Sizing Up Nanoelectronics: Gauging the Potential for New Productivity Wave

By Keith Phillips, Adam Swadley, Jackson Thies and Mine Yücel

The long-term impact of new technologies and innovation extends beyond economic effects, creating social and cultural benefits.

The Federal Reserve Bank of Dallas, in cooperation with the Semiconductor Industry Association (SIA), hosted a conference on nanoelectronics and the economy in Austin on Dec. 3, 2010. Economists and scientists explored how information technology has affected U.S. productivity and output growth and prospects for the future. A summary of conference highlights follows. Presenters' papers and presentations are available on the Dallas Fed website at www.dallasfed.org/news/research/2010/10nano.cfm.

Moore's law, the technology axiom holding that the number of transistors on a semiconductor chip doubles every two years, has led U.S. productivity growth over the past three decades. Many scientists expect this advancement to reach its limits within 20 years. As transistors approach their physical size minimums, potentially ending Moore's law, nanoelectronics may hold the key to further reducing size, leading to enhanced productivity and growth.

While nanoelectronics' potential economic benefits are large, numerous challenges exist, presenters at the Austin conference said. To remain a leader in the field, the U.S. must stay competitive in the research, development and manufacture of nanotechnology, which involves manipulating matter on an atomic and molecular scale. There must also be cooperation between governments, industry and educational institutions to ensure necessary physical and human capital.

George Scalise, SIA president emeritus, drew parallels between the emerging field and semiconductors. He noted that while government and industry were the initial mainstay semiconductor purchasers, consumers—with their personal computers, cell phones and other electronic products—now account for 55 percent of demand.

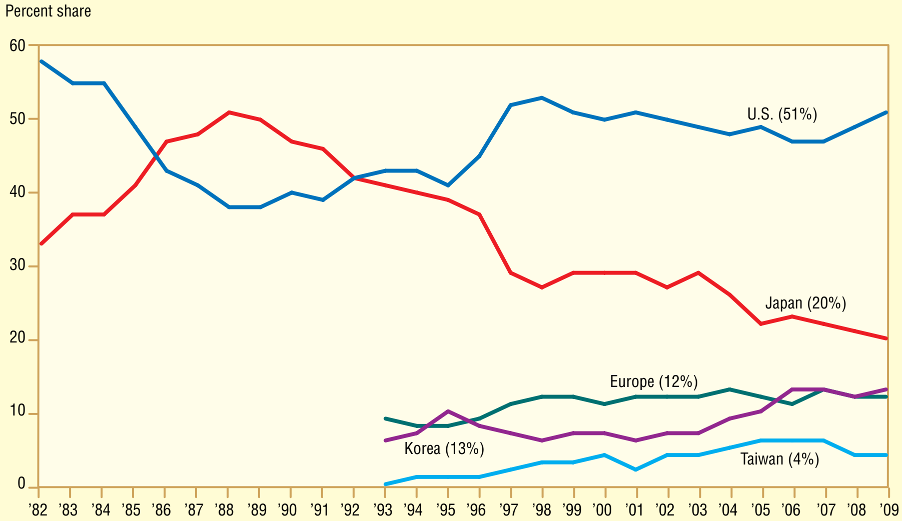
Companies headquartered in the U.S. represent more than half of world semiconductor production (*Chart 1*), Scalise said. Historically, research and development and manufacturing went hand-in-hand to create jobs in the U.S., though increasingly manufacturing is shifting overseas. To encourage industry growth in the U.S., the SIA established the collaborative Nanotechnology Research Initiative (NRI) in 2005. Its goal is development of a successor to today's semiconductor technology by 2020. Membership includes U.S. semiconductor companies, 30 universities and federal, state and local governments.

Scalise expressed unease that the U.S. regulatory and tax environment has put the nation's semiconductor factories at a competitive disadvantage to overseas plants. He proposed four goals to lead the U.S. into the "nano era": (1) maintaining market leadership, (2) retaining technology leadership, (3) keeping the semiconductor industry's No. 1 position in production, (4) creating U.S.-based jobs at all levels, from research to manufacturing.

Technology Aids U.S. Economy

Bart van Ark, senior vice president and chief economist at The Conference Board, noted that information and communications technology (ICT)—as evidenced by the computer, email and cell phone—has accel-

Chart 1
U.S. Companies Lead in Semiconductor Production Share



NOTE: Based on headquarters location of manufacturers.

SOURCE: Semiconductor Industry Association; adapted from a presentation by George Scalise on Dec. 3, 2010.

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erated productivity increases and contributed to economic growth. In the late 1990s, the U.S. experienced a significant increase in output per unit of labor partly because of greater production and utilization of information and communications technologies, he said.

Van Ark was concerned that advances may be shifting from developed countries to emerging economies, such as China and India (*Chart 2A*). Emerging economies' share of ICT investment as a percentage of global ICT investment increased to 25 percent in 2007 from 10 percent in 2000 (*Chart 2B*). The long-term impact of new technologies and innovation extends beyond economic effects, creating social and cultural benefits, van Ark said. For example, Facebook became a social phenomenon made possible by ICT advances. He recommended that the U.S. provide incentives for investment in productivity-enhancing endeavors.

Jan Youtie, a Georgia Tech University adjunct professor and principal research associate, said the transition from nanotechnology discovery to application can be measured by the ratio of research publications to patent applications.

She noted that the locations of nanotechnology research and commercialization differ. In Texas, for example, corporate entry into nanotechnology has exceeded research activity because the state's diverse high-tech companies are well positioned to benefit from knowledge developed and shared by national and local universities.

Nanotechnology has the potential to affect the entire economy and spawn additional technologies, Youtie said. Following 2006, research shifted from passive nanostructures—materials designed to perform one task, such as polymers and aerosols—to active nanostructures, which change or evolve during operation, such as targeted drugs or mechanical actuators (often used to translate a rotary motion into linear motion). This development is expected to become evident in commercialization of active nanotechnologies in the near future.

Moving From Microelectronics (Small) to Nanoelectronics (Smaller)

Pushkar Apte, a consultant to the technology consortium Sematech, said that while nanoelectronics will likely be an economic engine in this century, it must overcome many technological and economic challenges. Sematech and semiconductor industry leaders have developed a roadmap to aid creative collaboration and to identify potential problems. The difficulties are too numerous for a single entity to overcome, Apte said, and nanoelectronics' commercial success depends on industry participants working together. Most costs involve infrastructure investment, leaving a relatively small part as labor expense.

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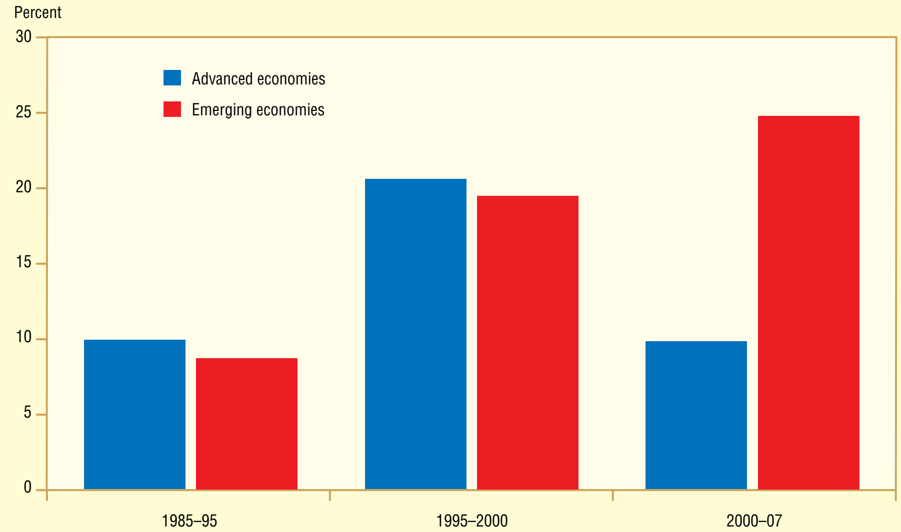
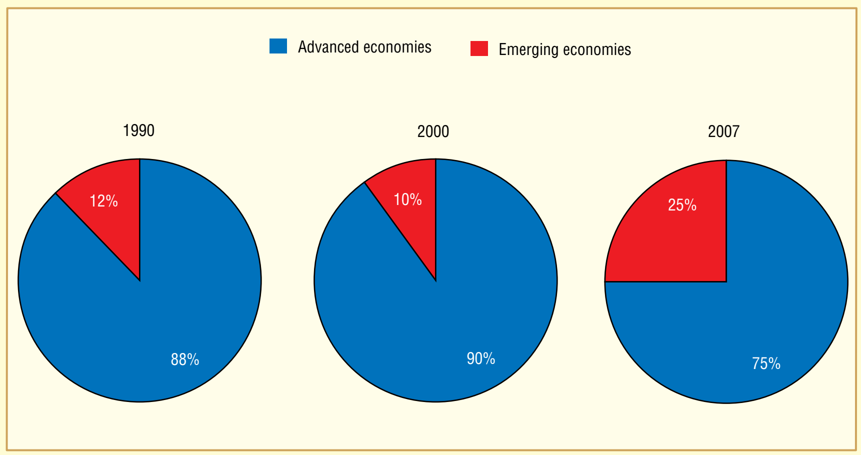
Chart 2

Emerging Economies Gain in Information and Communications Technology Investment

A. Growth of Total Investment by Period



B. Total Investment Shares



SOURCE: The Conference Board; adapted from a presentation by Bart van Ark on Dec. 3, 2010.

Sanjay Banerjee, director of the Microelectronics Research Center at the University of Texas at Austin, delved into the application side of nanotechnology, noting the rapid advance of information and communications technology over the past 50 years. Some of the most important achievements involve integrated circuits, a large number of semiconductor devices working together. Today, integrated circuits (also called chips or microchips) are a $300 billion industry and drive a $1 trillion electronics business. Transistors, used to amplify and switch electronic signals, are imbedded in these microchips. The average person owns more than 100 billion transistors; they are key components of everyday items, from cell phones to cars. Because of technological advancements, 100,000 transistors can fit across a single grain of rice and can cost less than that same rice grain.

Nanotechnology has the potential for greater advances and improvements in weight, size, speed, power consumption and electronic circuit efficiency. As the electronics industry moves from micro- to nanoscale designs, thermal management challenges abound because of increased power densities. Nanotechnology offers promising high-thermal-conductivity, low-contact-resistance materials to solve heat dissipation problems.

Research is moving toward more exciting nanostructures that hold innumerable possibilities, Banerjee said. However, for the U.S. to maintain its dominant position, the nation must ensure its education system is up to the task. The U.S. attracts top talent to its universities, but often loses promising individuals after they graduate. Revising immigration law is critical so those attaining high levels of education remain in this country, Banerjee said.

Nanoelectronics Enhances Other Industries

John A. Laitner, economic and social analysis program director for the American Council for an Energy-Efficient Economy, focused on how nanotechnology can help the economy achieve energy savings.

For example, a significant amount of generated power is lost through electric transmission lines. Nanotechnology could improve such systems, potentially lowering costs and increasing the viability of intermittent energy sources such as wind and solar. Collection sites are often located far from electricity-consuming urban areas. New nanotechnology structures used in high-capacity fuel cells could significantly enhance efficiency and aid storage of energy generated by intermittent energy sources.

Thomas Kenny, a Stanford University professor of mechanical engineering, similarly observed that nanotechnology has numerous applications, from solar cells to chip-cooling applications.

Still, considerable barriers remain, he noted. The industry lacks methods for large-scale manufacturing and integration of distinct technologies. Encouraging further development will require innovative funding. One financial source has been the federal Defense Advanced Research Projects Agency (DARPA), which has various teams working on nanotechnology-related issues. Zyvex Labs, a private Richardson, Texas-based company, has been developing nanotechnology manufacturing. It received funding from DARPA and the Texas Emerging Technology Fund, created by the Texas Legislature in 2005.

Anthony Tether, a former DARPA director, highlighted the importance of nanoelectronics development for the U.S. amid intense global competition. In military applications, for example, nanoelectronics sewn in soldiers' uniforms will act as an electronic interface, monitoring vital signs and other critical information, he said.

Finding Nanoelectronics R&D Funding

John Hardin, executive director of the North Carolina Board of Science and Technology, studied nanotechnology expertise among various North Carolina companies and found that the primary barrier to a broader application of nanotechnology was a lack of access to early-stage capital. A second hindrance was obtaining use of university facilities and equipment, Hardin said during a final panel discussion on methods of funding for companies involved in nanoelectronics research and development. Incentive for public/private partnerships for equipment and facilities sharing, similar to the federal government's National Nanotechnology Initiative, is a possible solution. The national program has invested almost $14 billion in nanotechnology research and development since 2001.

Clinton Bybee, managing director and cofounder of Arch Venture Partners, said there is a progression of ideas that begin in national research labs and subsequently develop into commercial technology. Commercialization is usually a seven- to 10-year process, costing $50 million to $75 million.

Venture capital is typically interested in investing at the early stages, when the potential of the innovation may not be fully understood. Bybee, who has been involved in partnerships with governmental agencies, noted that capital sources must be committed to a long-term investment.

Nanotechnology's prospects to open new frontiers at a time when the U.S. seeks to further assert its global leadership argue for a coordinated strategy, conference participants said. Public and private partnership in the still-developing field may hold the most promise as global competition intensifies. The U.S. economy faces many challenges, including an aging population and mounting government debt. Rising productivity, potentially led by the advancement of nanoelectronics, could provide a catalyst for new avenues of economic expansion.

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