it reviews estimates of the biotechnology industry's size and scope; and it gives some details on where biotechnology companies are active in the U.S., with emphasis on the industry's presence in the states of the Third Federal Reserve District: Pennsylvania, New Jersey, and Delaware.

THE RISE OF BIOTECHNOLOGY

Yeast has been a component of baking and fermenting throughout recorded history, and its use is probably older than the written record. Vaccination against the smallpox virus was

introduced in the 18th century, long before the details of cell structure and action were known. But it was James Watson and Francis Crick's discovery of the structure of DNA, the molecule that carries genetic information, in 1953 that ushered in the modern era of biotechnology. Since then, the science of genetics and its technological applications have advanced rapidly. In 1961, the first biopesticide was developed to protect important agricultural crops. In 1973, came the first alteration of a DNA molecule, the biotech process now referred to as recombinant DNA technology. (See the *Glossary of Biotechnology Terms*.) In 1982, the U.S. Food and Drug Administration approved the first drug developed by biotechnology: human insulin produced in genetically modified bacteria. In 1989, cotton was genetically modified to protect it against insects, and corn followed the next year. The first animal cloned from an adult cell, Dolly the sheep, arrived in 1997. Advances in biotechnology are accelerating, and the scope of biotechnology's applications is widening. More than 100 biotechnology drugs and vaccines are used today in the United States; agricultural applications of biotechnology are extensive; and industrial uses are growing.

MAJOR BIOTECHNOLOGY PRODUCTS

Recent advances in understanding the chemistry of cells and biological molecules, such as DNA and proteins, have been extensive. This growing knowledge has led to a variety of technologies and products that have provided benefits to human health and



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Glossary of Biotechnology Terms

Antibody – a protein produced in the body in response to foreign proteins entering the body, as in infections. Antibodies chemically deactivate the foreign protein to protect the body.

Antigen – a substance that induces the body's immune response system to produce an antibody.

Assay – a scientific test for measuring biological response to a drug or other treatments.

Autoimmune disease – a disease in which the body produces antibodies that attack its own tissues.

Biocatalyst – an enzyme that causes or facilitates a biochemical reaction.

Biochemical – a chemical resulting from a chemical reaction in a living organism.

Bioinformatics – the collection and analysis of data by computers for use in biological research; often used in genomic research.

Biologicals – medicines made from living organisms or their products; also known as biological drugs. Examples include vaccines and serums.

Chromosome – components of a cell nucleus that carry genes, made up of DNA and protein.

Clone – genes, cells, or organisms that are derived from a single common gene, cell, or organism and that are genetically identical.

DNA (Deoxyribonucleic acid) – the molecule that carries genetic information.

DNA probe – a piece of nucleic acid that has been labeled with a radioactive isotope and used to locate a particular gene on a DNA molecule.

Diagnostic – a product used for the diagnosis of a medical condition. Monoclonal antibodies and DNA probes are biotechnological diagnostics.

Enzyme – a protein that controls chemical reactions in living organisms.

Expression – manifestation of a characteristic that is based on a gene. Also used to refer to the production of a protein by a gene.

Gene – a segment of a chromosome that has a specific hereditary function. Genes control the production of proteins and regulate other molecular functions in living organisms.

Gene mapping – determining the location of genes on a chromosome.

Gene sequencing – determining the specific order of the nucleotide bases (constituent parts of the DNA molecule) in a strand of DNA.

Gene therapy – the replacement of a defective gene.

Genetic modification – altering the genetic material of living cells to make them capable of producing new substances or performing new functions.

Genome – the complete chromosome set in the cell nucleus.

Genomics – the study of gene function.

Monoclonal antibody – an antibody derived from one clone of cells that reacts to only one antigen.

Protein – a molecule made up of amino acids (acids containing one nitrogen and two hydrogen atoms in combination). Proteins carry out the chemical processes involved in genetic activity and other cell functions.

Proteome – the total collection of proteins in a cell, different for different types of cells.

Proteomics – the study of a proteome and the functioning of proteins.

Recombinant DNA – the process of making new DNA by combining DNA components from different organisms; used in genetic modification and gene therapy.

Stem cell – a cell that can grow into any specific type of cell in a living organism. Embryos develop from stem cells.

applications of economic significance to agriculture and other industries. (For a brief description of major biotechnologies, see *Biotechnologies and Their Applications*.)

Biotech Drugs. There were over 100 biotech drug products and

vaccines available in 2000.¹ Current biotech medicines include important treatments for anemia, cystic fibrosis, growth deficiency, hemophilia, hepatitis,

¹ See Biotechnology Industry Organization, 2001.

transplant rejection, and leukemia and other cancers. Biotech products are also used for several diagnostic procedures. Biotech drugs have been introduced at an increasing rate, especially since the mid-1990s. Approvals of new biotech drugs and new uses for existing biotech

drugs generally increased from 1993 to 2001.² In that same period — mid-1990s to the present — the number of new drug and new use approvals annually for nonbiotech drugs rose, but not by as much as biotech drugs. Thus, in the past several years, biotech drugs have become a larger percentage of the annual number of total new drug and new use approvals, increasing from 6 percent in 1993 to 15 percent in 2001 (Figure 1).

In 2000, the latest year for which data are available, 369 biotech medicines were undergoing clinical trials.³ Clinical trials usually come at around the mid-point in the drug development process, about eight years after research to discover a specific new drug begins and about seven years before FDA approval. Most new biotech drugs currently being tested are intended for cancer treatment (175 drugs). Other therapeutic categories with a large number of biotech drugs in the clinical trial phase are infectious diseases (39), neurological disorders (28), heart disease (26), and respiratory diseases (22).

Agricultural Uses. Biotechnology has become an important aspect of plant agriculture in a short time. The most important use of genetic modification in plant agriculture is herbicide tolerance. In this process, the genetic composition of plants is altered to make them resistant to damage from the chemical herbicides used to kill weeds in the fields where they are grown. In this way, crop losses from herbicides are reduced and yields are increased. When plants are made resistant to more lethal herbicides, fewer applications of

² Since 1993 the Food and Drug Administration has counted new use approvals (formally called “efficacy supplements”) separately from new drug approvals.

³ See Pharmaceutical Research and Manufacturers of America, 2000.

Biotechnologies and Their Applications

Cell culture technology is the growing of cells outside the living organism in which they develop naturally. Applications of this technology include growing cells on which to test new medicines, growing cells to replace dead or malfunctioning cells in human organs, and mass producing natural substances of medicinal value.

Cloning is the reproduction of molecules, cells, plants, or animals that are genetically identical to their source. Cloning gained notoriety in 1997 when scientists cloned a sheep from an adult sheep cell. Before that, animal cloning had been done with embryo cells. Monoclonal antibody production and much of cell culture technology are based on cloning. Cloning is used in livestock breeding, pharmaceutical manufacturing, and modification of agriculturally important plants. In addition, cloning is a basic part of other biotechnologies.

Genetic modification technology, sometimes called *genetic engineering* or *recombinant DNA technology*, is the insertion of genetic material from one organism into the genetic material of another organism. In a sense, this technology is a more specific and direct approach to the same ends as selective breeding in that desirable traits, coded in genetic material, are transferred from one organism to another. Subsequent generations of this organism will have these traits. Genetic modification technology is already widely used in agriculture. Other uses of this technology include production of medicines and vaccines, treatment of genetic diseases, and nutritional enhancement of foods.

Monoclonal antibody technology develops antibodies from cloned cells that can be used to identify and treat antigens that infect humans, animals, and plants. Because antibodies are very specific in their action, monoclonal antibody technology encompasses an extensive field of research. One of the more important applications of this technology is cancer treatment and vaccines, such as the biotech vaccine against hepatitis B. Another important use is the diagnosis of infectious diseases in humans, animals, and plants. Monoclonal antibody technology is also used to locate environmental pollutants and to detect harmful microorganisms in food.

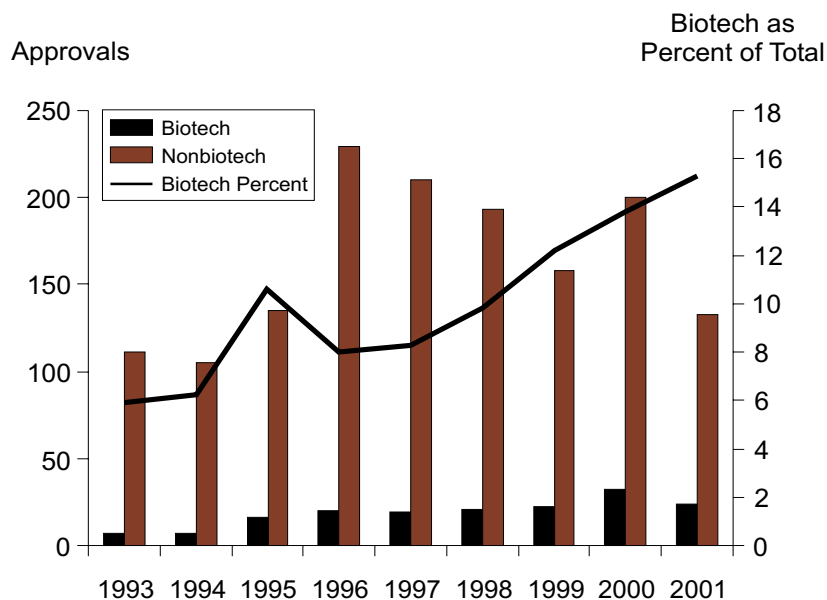
Protein engineering technology is used to modify proteins, which are constituents of genes and enzymes. Proteins are the chemical substances through which much genetic and cellular activity occurs, so there is a growing research effort to understand and manipulate proteins. Currently there are several biotech drugs based on protein chemistry for treatment of anemia, cystic fibrosis, hemophilia, leukemia, and some cancers. Besides their functions in living organisms, enzymes are also used as biocatalysts to improve the efficiency of production processes for chemicals, textiles, pharmaceuticals, pulp and paper, food, and animal feeds.

herbicide can be used, reducing both farmers’ production costs and environmental damage.

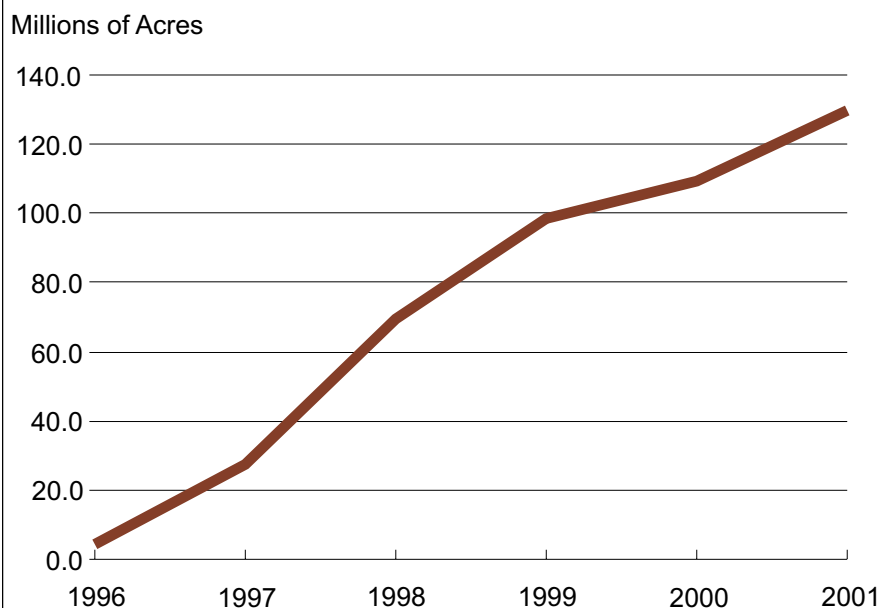
The second major use of genetically modified crops is insect resistance. This process involves taking genetic material from naturally occurring organisms that are lethal to insects and inserting it into plants. When the genetic insecticide from a naturally occurring bacterium is inserted in the genetic makeup of plants, the insects

that feed on them are killed before they destroy the plant.⁴ This obviates the need for chemical insecticides, thereby protecting crops more efficiently and reducing the threat of poisoning animals and humans.

⁴ The most common source in this application is genetic material from *Bacillus thuringiensis* (Bt), a naturally occurring bacterium lethal to insects.

FIGURE 1**New Drug and New Use Approvals**

Source: FDA Center for Drug Evaluation and Research; Biotechnology Industry Association

FIGURE 2**Global Area of Transgenic Crops**

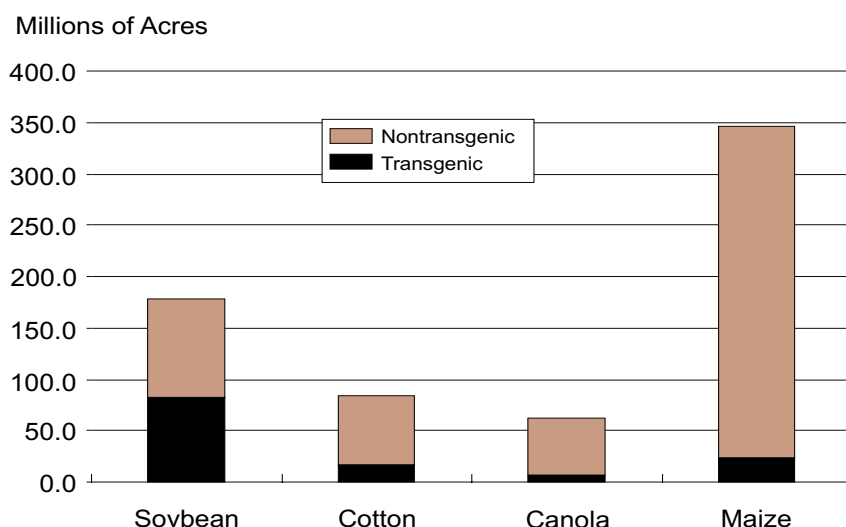
Source: International Service for the Acquisition of Agri-Biotech Applications

Agriculture has also made use of genetically modified seeds, which first became commercially available in 1996. Between 1996 and 2001, the area planted with genetically modified crops worldwide increased 30 times (Figure 2). Although the share of the world's total cropland planted with genetically modified seeds is small — approximately 3 percent — genetically modified seeds are a large share of the acreage of some important food crops. Of the four main crops — soybean, cotton, canola, and maize (corn) — for which genetically modified seeds are used, the portion planted with genetically modified seeds comprises 19 percent of the world's total acreage planted with those crops (Figure 3).

The use of transgenic crops continues to grow, and American farmers have been the world leaders in adopting their use.⁵ Recently, the U.S. Department of Agriculture estimated that American farmers will increase their plantings of genetically modified corn, soybeans, and cotton this year to 32 percent, 74 percent, and 71 percent, respectively, of the total acreage for these crops. Although farmers' interest in using transgenic crops appears to be increasing, there is growing public concern about possible harm to human health and unintended effects on naturally occurring plants through uncontrolled dissemination of transgenic agricultural products. Many national governments have begun to regulate transgenic food products, and an effort is under way through the United Nations to establish international rules for identifying, packaging, and handling genetically modified living organisms.⁶

⁵ "Transgenic" means carrying genes transferred from another species or breed. Data on U.S. farmers' use of transgenic seeds are from the U.S. Department of Agriculture crop and planting reports (U.S. Department of Agriculture, 2001a, 2002).

⁶ See United Nations, 2000.

FIGURE 3**Transgenic Crops vs. Total (2001)**

Source: International Service for the Acquisition of Agri-Biotech Applications

Industrial Applications. In industry, the most prevalent biotech products are enzymes used in chemical processes. There is a wide variety of enzymes, each acting on different compounds. The most commonly used enzymes in industry break down protein, cellulose, fats, and starches. These enzymes are used in detergents and industrial cleaners, in baking and brewing, and in the production of cheese and other dairy products.

BIOTECHNOLOGY AS AN INDUSTRY

Specialized medical biotech firms fall mainly within the pharmaceutical and the physical and biological research industries. There is no industrial classification for biotechnology, as such. Furthermore, educational institutions and hospitals conduct biotech research, and chemical firms carry out research as well, especially for

agriculture. Consequently, data on the economic scale of biotechnology are difficult to obtain. Information on revenue, employment, and other aspects of the biotechnology industry must be obtained primarily from industry sources, such as the Biotechnology Industry Association, and individual companies.

Biotechnology companies had sales of \$18 billion in 2001, according to the Biotechnology Industry Association.⁷ The industry's revenues are still small compared with the overall U.S. pharmaceutical industry, which had estimated worldwide sales of around \$180 billion in 2001, but they have been growing rapidly.⁸ Aggregate sales

⁷ Data on biotech sales, revenue, and employment are from the Biotechnology Industry Association, 2002a.

⁸ Data on the overall pharmaceutical industry are from Pharmaceutical Research and Manufacturers of America, 2001.

revenue of biotechnology companies has increased more than 200 percent since 1993, compared with an increase of 137 percent since then in sales of the overall U.S. pharmaceutical industry. Moreover, sales figures of biotech firms do not represent the true importance of biotechnology. Biotechnology research and development (R&D) is an important and growing part of larger, more diversified firms in the medical, pharmaceutical, agricultural, and industrial sectors.

According to the Biotechnology Industry Association, there are about 1400 biotechnology companies in the U.S., of which approximately 340 are publicly held. Many, but not all, of the companies are classified in the pharmaceuticals industry. Employment in the biotech industry is estimated at 174,000 jobs. Total employment in the pharmaceutical manufacturing industry is 214,000.⁹ These numbers are not strictly comparable because biotech firms and employment in those firms encompass not just biotech-based drug companies but also other nondrug companies related to biotech, such as research firms, universities, and firms providing services to the biotech industry. Outside of specialized biotech firms, many people are employed in biotechnology research and the production of biotechnology products in large firms, primarily major pharmaceutical companies, and in chemical companies that produce agricultural products, such as seeds and pesticides.

Capital invested in biotechnology firms can also give us a measure of the industry's size. This measure is especially relevant for this industry because the industry is new and many firms are spending on R&D, without significant sales. Estimates of the funds raised by biotech firms approached \$40

⁹ U.S. Bureau of the Census, 2002.

billion in 2000, the recent peak year, with approximately \$25 billion of that coming from public stock and debt offerings, such as bonds.¹⁰ In comparison, total funds raised via stock and debt offerings by all U.S. public corporations in that year were \$944 billion.¹¹ As the stock market weakened subsequently, biotech financing shrank along with the overall decline — to about \$11 billion in 2001.¹²

Biotechnology firms rely on a variety of financing methods (Figure 4). Public financing comes primarily from initial public offerings (IPOs) of stock and follow-on stock offerings. Publicly held biotech firms also use loans, warrants, debt offerings, and private placements to finance their work.¹³ Lesser amounts are raised by companies that have not yet tapped the public market. Financing for these companies comes primarily in the form of venture capital and equity buys from partners, often large pharmaceutical companies. Although the amount of money raised in this way is lower than publicly raised funds, it is critical for biotech firms in the early stages of R&D, when the need for financing is great but the ability to attract investment in the market is slight.

Venture capital was around 10 percent of total biotech industry funding in 2000, according to industry sources. Although venture capital accounts for a small portion of the industry's funding,

¹⁰ See Biotechnology Industry Association, 2001.

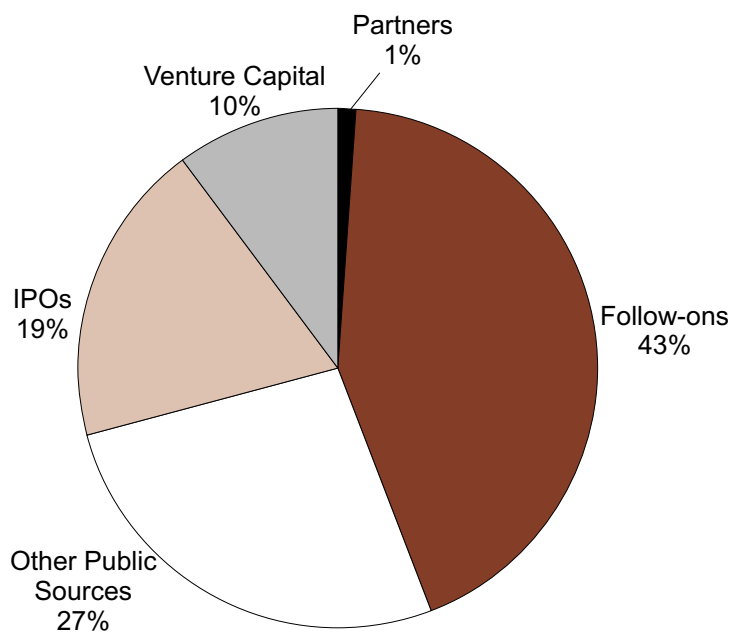
¹¹ See Board of Governors, 2001.

¹² See Burrill and Company.

¹³ A warrant is a company-issued certificate that represents an option to buy a certain number of stock shares at a specific price before a predetermined date. A private placement is a large block of securities offered for sale to an institutional investor or a financial institution through private negotiations.

FIGURE 4

Biotech Industry Funding (2000)



Source: BioWorld Financial Watch

venture capitalists serve important functions for young biotech companies by providing management expertise and preparing the firms for their initial public offerings.¹⁴ Nationally, venture capital invested in biotechnology companies was 6 percent of total venture capital investments in 2001.

In our tri-state region, the proportion of venture capital going to biotechnology has been greater than in the nation as a whole. In New Jersey, biotechnology venture capital was 19 percent of the state total; in Pennsylvania, it was 15 percent (see the Table).¹⁵

Another common feature of early-stage biotech financing is collaboration with a major pharmaceutical company. The larger firm in a collabora-

tive agreement often provides R&D support, production facilities, and marketing arrangements for the biotech firm. The larger firm recoups its investment through marketing rights under a license agreement. Although funds provided through collaborative agreements are not a large portion of the biotech industry's total capitalization, the money is an early source of much needed capital, and the interest of a large pharmaceutical firm can be an important signal to the markets about the biotech startup's prospects.

Once beyond the early financing stage, biotech firms rely on initial public offerings of stock, loans, private placements, and other forms of capital. These more traditional forms of corporate financing have recently become more available to biotech firms than they were in the past. According to industry analysts, by the end of the 1990s, a number of large, well-capital-

¹⁴ See the article by Mitchell Berlin.

¹⁵ No amounts of venture capital for biotech firms were reported for Delaware.

TABLE

Biotech Venture Capital Invested (2001)

State	\$Million	Percent of State Total Venture Capital
California	845	5.4
Massachusetts	310	6.6
New Jersey	268	18.9
New York	150	7.2
Maryland	149	14.6
Colorado	131	9.9
Pennsylvania	123	14.5
Connecticut	110	18.9
North Carolina	60	12.8
Washington	57	5.5
Virginia	50	7.6
Texas	44	1.6
Illinois	21	3.4
Michigan	21	13.0
Utah	18	9.2
Rhode Island	13	29.8
Wisconsin	10	2.1
Georgia	9	1.1
Indiana	8	15.8
Arizona	7	4.5
Minnesota	7	1.3
Nebraska	6	66.7
Maine	3	36.8
New Mexico	2	9.0
Alabama	1	1.4

Source: PricewaterhouseCoopers/Venture Economics/National Venture Capital Association Money Tree Survey

ized biotech firms had emerged, and these firms now have the financial resources to fund their development efforts for several years.

GEOGRAPHIC DISTRIBUTION OF BIOTECHNOLOGY

Biotechnology firms are concentrated in places that are popularly considered high-tech areas. According to Ernst & Young, there are approximately 1460 major biotech firms in the country, concentrated in a few

states. A little over 400 are in California, just over 200 in Massachusetts, nearly 100 in Maryland, about 90 in North Carolina, and approximately 70 each in Pennsylvania, New Jersey, and New York. Other leading states are Washington, Georgia, and Texas (around 40 companies each) and Florida and Colorado (approximately 30 companies each). These 12 make up the top biotech states in Ernst & Young's tally (Figure 5).

The geographic distribution of

research efforts shows a cluster pattern as well. A few biotech centers dominate the rankings of metropolitan areas in terms of number of biotech patents granted between 1975 and 1999. The New York consolidated metropolitan area is first with nearly 12,000 patents, followed by San Francisco and Philadelphia with over 5000 each. Next comes Boston with over 3000, and Washington, D.C. and Chicago with over 2000 each. Only six other metropolitan areas have more than 1000 biotech patents each.¹⁶ The data for the New York area reflect much of the biotech activity that takes place among the many pharmaceutical firms located in the New Jersey portion of New York's metropolitan area. Likewise, a substantial share of biotech activity in the Philadelphia area takes place among the chemical firms located in the Delaware portion of the metropolitan area as well as among biotech and pharmaceutical firms in the Pennsylvania portion.

Because the biotechnology industry is growing rapidly and because many biotech firms are small, any count of their numbers is likely to be an underestimate. Furthermore, universities and other nonprofit organizations as

¹⁶ Data on patents issued 1975-99 are from the paper by Joseph Cortright and Heike Mayer. The patent data used include patent classes for drugs, molecular biology, and multicellular living organisms. The patent class for drugs includes biotech and nonbiotech drugs. When only data from the patent classes for molecular biology and multicellular living organisms are used, as a more restricted classification of biotech, the geographic distribution of patents is substantially similar among the top six metropolitan areas, but there is some reordering within the group and two areas are displaced by others not in the first grouping. Using the restricted classification the order is Boston, San Francisco, San Diego, Raleigh, New York, and Philadelphia. The areas moving down, including Philadelphia, have proportionately more of their biotech research devoted to discovering new drugs compared with the areas moving up or retaining their original ranking.

well as large pharmaceutical firms undertake biotech research. These factors should be taken into account to accurately assess the biotechnology industry nationally and in the region.

BIOTECHNOLOGY IN THE REGION

Biotechnology is well represented in the three states of the Third District. As noted above, data from Ernst & Young place New Jersey and Pennsylvania among the top biotech states in terms of the number of major biotech firms located in the two states. Both states, as well as Delaware, figure prominently in biotech patenting. State biotechnology associations are active in Pennsylvania and New Jersey, and membership in these associations takes in more firms and institutions than are included in Ernst & Young's count. Within the region, biotech firms tend to cluster in locations that have established bases of pharmaceutical firms and life sciences facilities, such as research universities and medical centers (see the map).

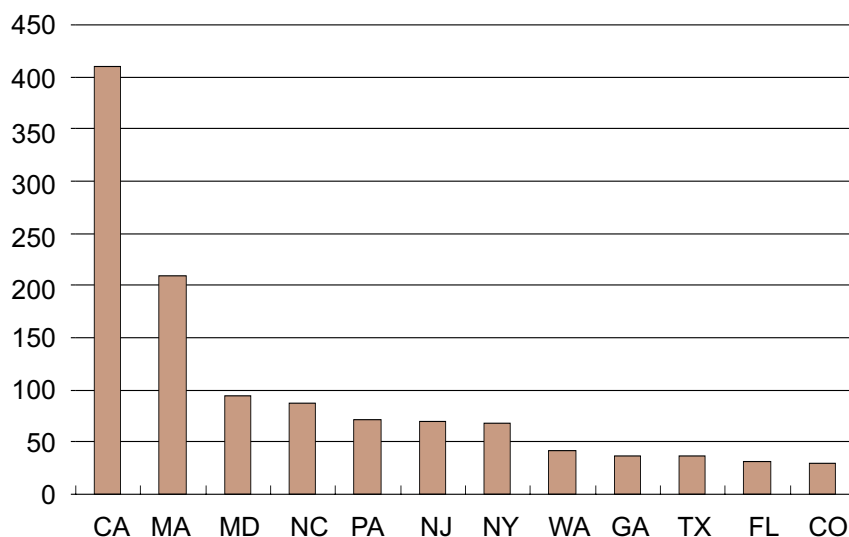
In New Jersey, biotechnology firms have sprouted in an area where many of the world's largest pharmaceutical firms have been well established. Universities in the state are also engaged in biotech research. Biotech and other life sciences firms are concentrated in the middle and northern parts of the state.

In Pennsylvania, the Philadelphia metropolitan area is a biotech hub, but there are also biotech clusters in central Pennsylvania, centered on Pennsylvania State University, and in the Pittsburgh area, the location of Carnegie Mellon University and the University of Pittsburgh, which have active biotech research programs. In the Philadelphia area, the life sciences are represented by major pharmaceutical firms as well as educational institutions with health and medicine programs,

FIGURE 5

Leading Biotech States (2001)

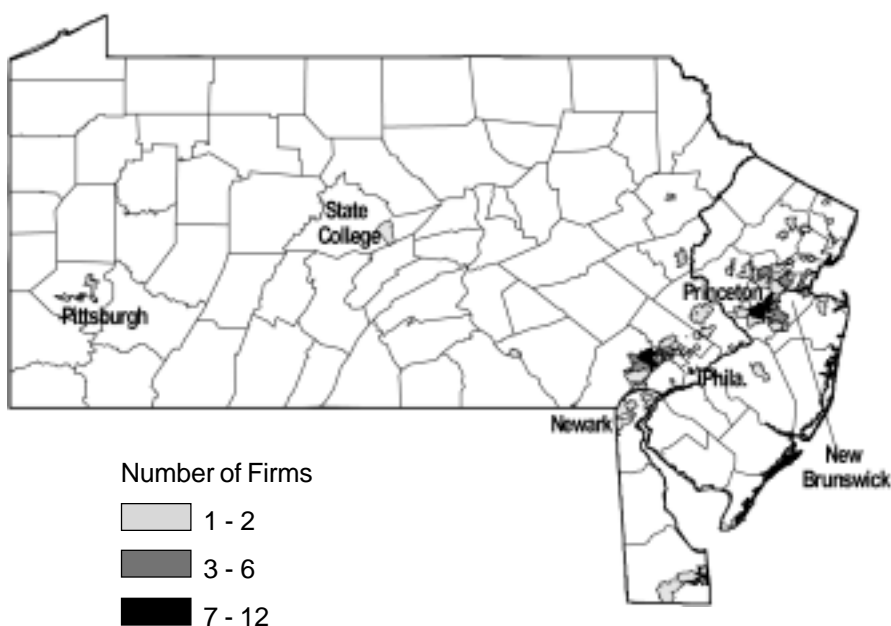
Number of Firms



Source: *Beyond Borders*, Ernst & Young's 2002 Global Biotechnology Report. Used with permission.

MAP

Biotech Firms Pennsylvania, New Jersey, and Delaware



such as the University of Pennsylvania, Thomas Jefferson University, University of the Sciences, and Drexel University/MCP Hahnemann University.

Delaware should not go unmentioned; the state's traditional chemical industry is evolving from producing basic chemicals to more specialized products, including pharmaceuticals. Besides Wilmington, where chemical and pharmaceutical companies have a well-established presence, the New Castle area is developing as a center for biotech firms.

Biotechnology firms and other establishments engaged in biotech research in the region are using all the major technologies outlined earlier. They are applying these technologies in human health, agriculture, and environmental protection. The region's firms and other institutions have developed expertise in several major technologies. A partial list includes genomics, proteomics (the study of the functioning of genes and proteins, respectively), monoclonal antibody production, implants and tissue substitutes, combinatorial chemistry, gene therapy, genetic modification of plants, and DNA sequencing.

In addition to these relatively more established technologies, firms and institutions in the region are taking the lead in newer biotechnologies.¹⁷ One of these is bioinformatics, the use of computer database management and computer simulation to model cells and biological molecules. A broader use of bioinformatics is to analyze data from different research and testing sources in an integrated way. Another new biotechnology in which the region's

institutions are at the forefront is biosensor and bio-nanotechnology, which combine information about cellular activity gained by biotechnology with nano-scale electronics. Some applications of this technology are monitoring single-cell activity electronically, analyzing blood components in real

efforts of Pennsylvania State University, Penn State Milton S. Hershey Medical Center, Penn State College of Medicine, and Lehigh University. The greenhouses will be consortiums of educational institutions, medical research establishments, private companies, and industry groups. They will provide

The region's firms and other institutions have developed expertise in several major technologies.

time, and testing food products for safety and nutritional value.

Recognizing the economic potential of biotechnology, educational institutions and state and local governments have joined with biotechnology companies and industry groups to promote the industry in their areas. Sixteen states are using funds from the tobacco industry case to support bioscience research and development, and 10 states have formulated biotechnology or life sciences strategic plans.¹⁸ Important aspects of joint public and private efforts to facilitate the development of biotech firms will be early-stage funding, academic and industry cooperation, and alliances between established large firms and startups, all of which have been key elements in the early growth of the biotech industry.¹⁹

Pennsylvania has sketched out an ambitious program to support the biotechnology industry in the state, using funds from the tobacco settlement. The state is establishing a life sciences venture fund and creating three "biotech greenhouses." One will be located in Philadelphia and one in Pittsburgh; the third, in central Pennsylvania, will coordinate the biotechnology

venture capital, promote commercialization of technology developed at universities, operate business incubators for biotechnology startups, and market their areas' biotechnology resources. The goal of the greenhouses is to commercialize the biotech expertise of the educational institutions and start-up companies in their areas.²⁰

In New Jersey, state government agencies, universities, and the Biotechnology Council of New Jersey, an industry association, have formed the New Jersey Coalition for Biotechnology to promote the state's biotechnology industry and facilitate pharmaceutical research. In recent years, the state's Commission on Science and Technology has provided start-up funds for several biotechnology research facilities, including the Biotechnology Center for Agriculture and the Environment and the Center for Advanced Food Technology at Rutgers University/Cook College, the Center for Advanced Biotechnology and Medicine at the University of Medicine and Dentistry of

¹⁷ See the reports of the three Pennsylvania biotech greenhouses (Biotechnology Greenhouse Corporation of Southeastern Pennsylvania, 2001; Pittsburgh Life Sciences Greenhouse, 2002; Life Sciences Greenhouse of Central Pennsylvania, 2002); Biotechnology Council of New Jersey, 2001; Delaware Biotechnology Institute, 2002.

¹⁸ See the paper from Battelle Memorial Institute.

¹⁹ See the article by Martha Prevezer.

²⁰ The Philadelphia greenhouse will focus on research in genomics, proteomics, monoclonal antibodies, diagnostics, implants, and bioinformatics. The Pittsburgh greenhouse will conduct research on proteomics, bioinformatics, gene therapy, diagnostics, and bio-nanotechnology. The central Pennsylvania greenhouse will focus on biotech drug design and delivery techniques, implants, and bio-nanofabrication.

New Jersey and Rutgers University, and the Lewis Thomas Molecular Biology Laboratory at Princeton University. In other forms of state support, the New Jersey state pension fund has begun making investments in biotechnology firms, and the state has enacted several tax credits that benefit biotech and other high-tech companies.

In Delaware, a consortium of state government, higher education institutions, and biotech companies was formed in 1999. This Delaware Biotechnology Institute opened a research facility in 2001 in the Delaware Technology Park, adjacent to the University of Delaware's campus in Newark. The institute provides research facilities and offers educational programs in the sciences and in the business aspects of biotechnology. The institute focuses on biotech applications in agriculture, biomaterials, human health, and marine ecosystems. In addition to funding the institute, the state of Delaware invests in biotech firms through several venture capital funds. Delaware also offers tax credits to businesses that engage in R&D in certain fields, including biological sciences, beyond the credits available for other types of industrial research and development.

OUTLOOK FOR THE BIOTECHNOLOGY INDUSTRY

Most industry analysts expect strong growth in the biotechnology industry in terms of both number of new products and revenue. Cancer has emerged as a major target of biotechnological research. Around half of the 500 drugs expected to be in development during 2002 will be aimed at treating a range of cancers.²¹ Developments in proteomics are stimulating much of this work.

²¹ See Frank DiLorenzo's *Industry Surveys*.

Another stimulus is the national effort to develop and stockpile vaccines and medicines to cope with biological terrorism. Short-term efforts to defend against bioterrorism are focused on developing vaccines and antibiotics to treat such diseases as anthrax, plague, and smallpox.²² But longer term, there will be an increased effort to develop means of detecting and responding to bioterror attacks based on DNA testing

Most industry analysts expect strong growth in the biotechnology industry in terms of both number of new products and revenue.

and bio-nanotechnology. In an effort to speed up the testing process, biotech firms will develop genetically appropriate organisms for drug trials. In addition, decoding the genomes of disease-causing bacteria and viruses will receive greater emphasis.

Some public policy issues might affect biotech R&D in medicine, chiefly stem cell cloning and patent protection for biotechnology products. The biotechnology industry generally supports the current voluntary moratorium on attempts to clone a complete human being, but it opposes total restriction on cloning human stem cells.²³ With respect to patenting, Congress is considering changes to U.S. patent law that will promote biotech research on a wide scale while providing effective patent protection to developers of new biotech products. The biotechnology industry favors maintaining and

²² See Pharmaceutical Research and Manufacturers of America, 2002.

²³ See Biotechnology Industry Association, 2001.

strengthening patent protection of modified genes and other biotechnological products. Areas where biotech patent protection might be vulnerable, according to industry organizations, are generic biotech products and the timing of patent protection during the drug approval process.²⁴ Specifically, the industry argues that the long lapse between the application for a drug approval and commercial introduction of a drug reduces the amount of time the patent protects the product once it is on the market.

In agricultural biotechnology, consumers' attitudes toward genetically modified foods might hinder further development. To date, genetically modified foods have gained acceptance among U.S. consumers, but they have been less well received in Europe. Surveys indicate that when consumers are aware of the desirable characteristics possible through genetic modification, they are more likely to have positive attitudes toward genetically modified foods.²⁵ Some agriculture industry analysts speculate that a dual market for foods may develop, in which consumers will tend to choose either genetically modified foods or nonmodified foods.²⁶ Such a development might ensure a continuing market for genetically modified foods, but the costs of segregating modified and nonmodified foods from farm to table is currently estimated to be almost prohibitively high. Working in the opposite direction, however, is the increasing effectiveness of genetic modification in reducing food-production costs.

With respect to the industry's structure, some maturing is in prospect.

²⁴ See Biotechnology Industry Association, 2002b.

²⁵ See U.S. Department of Agriculture, 2001b.

²⁶ See the article by Nicholas Kalaitzandonakes.

Interest in the industry is growing among venture capitalists, institutional investors, and large pharmaceutical firms. Although early-stage investments will still be important to young biotech firms, more and more biotechnology companies have amassed sufficient capital and personnel to bring new drugs to market without the need for alliances with major pharmaceutical firms. Thus, an increasing number of biotech firms will remain independent of pharmaceutical companies as they expand from research into manufacturing and marketing. At the same time, mergers and alliances between biotech firms, rather than between biotech and pharmaceutical firms, are likely to become more common. Nonetheless, major pharmaceutical firms are expected to retain an interest in alliances with biotech companies in order to ensure themselves of a continuing stream of new products and to complement their own biotechnology research.

In agricultural biotechnology

there has been an increase in vertical combinations of firms. For example, chemical companies and other biotech firms have merged with or acquired seed companies to obtain sources of seeds for modification and sales channels for modified seeds. In addition, high levels of research expenditure, the need to protect intellectual property rights, and increasing globalization of the agriculture industry in general have fostered increases in joint ventures, licensing agreements, and strategic alliances among biotech and traditional agricultural firms. These trends are expected to continue.

SUMMARY

The biotechnology industry is advancing rapidly in its ability to develop new medicines, diagnostic methods, and agricultural products. It is also growing as an industry. Capital investment in the industry is forecast to increase sharply, and as more new products are brought to market over the

next several years, the industry is expected to experience strong revenue growth. More companies as they grow will add production and marketing to their research and development efforts. Nevertheless, rapid advances in the life sciences that support commercial applications of biotechnology will mean that research remains a large and vital activity for successful biotech firms.

In the region, the well-established biotech presence should continue to grow. Public and private efforts in the region to further stimulate the industry are expanding. Particularly important, according to industry analysts, is a strategy for taking research discoveries on to successful product launches. This process of commercialization is a focus of state government and other efforts to encourage the industry here. The region is a biotechnology wellspring, and private and public interest in biotechnology in the region should ensure its continued success. 

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A Lifeline for the Weakest Link?

Financial Contagion and Network Design

BY YARON LEITNER

Links between firms, individuals, or countries are more common in this age of computers and global interdependence. While such links benefit participants, a tightly interconnected marketplace also has a downside: Problems at one firm can be quickly transmitted to others in a process economists call contagion. The possibility of contagion has led many people to worry about excessive linkages among financial institutions. In this article, Yaron Leitner describes how contagion can occur, explains why the threat of contagion is not necessarily a bad thing, and shows why some firms may choose to bail out other firms that are facing financial problems.

In the normal course of business dealings, banks, commercial firms, individuals, and even countries become interlinked in many ways. For example, banks enter financial contracts (such as interest rate swaps and forward contracts) with one another, individuals invest in the same stock, or firms provide credit to one another.

While everyone in the examples above clearly benefits from such linkages — otherwise, they

wouldn't have entered into contracts in the first place — there is a downside to a tightly interconnected marketplace. Problems at one firm can be quickly transmitted to others in a process economists call contagion.

The negative effects of contagion have led many people to worry about “excessive” linkages among financial institutions. Whether this concern is valid is an open question.

In this article, I will discuss some examples of the ways in which linkages can lead to contagion. Interestingly, these linkages may also lead to private-sector bailouts where one firm is rescued by other firms linked to it to prevent the spread of crisis. Webster's dictionary defines “bailout” as a “rescue from financial distress.” Usually this word carries

negative connotations because people associate financial distress with the misbehavior of firms' managers and assume that the bailout will require taxpayers' funds. But financial distress can also occur as a result of bad luck, and bailouts (for example, the ones discussed in this paper) need not necessarily involve public money. Therefore, in this article I will use the word bailout without any pre-judgment. In particular, I will show that interdependence may improve *private* incentives to provide insurance in the form of private-sector bailouts and that this may sometimes be beneficial both to individuals and to society as a whole.

I will also explain why the *threat* of contagion is not necessarily a bad thing and examine some of the tradeoffs involved in the design of a financial network. One benefit of understanding these tradeoffs is that we can then attempt to answer questions such as whether financial institutions should be closely interlinked or how many institutions should belong to a particular financial network.

HOW CAN FINANCIAL CONTAGION OCCUR?

A necessary ingredient for contagion is some sort of linkage among firms (or investors). For example, suppose that I plan to pay you next month out of the money that I receive from Dan. But what if Dan gets into financial trouble and can't pay me back? In other words, what if Dan defaults? I will not have the money to pay you, so I will default as well. What's more, if lots of people were linked in this way, Dan's default could trigger not only my



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default but also your default and the defaults of many others in a domino effect.

Researchers have studied several examples of financial contagion.

Trade Credit. In a 1997 working paper, Nobuhiro Kiyotaki and John Moore took the idea in the example above a bit further. In their model, firms form links by giving trade credit to one another. In other words, firms that supply goods to other firms agree to receive payments upon the delivery of those goods (and not when the order is made). In addition to illustrating how such linkages may lead to contagion, Kiyotaki and Moore also showed that flexibility in carrying out agreements does not necessarily promote stability.

To understand how their model works, consider the following: There are three firms: Mandark Time Dilators, Tom Swift Encyclotronics, and Dexter Lab Supplies (Figure 1). Mandark ordered 100 units of encyclotrons from Tom Swift. Mandark needs these encyclotrons to produce time dilators, so it is willing to pay \$1 per unit. Other firms don't value encyclotrons as much, so they will pay only 50 cents per unit. Mandark does not have cash today (when the order is placed), but it plans to have the cash next month when the goods are delivered. Thus, the contract calls for payment upon delivery.

Swift, in turn, ordered 100 units of special tubes from Dexter. As before, Swift needs these tubes for its production process. Swift agrees to pay \$1 per tube, and payment is due next month upon delivery. However, Swift does not plan to have any cash of its own next month. It intends to use the \$100 receivable from Mandark to pay Dexter.

This arrangement usually works well, but in some cases, it doesn't. Suppose, for example, that when we reach the delivery date, Mandark finds

out that it has a temporary liquidity problem — its profits turned out to be lower than expected (after an eclipse of the sun caused some unexpected delays in the production of time dilators); therefore, it has only \$60 rather than the anticipated \$100. Suppose further that the three firms aren't well enough known to be able to borrow against future revenues. In other words, Mandark cannot raise more money from a bank today to pay Swift, according to their initial agreement. Thus, it can buy only 60 units, for a total of \$60. This means that Swift is left with 40 units of encyclotrons.

Swift has two options. The first is to keep the undelivered units and wait until Mandark has the money (say, in three weeks). Then it will sell the 40 units at \$1 per unit. The second option is to "liquidate" the remaining 40 units, that is, sell them to another firm at a low price of 50 cents per unit, for a total of \$20.

If Swift chooses the first option, it will have \$60 (rather than the anticipated \$100) to pay Dexter; hence, it will buy only 60 tubes, for a total of \$60 (Figure 2). If Swift chooses the second option, it will have \$80 today — \$60 receivable from Mandark and \$20 from liquidation of the remaining units. Consequently, it will buy 80 units from

Dexter, for a total of \$80 (Figure 3). In both cases, Dexter will receive less than the \$100 it was supposed to get, so it may develop a liquidity problem as well. In other words, Mandark's financial problem can trigger financial problems at both Swift and Dexter. If many firms are linked in this way, a problem that originates in Mandark can spread to many firms in a contagious fashion.

But comparing Figures 2 and 3 illustrates another interesting point: You might think that flexibility in carrying out agreements — in our case Swift's giving Mandark some extra time to make payments — would promote stability. But in our example, the opposite is true. If Swift chooses to liquidate rather than reschedule Mandark's payments, Mandark's initial problem will have smaller effects on the whole chain of firms because Swift could buy 80 units from Dexter rather than only 60.¹ Of course, if all firms could postpone payments, no problem would arise. But it may be the case that

¹ If there were more firms linked in this way and each firm liquidated the undelivered units, Dexter could buy 90 units from its supplier, for a total of \$90; Dexter's supplier could buy 95 units from its supplier for a total of \$95; and so on. Eventually, firms could buy almost all of the goods they initially ordered.

FIGURE 1

Payments on Scheduled Delivery Date per Initial Agreement

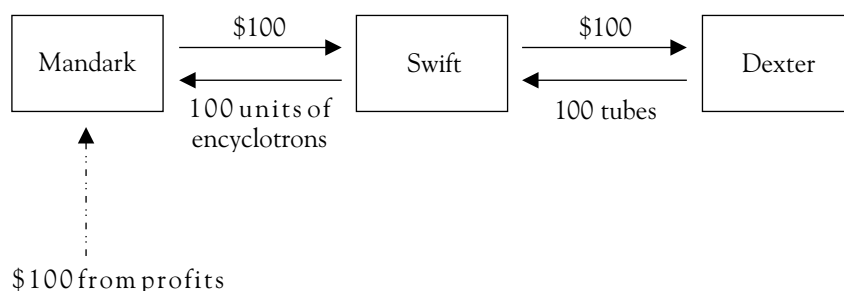
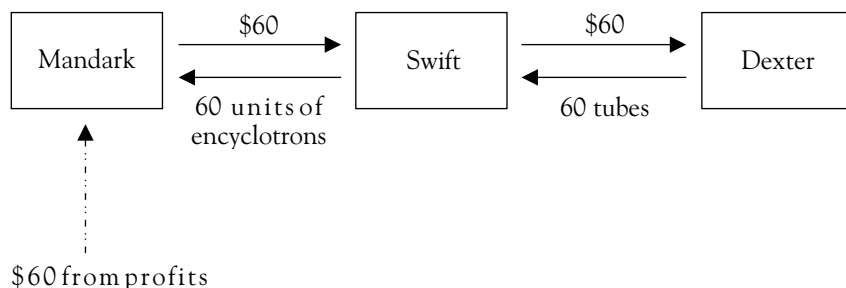
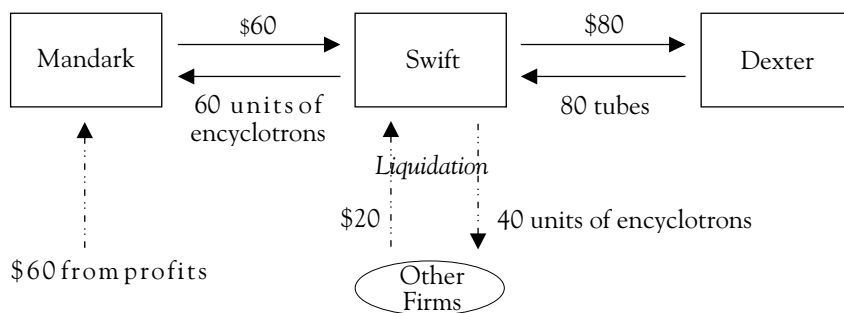


FIGURE 2

Payments on Scheduled Delivery Date If Swift Reschedules Payment for Remaining Units

**FIGURE 3**

Payments on Scheduled Delivery Date If Swift Liquidates Remaining Units



some firms along the chain must have the cash (or most of it) today or that the cost of postponing payments is too high for some firms. If this is the case, rescheduling payments may not be good for the entire group of firms (or, more generally, for the economy as a whole), although it may be privately beneficial for Mandark and Swift.

Interbank Deposits. The article by Franklin Allen and Douglas Gale demonstrates that linkages among banks can also lead to contagion. Banks often hold deposits with each other to facilitate the clearing of checks and other payments. Suppose, for example, that Janeway Bancorp holds some deposits in Picard Bancorp. When

Picard has liquidity problems because a number of borrowers are temporarily unable to make loan payments, its depositors may become worried about its

If many banks are linked to one another, the initial crisis at [one bank] may spread to other banks.

financial strength and its ability to honor agreements. In extreme cases, they may all panic and “run” to the bank to withdraw their money. Of course, the bank does not have enough cash for everyone. It can attempt to raise more cash by selling assets or calling in loans

early, but if it does so, the bank will receive less than full return. Thus, the bank may not be able to raise enough money to pay all of its depositors, so it goes bankrupt, that is, it is closed by its regulator.

How does Picard’s bankruptcy affect Janeway? Janeway Bancorp has many assets, some of which are the deposits it holds with Picard. But if Picard goes bankrupt, its uninsured deposits may lose most of their value. Therefore, Janeway may see a significant decline in the value of its assets. Like Picard’s depositors, Janeway’s depositors may also become worried and run to withdraw their deposits, thereby creating a liquidity problem for Janeway. If this liquidity problem is very severe, Janeway may go bankrupt and have to be closed as well. More generally, if many banks are linked to one another, the initial crisis at Picard Bancorp may spread to other banks.

Changes in Investors’ Wealth. Consider another example of contagion. When I invest my money in a stock issued by AlphaBeta Corporation, I am essentially linked to all other investors who buy that stock. If some of these investors also have XYZ Corporation’s stock in their portfolios, I may become exposed to changes in the price of XYZ, even though I do not hold that stock directly in my portfolio.

To see why, suppose that the price of XYZ declines because of some change in that company’s expected profits. Investors who hold XYZ’s stock in their portfolios lose money — their total wealth declines. As a result, they may become more careful with their

remaining money. Rather than investing it in the stock market, they may decide to invest in safer assets such as Treasury bills. Or maybe they'll just put their money in savings accounts in a bank. Thus, they may choose to sell XYZ's as well as other stocks they currently hold, for example, AlphaBeta's. This type of behavior may lead to a decline in the price of AlphaBeta's stock.² In other words, the contagion may spread from one stock to another.³

Note that the argument above does not require that the two firms, AlphaBeta and XYZ, be in the same industry. If this were the case, prices of these two stocks could rise or fall together simply because the two firms are similar. Thus, one important insight is that contagion may reduce the benefits of portfolio diversification.⁴

Another scenario in which changes in wealth can trigger contagion is when a firm needs to post collateral in order to borrow. Realizing that firms don't always pay back loans, lenders usually require collateral. For example, when a firm borrows in order to expand, it has to post its physical assets (for example, plant and equipment) as collateral to secure the loan. However, in an economic downturn, the value of that collateral might fall, even when the borrowing firm is doing well. Why? If other firms are doing poorly and their demand for new equipment decreases, this decline in demand will cause prices for all equipment to fall, including the

items posted as collateral. Since the value of the borrower's collateral has gone down, it might not be able to borrow as much as it originally planned, and it may not be able to expand by buying additional equipment. This, in turn, can translate into an even stronger decline in prices affecting even more firms.⁵

THE DESIGN OF FINANCIAL NETWORKS: COMMITMENT VS. SYSTEM FAILURE

All the examples in the previous section describe *financial networks*, a term that refers to the ways in which banks, firms, and investors are

requirements for banks. Margin requirements are cash or securities that an investor must set aside as collateral to make sure that he or she can honor a commitment. Capital requirements force banks to maintain a minimum equity-to-debt ratio. In some cases, these requirements may prevent a chain of defaults: A trader who requires high margins is less likely to be affected, should one of its counterparties default. Similarly, a bank with a large capital cushion is less likely to fail, should its deposits with another bank lose value.⁶

In many instances, networks don't just arise spontaneously; they are designed. One example is a joint liability

When we choose between being linked and not being linked, we need to weigh the benefits of better insurance against the potential for the whole group's collapse.

linked to one another through financial commitments or financial markets.

Networks can arise in different ways. Regulators often make rules that affect the extent to which financial institutions or investors are exposed to one another's problems. These rules can indirectly affect which types of networks develop. For example, by imposing restrictions on cross-border trade, regulators can make some links infeasible, thus preventing the spread of contagion from one country to another. Regulators can also set margin requirements for exchanges or capital

arrangement in which every member of a group is responsible for the others' debts. The Grameen Bank uses such arrangements to make unsecured loans to people in Bangladesh.⁷ In this arrangement, if one member of the group defaults, she and other members in her group are denied future loans.⁸

² See the article by Albert Kyle and Wei Xiong.

³ To learn more about the speed with which contagion develops, see the article by Roger Lagunoff and Stacey Schreft.

⁴ The argument in the previous paragraph can also be used to show how crises can spread across countries. If, for example, the two stocks were traded in two different countries, political instability in one country could result in price declines of the stocks in both countries.

⁵ This point is developed in the article by Nobuhiro Kiyotaki and John Moore. They also show that the crisis may even carry on to the future. In other words, small liquidity problems today can persist over time. The basic idea is that lower levels of investments today may translate to a decline in the value of the firm's assets in the future. This reduces the firm's ability to borrow in the future, leading to a further reduction in investments and a further decline in the value of the firm's assets.

⁶ One should be cautious, however, when setting margin requirements. If margins are adjusted daily, as in a futures exchange, temporary liquidity problems may mean that firms do not have enough cash to meet the margin requirements. This by itself may sometimes trigger contagion.

⁷ See the book by David Bornstein for more information about Grameen Bank.

⁸ One explanation why these loans work is that group members can impose additional penalties on a defaulting member, thereby encouraging her to take more care and pay her loan. This is sometimes referred to as social collateral. An alternative explanation suggested by my own work is that joint liability arrangements induce members of the group to bail out other members who may have difficulties repaying their loans.

Grameen Bank is not a public charity. To make profits, it needs to carefully design the loans. In particular, it may need to come up with answers to questions such as: How many members should form a group? What factors should be taken into account in determining the group's size?⁹

Networks can also arise from the choice of production methods. In the trade credit example, linkages would not arise if each firm produced its own inputs, rather than relying on other firms.¹⁰

Linkages May Enhance Commitment. When thinking about how to design a network, one factor that should be taken into account is that linkages can affect firms' ability to make commitments.

Companies often enter financial contracts (for example, forwards, futures, options, and swaps) for insurance purposes. This is sometimes referred to as hedging. One of the great benefits of insurance is that it permits the parties involved to undertake risky (but promising) activities efficiently. For example, suppose that I am uncertain about the future profitability of the firm I own. However, I know that it will either face liquidity problems or have more cash than it can use profitably. Suppose also that the same is true of the firm that you own. Both of us would find it profitable to enter insurance contracts that say: "I will give you cash when I have plenty and you have

liquidity problems, and you will give me cash when you have plenty and I have liquidity problems."¹¹ If the uncertainty about future profits resulted from some new, promising project I was considering, the inability to obtain insurance could mean that I would not undertake the project.

In some cases, however, it may be difficult or even impossible to ensure that anyone will actually honor such an agreement. People can walk away from agreements, hiding money or changing accounting figures. Many times you cannot do much about a broken agreement, or it may not be worth your time or money to go to court.

Firms that have a lot of cash will give cash to firms that face liquidity problems, not because of a formal contractual commitment but because of the threat of contagion.

Another potential problem is that it may be difficult for the contracting parties to ascertain precisely how much cash a firm can actually raise on short notice. Thus, if you entered a contract that says, "I will give you cash when I have plenty and you have liquidity problems," the court would not be able to enforce it. These are all special cases of what economists call lack of commitment — a person cannot commit to pay even if he is able to.

Without some method for enforcing commitments, companies simply won't sign such contracts, and everyone will be worse off because of the loss of insurance.

In a recent working paper, I show that linkages can lead firms to honor commitments that no contract could enforce. Firms that have a lot of cash (or a lot of liquid assets) will give cash to firms that face liquidity problems, not because of a formal contractual commitment but because of the threat of contagion. In other words, cash-rich firms are willing to bail out firms with financial problems to make sure that these problems will not spread to them. The idea is simple: If I bail you out, I lose something because I give you cash for free. On the other hand, if I choose not to bail you out, I may lose much more.

Consider, for example, the case in which I rely on you to supply my firm with an essential input. Suppose further that you have liquidity problems while I have extra cash. I can choose one of two options: either bail you out or not bail you out. If I choose to bail you out, I lose some money, say, \$1 million, because I am giving you cash that I could invest elsewhere for a higher return. However, if I choose not to bail you out, I may see a decline of, say, \$3 million in future revenues because you did not provide me with the essential part. This may even drive me out of business. Obviously, I am better off bailing you out.

Note that when I'm forced to bail you out, I — like any insurer forced to pay a claim — will probably regret the linkage that made the bailout necessary. I may wish that I had spread my business among many input suppliers, even those that charged me more. Remember, however, that the initial supply arrangement was made at a time when neither of us knew who would face liquidity problems and who would have extra cash. If we were both equally

⁹ Networks are also designed in payment systems. See the paper by Xavier Freixas and Bruno Parigi or my working paper.

¹⁰ Alfred Chandler's account of large firms taking over input suppliers and retail distribution in the early 1920s provides an example of a (nonfinancial) network designed to reduce linkages. According to Chandler, these firms became vertically integrated to enhance coordination and to prevent delays that would hold up the chain of production and distribution.

¹¹ This simple type of insurance contract is seldom observed in real financial markets, but an agreement like this underlies the more complicated contracts we do observe, such as options.

likely to face problems, the mutual exposure created by the exclusive supply arrangement was a good idea for both of us: Each expected the other to provide insurance against the possibility of liquidity problems. In other words, the benefit of being linked is that it leads each of us to bail out the other, just as if we were able to commit to honor formal insurance contracts.

But Linkages Also Promote Contagion. Remember, however, that linkages may lead the whole system to collapse as problems at one firm spread to others. In my working paper I illustrate two general reasons the whole financial network may collapse.

The first reason is obvious: There may not be enough cash to carry out the bailout. For example, suppose that you need \$1 million to cover your financial problems. What if I only have half a million dollars today? If we were not linked to one another, my firm would survive while your firm would go bankrupt. But when we are linked to one another, both your firm and mine will go bankrupt.

The second reason, which is not so obvious, is that there may be enough cash to carry out a bailout, but it is concentrated in the hands of very few firms. Suppose, for example, that there are six firms: five that have enough cash to carry out their business and one with significant liquidity problems. Now, take an extreme case and suppose that only one of those five firms has extra cash. If that firm decides to handle the bailout on its own, it will need to spend a lot, say, \$5 million. If the firm with extra cash decides not to bail out the troubled firm, it will be able to keep all its money but may lose future revenues of, say, \$3 million because of its linkage. In this case, the threat of contagion is not severe enough to compel the healthy firm to carry out the bailout on its own; therefore, all the firms will face the negative consequences of contagion

(losing future profits and potentially going out of business). On the other hand, if wealth were spread more evenly among the five healthy firms (for example, if each of the five healthy firms had \$1 million to spare), a bailout could occur and contagion would be contained, since the cost of not bailing out the firm would exceed the cost of joining the bailout.

Network Design Involves Tradeoffs. As we can see from the discussion above, when we choose between being linked and not being linked, we need to weigh the benefits of better insurance against the potential for the whole group's collapse. Note that the choice is not necessarily between having everyone linked to everyone else or having no one linked to anyone else. Sometimes the best solution is to create smaller groups of individuals who are linked to one another. In the case of loans made by Grameen Bank, groups usually include five individuals.¹²

THE PROS AND CONS OF BAILOUTS

So far we have seen how contagion can happen (because of linkages among firms and individuals) and how the threat of contagion can induce voluntary bailouts that may prevent contagion. (That is, these same linkages enhance commitment.) In some cases, a bailout can succeed only if many firms participate because any one firm may not have enough cash for the bailout or because one firm alone doesn't have the incentive to bail out another because the cost to the firm is too high.

Participation by many firms raises a new issue: All firms might

¹² In my working paper I present examples in which the group size that best balances the benefits of greater commitment and the problems of increased risk of system failures is small (say, three), for small economies (of, say, 12 people), large economies (of, say, 12 billion people), or even infinitely large economies.

benefit if they could coordinate to bail out a single firm in trouble, but acting in concert can be difficult without some formal organization. This may be especially true if the number of firms that need to coordinate their actions is large. One reason coordination may be unusually difficult is "free-riding." Each firm would like the other firms to do the work. In other words, if other firms participate, my participation may not be crucial for the success of a bailout. So I may decide to save money and not participate. But if many firms reason this way, coordination fails and the bailout never takes place.

An Example of Successful Coordination. Both the difficulties of coordination and the availability of coordinating mechanisms are well illustrated by the private-sector bailout of Long Term Capital Management (LTCM), in which the Federal Reserve Bank of New York acted as coordinator. LTCM, a prominent hedge fund, suffered large losses and was on the verge of bankruptcy after Russia declared a debt moratorium on August 17, 1998. Throughout September, LTCM tried to initiate an infusion of funds from its bankers. Coordination was necessary because any individual bank that attempted to bail out LTCM would simply be reducing the other banks' losses without providing enough funds to solve the problem. One problem that made coordination difficult was that different banks had different levels of exposure to LTCM. Herbert Allison, then president of Merrill Lynch, was one of the leaders in the effort to organize the bailout. After analyzing the plan, he advised the New York Fed's Peter Fisher that "the only way to get the banks together was for the Fed to call them and offer to hold a meeting."¹³

¹³ As reported in Roger Lowenstein's book, p. 198.

On September 22, Peter Fisher contacted the 16 banks that were the largest counterparties to LTCM and organized an emergency meeting at the New York Fed. On September 28, a consortium of 14 commercial and investment banks agreed to bail out LTCM. The total amount was \$3.6 billion, and the consortium of bankers contributed all the money; the government provided no funds or guarantees. Some banks (those with high exposure) contributed \$300 million each while other banks (those with low exposure) contributed \$100 million each. Two banks (Citicorp and Bear Stearns) declined to participate.

On October 1, 1998, in his testimony before the House Committee on Banking and Financial Services, Federal Reserve Chairman Alan Greenspan said: "Officials of the Federal Reserve Bank of New York facilitated discussions in which the private parties arrived at an agreement that both served their mutual self-interest and avoided possible serious market dislocations." He also said, "The Federal Reserve provided its good offices to LTCM's creditors, not to protect LTCM's investors, creditors, or managers

from loss but to avoid the distortions to market processes caused by a fire-sale liquidation and the consequent spreading of those distortions through contagion."


Bailouts May Undermine Incentives to Be Careful. During that same testimony, Chairman Greenspan also acknowledged the problem of moral hazard: "Of course, any time that there is public involvement that softens the blow of private-sector losses — even as obliquely as in this episode — the issue of moral hazard arises." What does *moral hazard* mean? Moral hazard usually refers to high-risk activities in which an insured person might choose to engage, *but that the insurer cannot monitor*. For example, if you have homeowners insurance, you may be less careful about locking the doors when you go out or you might leave a fire unattended in your fireplace. Similarly, if you thought that you would always be bailed out, you might choose to take excessive risks, that is, risks that would not be sanctioned by an insurer.

Does this mean that we should try to avoid bailouts at all costs? The answer is not necessarily. That would be like saying that we should not be

allowed to get homeowners insurance. However, incentives such as those created by moral hazard are another factor that must be taken into account when designing financial networks.

SUMMARY

In this article, we have seen how the ways in which firms are linked to one another may trigger contagion. We discussed the issue of an optimal design for networks and showed that we need to be careful not to fall into traps. Things may not be as simple as they first appear. The negative effects of contagion may lead us to believe that we should limit exposure between financial institutions.

We have seen, however, that in some cases such exposure may be good for everyone despite and because of the threat of contagion: The threat of contagion enhances commitment. We have also seen how bailouts may prevent contagion, but they may require a coordinator to bring them to fruition. Like any form of insurance, bailouts may create a moral hazard, but that does not necessarily mean we should avoid them at all costs. We should always think about the tradeoffs. 

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Widening the Wage Gap:

The Skill Premium and Technology

BY KEITH SILL

Workers who acquire more skills and more knowledge typically earn a higher wage than those who don't. Economists call this difference in wages between high-skill and low-skill workers the skill premium. Over the past 30 years, the skill premium has increased dramatically. Although economists are still debating the causes of this increase, it seems likely that skill-biased technical change has played a large role. As companies have invested in new technologies, demand for workers who can use them has surged. Keith Sill reviews the literature and tells us why some theories fall flat and why technology seems to be the key to the widening wage gap.

Data on earnings and wages show that workers receive a monetary reward for attaining high levels of skills and that this reward has been increasing over time. In fact, over the past 30 years, the wages paid to the most highly skilled workers — those who have higher levels of education, ability, or job training — have increased dramatically relative to the wages of the least skilled workers. This difference in wages between skilled and unskilled workers is called the *skill premium*.



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Workers have responded to these monetary incentives by acquiring more skills through schooling. From the 1970s to the mid-1990s, the number of college-educated workers in the United States almost doubled, and they now represent a much larger share of the workforce. If we equate skill with college education, the supply of skilled workers was increasing dramatically at the same time that the skill premium was rising. We might think that a greater supply of skilled workers would lower wages for those workers, thereby lowering the return to acquiring skills and the skill premium. But since the supply of skilled workers increased dramatically at the same time that the skill premium increased — and supply increased even more rapidly in the 1980s — demand for skilled workers must also have increased.

In this article, I will examine theories and evidence that shed light on the dramatic increase in the skill premium over the past three decades. Explanations that have been proposed to account for the increase include the decline in the fraction of the labor force that is unionized and increased wage competition from unskilled workers in less developed countries. However, these theories are unable to explain important facts about the skill premium. Rather, the increased relative wage paid to skilled workers appears to be linked to new technologies that firms are using and to investments that firms are making in new equipment that embodies new technologies. For firms to take full advantage of this new equipment, they need high-skill workers to design, install, operate, and maintain it. At the same time, this new equipment often performs tasks that unskilled workers used to perform. As the economy has become more knowledge based, the demand for skilled workers has surged.

ESTIMATING SUPPLY

We can roughly estimate the supply of skilled workers by examining educational attainment. Generally, we consider workers with a college degree to be skilled and those with no college education to be unskilled. To account for workers who have some college education but no degree, we divide those workers evenly between skilled and unskilled workers. This measure of skilled workers is called *college-equivalent workers*. The relative supply of skilled (that is, college-equivalent) workers rose from 17 percent of the labor

force in 1960 to about 43 percent in 1996 (Figure 1). There was slightly faster growth in the supply of college-equivalent workers in the 1970s.

MEASURING THE RETURN TO ACQUIRING SKILLS

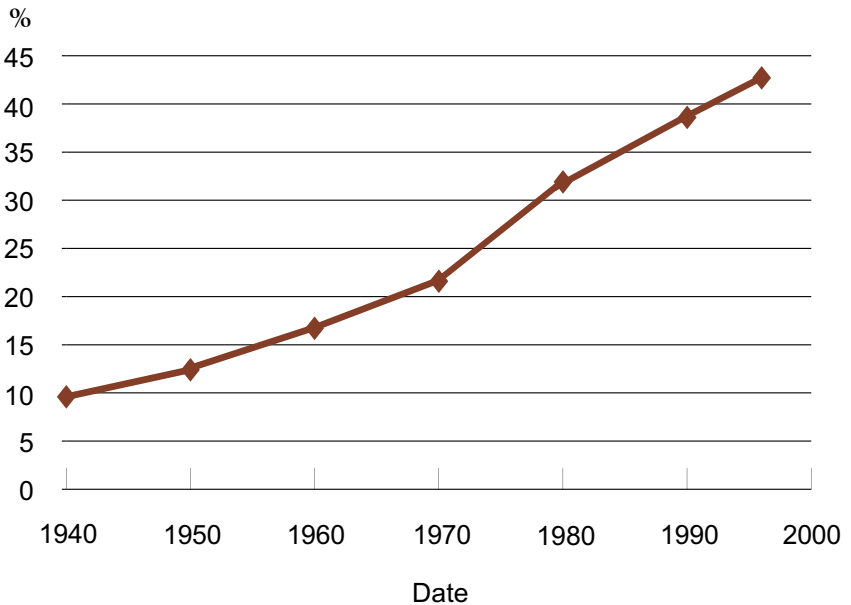
There are several ways to measure the extent to which the disparity in wages between skilled and unskilled workers has been increasing in the U.S. economy. Often, analysts focus on the average wages of skilled workers and compare them to the average wages of unskilled workers. The higher the disparity in wages between skilled and unskilled workers, the higher is the skill premium.

Returns to Education. A higher level of education is one way that workers can upgrade their skills and increase their wages. Thus, we can examine how the return on earnings from acquiring more education has changed over time, since, generally, the return to years of schooling tracks changes in the wage structure. For example, we can study how earnings tend to increase after a worker spends another year in college. A 1999 paper by Claudia Goldin and Lawrence Katz examined the returns to education for U.S. workers. The return to education is measured as the percent increase in wages, calculated at an annual rate, that workers with more education get compared with workers with less education. Goldin and Katz found that the return to a year of college education for young men fell slightly, from 9.6 percent in 1969 to 8.4 percent in 1979, then shot up to 13.3 percent in 1995.¹ Thus, workers who acquire more

¹ The return to a year of college is defined as the natural log of the ratio of mean wages for those with exactly 16 years of schooling and those with exactly 12 years of schooling divided by 4. The wage data were adjusted for workers' experience and geographic differences. See Goldin and Katz's 1999 paper for details.

FIGURE 1

Supply of Skilled Workers



* Supply of college-equivalent workers as a fraction of the labor force. College equivalent workers are defined as workers with a college degree plus 50 percent of workers with some college education. Data taken from Table 1 in David H. Autor, Lawrence F. Katz, and Alan B. Krueger, "Computing Inequality: Have Computers Changed the Labor Market?" *The Quarterly Journal of Economics*, 113:4 (November 1998), pp. 1169-1213. © 1999 by the President and Fellows of Harvard College and the Massachusetts Institute of Technology. Used with permission.

education and improve their skills receive a greater return from that education today than they did in the 1960s. This suggests that earnings inequality between high-education and low-education workers has risen compared with what it was in 1969. Data for 1999 show that having more education tends to pay off: The average earnings of high-school-educated workers were \$24,572, compared with average earnings of \$45,678 for college-educated workers and \$67,697 for workers with advanced degrees.²

We can also directly compare the wages of workers who went to college and those who did not. The average wage of a college-educated worker was about 59 percent higher

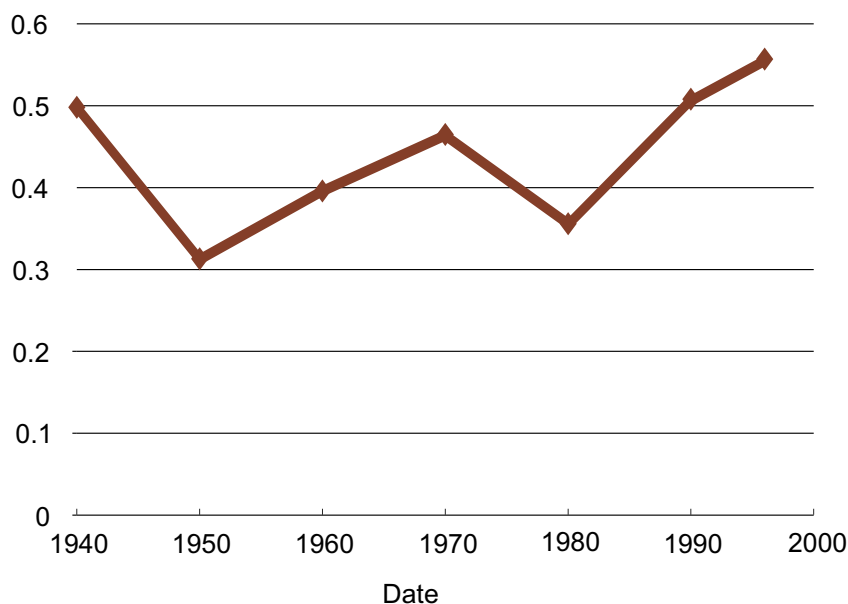
than that of a high-school-educated worker in 1970 and about 75 percent higher in 1996. The skill premium began to rise dramatically beginning around 1980 (Figure 2).³ More recent data suggest that the skill premium continued to rise from the mid-1990s through 2000.⁴

Distribution of Wages. Other measures of wage disparity tell a similar story. We can summarize wage disparity by examining the distribution of wages across workers, which shows the frequency with which wages of a

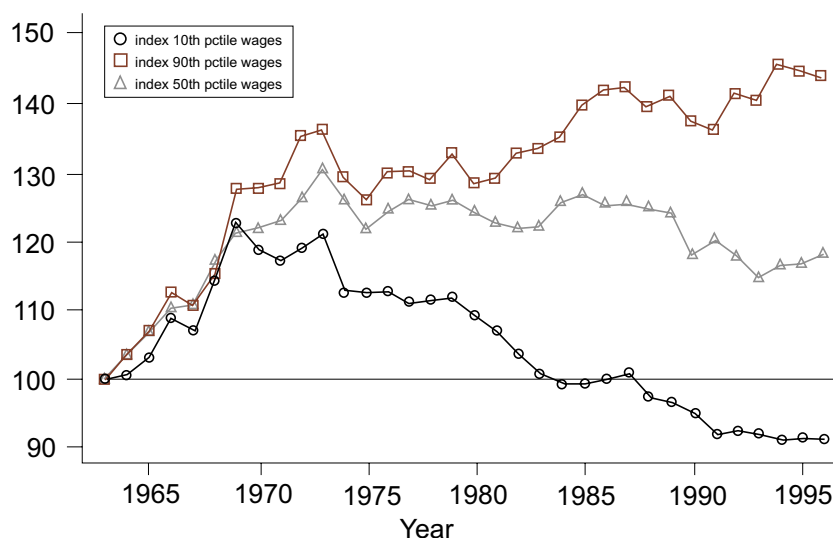
³ These numbers are based on those in the paper by David Autor, Lawrence Katz, and Alan Krueger. They report that the natural log of the ratio of a weighted average of college and post-college wages to high-school wages was 0.465 in 1970 and 0.557 in 1996.

⁴ See the paper by Paul Beaudry and David Green.

² For more on recent trends in the dispersion of wages, see the article by Bharat Trehan.

FIGURE 2**College Skill Premium***

* Log relative wage of college plus post-college workers to high-school workers. Last point plotted is for 1996. Data from Autor, Katz, and Krueger.

FIGURE 3**Indexed Wages for White Males 1963-1997***

*Changes in the indexed value of the 90th, 50th, and 10th percentiles of the wage distribution for white males (1963 values normalized to 100). Data from March CPSS.

Figure taken from Daron Acemoglu, "Technical Change, Inequality, and the Labor Market," *Journal of Economic Literature*, 40, 1, 2002 (Figure 2). Used with permission.

certain level are likely to occur in the population of workers. For example, we would expect to find relatively few workers who make over \$200,000 a year, but many more workers who make around \$40,000 a year. We can then use this distribution to examine how the wages of the richest and poorest workers change over time. In fact, the wage differential between workers whose earnings are in the top 10 percent of the wage distribution (the richest workers) and workers whose earnings are in the bottom 10 percent of the wage distribution (the poorest workers) has increased dramatically since the 1970s. So has the wage differential between the average worker (50th percentile) and workers in the lowest 10th of the distribution. Wages of high-earning white males and low-earning white males rose in tandem during the 1960s (Figure 3).⁵ Beginning in the 1970s, wages began to diverge. By 1995, top earners' wages were about 40 percent higher than they were in the early 1960s (that is, the index rose to 140), while earners at the bottom of the distribution saw real wages fall 10 percent (the index fell to 90). Workers in the middle of the distribution fared somewhat better than those at the bottom: The average worker saw his wage rise about 15 percent from the early 1960s until 1995.

EXPLAINING THE INCREASE IN THE SKILL PREMIUM

The rise in the skill premium could be due to rising wages for skilled workers or falling wages for unskilled workers, or both. The data show that the real wages (wages adjusted for inflation) of skilled workers generally have risen since the mid-1970s. However, the real wages of unskilled workers

⁵ We look at white males to control for changes in demographics over time, such as the increasing share of women in the labor force. A change in the index represents a percent change from 1963, the base year for the index.

fell from the mid-1970s to the early 1990s, then began to rebound. Thus, part of the story for the rise in the skill premium since the 1970s is that real wages for unskilled workers fell over much of the period.

Several theories have been proposed to account for the increase in the skill premium in the United States.

Globalization. One commonly proposed explanation highlights globalization and increased trade with less developed countries. In less developed countries, low-skill workers are more abundant than high-skill workers because workers in poor countries tend to have less training and education and to work in industries not as technically advanced as those in developed countries. When the U.S. increases its trade of goods and services with less developed countries, the low-skill workers in poor countries put downward pressure on the wages of low-skill workers in the U.S., since the two sets of workers often produce comparable items. Similarly, the goods that high-skill workers produce in the U.S. are scarce in less developed countries. So when less developed countries import more of those goods, demand increases, and there is upward pressure on the wages of high-skill workers in the U.S.

Empirical support for the globalization theory is weak, though. For the U.S., trade with less developed countries represents, at most, 2 percent of gross domestic product (GDP). Because it contributes such a small part to U.S. GDP, trade with less developed countries is unlikely to be driving the trend in the skill premium. Furthermore, the trade-liberalization story implies that the prices of less skill-intensive goods in the U.S. economy should fall relative to the prices of more skill-intensive goods because the U.S. would import the goods produced by low-skill foreign labor and export goods produced by high-skill U.S. labor. But the data contain little

evidence for this price behavior.

If trade were the main force behind the rise in the skill premium, we would find that increased production of skill-intensive goods (to meet increased demand for these goods from foreign countries) would be drawing workers

increased wage inequality is the subject of much research.⁷

In the United States, the big decline in unionization came during the 1980s, after the defeat of the air-traffic controllers' strike. This large drop in unionization occurred after the rapid

The rise in the skill premium could be due to rising wages for skilled workers or falling wages for unskilled workers, or both.

away from other sectors of the economy. However, some studies have indicated that all sectors, even those that produce less skill-intensive goods, have increased their demand for skilled workers, that is, production of many goods is becoming more skill-intensive.⁶ Thus, we do not see the across-industry shift in employment implied by the trade story.

Decline in Unionization.

Another theory that has been proposed to explain the rise in the U.S. skill premium is that the fraction of the workforce that is unionized has been declining for some time. Union contracts tend to be written in such a way that the difference in wages between the highest and lowest paid workers is less than what it would be if there were no unionization. For example, some union contracts may tie salary increases more to tenure on the job than to merit.

Unions had set wages for many occupations in the postwar U.S. However, the fraction of the civilian labor force that is unionized peaked at about 25 percent around 1970, then fell to about 13 percent in the early 1990s. Could this decline in unionization have contributed significantly to the increase in wage inequality? The theory that the decline in unionization has caused

increase in the skill premium in the 1960s. Note, though, that the decline in unionization does coincide with the drop in wages of unskilled workers, and so it may be a contributing factor in the rise in the skill premium. One difficulty with the unionization theory is that wage inequality (the difference between the highest paid workers and the lowest paid workers) has also increased in many professions, such as medicine and law, that are not generally unionized. Evidence from other countries, such as the United Kingdom and Canada, also shows little correlation between the extent of unionization and trends in wage inequality. Thus, while the decline in unionization may have been a contributing factor to the increase in the skill premium in the U.S., it does not appear to be a primary explanation.⁸

Advances in Technology.

The most promising theory to account for the rise in the skill premium ties the

⁷ A readable discussion of such research is Martin Asher and Robert DeFina's 1995 *Business Review* article.

⁸ Another potential explanation for the rise in the skill premium and the fall in wages of low-skill workers is immigration. Immigrants have tended to be low-skill workers; thus, an influx of these workers may have depressed wages of other low-skill workers. However, empirically, immigration's effect on the skill premium appears to be small. See the paper by George Borjas, Richard Freeman, and Lawrence Katz.

⁶ See the article by Berman, Bound, and Griliches and the one by Autor, Katz, and Krueger.

change in wages to the advancement of technology. When advances in technology increase demand for skilled workers more than demand for unskilled workers, economists say that technical change is skill-biased.

New technologies are constantly being developed, and firms have been investing heavily in equipment that uses these new technologies. The new high-tech equipment, such as computer-controlled machines, industrial robots, and flexible manufacturing systems, performs more efficiently in the hands of skilled workers. As this advanced technology becomes more common in the workplace, it tends to replace unskilled workers; at the same time, it requires additional skilled workers to operate it.

Directly measuring the amount of technological progress in the U.S. economy is difficult. Indirect measures, such as the amount of spending on research and development and the amount of spending on computers, are available. A 1994 study by Eli Berman, John Bound, and Zvi Griliches found that spending on research and development and computers accounts for about 70 percent of the shift of the manufacturing labor force from production workers to nonproduction workers from 1979 to 1987. Conceptually, production workers are typically associated with “blue-collar” jobs and nonproduction workers with “white-collar” jobs.⁹ In addition, the classification of workers into blue-collar

and white-collar jobs closely reflects their classification into those with a high-school education and those with a college education. Hence, the shift from production workers to nonproduction workers indicates a shift from low-skill to high-skill workers. By this measure, spending on new technologies has helped boost demand for skilled workers.

For the most part, new technologies that were introduced in the 20th century tended to replace unskilled workers and favored the use of skilled workers.

Other studies have found that the share of college-educated workers has increased substantially in all sectors of the economy since the mid-1970s.¹⁰ The demand for skilled workers must have been increasing even faster than the supply, however, since the skill premium has been rising.

The data suggest that new technologies, new capital (machines), and skilled labor go together and that new machines are more likely to replace unskilled workers. As firms invest in new technologies, the demand for skilled workers increases relative to the demand for unskilled workers, and the

relative wage paid to skilled workers rises.

Remember, though, that not only have the wages of skilled workers increased, but also those of unskilled workers have decreased. Can technological change lead to lower wages for unskilled workers at the same time that it increases wages for skilled workers? Under certain conditions, the answer is yes. Suppose there are two production sectors in the economy: One sector uses capital and skilled workers to produce goods, and the other uses capital and unskilled workers. A new technology that works well with skilled labor might induce a flow of capital from the sector with unskilled workers to the one with skilled workers in order to take advantage of skilled workers’ increased productivity. As capital flows out of the unskilled sector, workers in that sector will have less capital to work with, making them less productive and leading to a decline in wages paid to unskilled workers. Hence, technical change that favors skilled workers could lead to a drop in the wages of unskilled workers and a simultaneous rise in the wages of skilled workers.¹¹

THE SKILL PREMIUM SURGED IN THE 1980s

If changes in technology explain the increase in the skill premium, the next question is: Did changes in technology accelerate in the 1980s and lead to a surge in the skill premium in that decade?

Historical studies have found that skill-biased technical change was prevalent throughout the 20th century. For the most part, new technologies that were introduced in the 20th century tended to replace unskilled workers and favored the use of skilled workers. In their 1998 article, Claudia Goldin and

⁹ The paper by Berman, Bound, and Griliches uses the Annual Survey of Manufactures’ definition of production workers: “workers (up through the working foreman level) engaged in fabricating, processing, assembling, inspecting, and other manufacturing.” Nonproduction workers are “personnel, including those engaged in supervision (above the working foreman level), installation and servicing of own product, sales, delivery, professional, technological, administrative, etc.”

¹⁰ Berman, Bound, and Griliches found that the shift of workers from production tasks to nonproduction tasks is happening within industries. Thus, many industries increased their demand for skilled workers as a result of advancements in technology; it is not the case that the main driver has been a shift from low-tech to high-tech industries. Autor, Katz, and Krueger’s research also confirms this finding.

¹¹ See the paper by Beaudry and Green.

Lawrence Katz argue that new manufacturing technologies that replaced unskilled workers and increased the demand for skilled workers became prevalent with the introduction of batch and continuous-process methods of production in the early 20th century.¹² Similarly, the switch from steam and water power to electrical power reduced the demand for unskilled workers in many transportation and assembly tasks. More recent examples of new technologies that have replaced unskilled labor include robotic assembly operations and programmable machine tools.

But if skill-biased technical change was occurring throughout the 20th century, potentially raising the relative wages of skilled workers versus those of unskilled workers, how do we account for the dramatic increase in wage inequality over the past 20 years? Figure 2 shows that the rise in the skill premium was particularly large in the 1980s. Why?

Accelerating Demand. Did skill-biased technical change accelerate in the 1980s and boost demand for skilled workers? Several pieces of indirect evidence suggest this may be the case. Studies have found that almost all industries began to employ more educated workers in the 1970s and 1980s. Furthermore, industries that used computers more intensively experienced more rapid upgrading in the skills of their workforces.¹³ However, it is not clear that advances in computers and information technology increased the demand for skilled workers more rapidly than other new technologies did in the

1950s and 1960s. In other words, we cannot conclude just by looking at patterns of computer use that demand for skilled workers has accelerated.

Autor, Katz, and Krueger provided evidence in support of an accelerating demand for skilled workers. They compared data on the skill premium and the supply of skilled workers during two periods: 1940 to

We cannot conclude just by looking at patterns of computer use that demand for skilled workers has accelerated.

1970 and 1970 to 1995. The period from 1940 to 1970 was characterized by slow growth of both the skilled labor supply and the skill premium. From 1970 to 1995, both the supply of skilled workers and the skill premium grew rapidly. If demand for skilled workers had not accelerated, we would expect the skill premium to have grown more slowly from 1970 to 1995 than over the earlier period, since the supply of skilled workers was growing faster in the later period.

Other evidence is consistent with the view that skill-biased technical change has accelerated. The data suggest that new capital equipment has become cheaper. This new equipment often replaces unskilled workers because it can perform tasks they previously did. In addition, adding new capital equipment to the workplace means that firms must hire skilled workers to use, operate, and maintain it. As the price of new capital equipment falls, firms acquire relatively more of it, boosting demand for skilled labor and decreasing demand for unskilled labor. Data on the price of new equipment suggest that the decline in price accelerated at the beginning of the 1970s.¹⁴ Hence, the demand for skilled workers may have

accelerated as firms responded to the price incentive to invest more in new capital equipment.¹⁵

Total Factor Productivity.

One caveat in tying the rise in the skill premium to advances in technology and the associated investment in high-tech goods is the behavior of measured technological progress. Has technology advanced at a more rapid pace since the

1970s? A broad measure of technical change is total factor productivity (TFP) growth. TFP growth, growth in capital stock, and growth in total hours worked in production are combined to determine output growth, and TFP is the part of output growth unexplained by growth in capital stock and the labor force. In the data, though, measured TFP growth did not surge upward during the period in which the skill premium shot up, casting some doubt on the view that technical progress has accelerated since the 1970s.¹⁶

¹⁴ See the article by Per Krusell, Lee Ohanian, Victor Rios-Rull, and Giovanni Violante.

¹⁵ There are reasons to be cautious about this story of more rapid investment. It is very hard to accurately measure the price of equipment that is undergoing rapid technological advance. Take the case of computers. The change in the quality of computers over time makes it difficult to quantify exactly how much cheaper computers are today than they were in the past. Difficulties in consistently measuring the price of new equipment over time make it harder to be confident that the decline in the relative price of new equipment accelerated in the 1970s, thus increasing investment. It certainly does seem plausible, though.

¹⁶ For more information about TFP, see the article by Satyajit Chatterjee.

¹² Batch processes are used for processing liquid and gaseous materials such as chemicals, wood pulp, and dairy products. Continuous-process methods are used for products that require little assembly and have few moving parts such as canned foods, soap, and cigarettes. See Goldin and Katz 1998.

¹³ See the paper by Autor, Katz, and Krueger.

Is the lack of evidence for faster TFP growth a nail in the coffin for technology-driven gains in the skill premium? Possibly not, given that true TFP growth is hard to measure. One consequence of rapid technological advance is that prices may be hard to measure accurately over time. And those difficulties may increase over time as technology grabs an increasingly larger share of the economy. If price inflation is overstated, measured real output growth and measured TFP growth will be understated. Thus, the lack of evidence for faster TFP growth since the 1970s may be a result of the way government statistics track prices over time.¹⁷

WHY HAS SKILL-BIASED TECHNICAL CHANGE ACCELERATED?

Notwithstanding the caveats mentioned above, the weight of the evidence seems to suggest that skill-biased technical change accelerated during the 1980s for the U.S. economy. Why? Several theories have been put forward. One possibility, explored in a 1998 article by Daron Acemoglu, is that designers and implementers of new technologies, such as scientists and engineers, recognized that the relative supply of skilled workers had increased, then developed technologies that took advantage of the increasingly skilled workforce. Perhaps engineers specifically designed new machines in a way that could better use the abilities of skilled workers. Economists call this theory *directed technical change*. An attractive feature of this story is that it gets the timing right between the increase in the

number of skilled workers and the increase in the skill premium — they showed faster growth at about the same time.

However, we should be cautious in using the theory of directed technical change to interpret the recent facts because another important episode in U.S. history seems to contradict the theory's predictions. During the 1940s, there was a surge in the supply of high-school-educated workers, who were the skilled workers of that time. But the data show no dramatic increase in the wages paid to high-school-educated workers in the 1940s.¹⁸ Why didn't the engineers of the 1940s design new

diffuse through the economy, but they eventually lead to an increase in worker productivity. Early examples of GPTs include the invention of writing, typesetting, and printing, and the development of electric motors.

If the computer and communications revolution is an example of GPT that slowly diffused through the economy, could it explain the acceleration of skill-biased technical change and the effect of that acceleration on wages? It is likely that it takes time for firms and workers to learn to use new technologies in the most efficient manner. When computers and new software were first introduced, there was a steep learning

The weight of the evidence seems to suggest that skill-biased technical change accelerated during the 1980s for the U.S. economy.

equipment that used the relatively abundant supply of skilled workers and thus increase demand for skilled workers more than enough to offset the increase in supply?

Another story that potentially explains the acceleration of skill-biased technical change is related to the computer and communications revolution and the extent to which it has affected many different sectors of the economy. The computer and communications revolution that began in the 1970s may be an example of what economists call a general purpose technology (GPT). A GPT is an innovation that has the potential to become widely used across many sectors of the economy and that drastically changes the way businesses and factories in the affected sectors carry out their operations. GPTs may be slow to

curve as workers learned to use them effectively. Measured productivity may have declined as workers learned because time was allocated away from directly productive tasks and into learning the new technology. Once firms and their workers became comfortable with the new technology and discovered effective ways to use it in production, productivity growth began to increase. At the same time, the demand for workers who could use the new technology rose. If demand accelerated more than supply, the skill premium paid to high-skill workers would have tended to rise.¹⁹

CONCLUSION

Which of these stories — directed technical change or GPT or perhaps an entirely different one — best fits the facts remains an open question.

¹⁷ An in-depth discussion of many of the issues surrounding these measurement difficulties and their implications for economic growth can be found in the 1997 *Business Review* article by Leonard Nakamura.


¹⁸ See the 1999 paper by Goldin and Katz.

¹⁹ See the article by Philippe Aghion.

What is clear is that wage inequality increased over the 1980s and even accelerated relative to its historical trend.

In their 1999 paper, Goldin and Katz claimed that “economic inequality is higher today than at any time in the past 60 years, measured by both the

wage structure and wealth inequality.” We have seen that demand for skilled workers rose dramatically in the 1980s. For policymakers to effectively address concerns about inequality created by the widening wage gap between skilled and unskilled workers, they must understand its potential causes.

Our discussion and review of the literature suggest that skill-biased technical change is likely an important part of the story of rising wage inequality. If so, policies that focus on helping workers acquire skills are a good place to begin in addressing concerns about inequality. 

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