

The Role of Industrial Clusters in Reshoring Semiconductor Manufacturing

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On August 9, 2022, President Joe Biden signed the CHIPS and Science Act into law, a major initiative that could restore U.S. manufacturing in semiconductors and bolster U.S. innovation and investment in a broad range of strategic, technology-intensive sectors.

A key goal of this legislation (along with the Inflation Reduction Act and the Infrastructure Investment and Jobs Act) is to revive the nation's innovation and manufacturing. The **White House fact sheet** released at the signing urged a renewed approach to restore American federalism:

The CHIPS and Science Act authorizes \$10 billion to invest in regional innovation and technology hubs across the country, bringing together state and local governments, institutes of higher education, labor unions, businesses, and community-based organizations to create regional partnerships to develop technology, innovation, and manufacturing sectors. These hubs will create jobs, spur regional economic development, and position communities throughout the country to lead in high-growth, high-wage sectors such as artificial intelligence, advanced manufacturing, and clean energy technology.

In addition to industrial and regional renewal, a major impetus for the bipartisan passage of the CHIPS and Science Act was concern about the resilience of the semiconductor value chain in the face of potential supply disruptions, whether from natural disasters or geopolitical constraints to trade. Expanding domestic semiconductor manufacturing in this regard is a national security imperative—one that will take time, focus, and additional resources but that the United States can begin to address by bolstering its research institutions and supporting new and existing manufacturing clusters.

What Are Industrial Clusters?

Clusters are “the concentration of specialized industries in particular localities” in what Alfred Marshall in 1890 **called** “industrial districts.” In these geographically limited areas, groups of manufacturers of related products, their suppliers and service firms, and a skilled local workforce combine to create a mutually reinforcing ecosystem in that industry. Marshall’s work has been carried forward through the present day—notably by scholars such as Michael Porter, Paul Krugman, and John A. Mathews—and the competitive advantages offered by clusters make them widely sought after, particularly in public policy circles.

Modern examples of successful clusters include not only Silicon Valley but also policy-driven networks such as the concentration of biotech firms in Boston and Cambridge based around the Massachusetts Institute of Technology (MIT) and Harvard University, as well as North Carolina’s Research Triangle based around North Carolina State University, Duke University, and the University of North Carolina at Chapel Hill—not to mention Taiwan’s semiconductor industry in Hsinchu Science Park and the Twin Cities’ medical-device cluster anchored around the Mayo Clinic and the University of Minnesota.

Clusters exhibit several characteristics that inure to the competitive advantage of firms located within them. Key among these are the following:

- **Specialized labor pools:** Specialized activities in the cluster give rise to a pool of workers with specific, relevant skills. Thus, most workers with semiconductor manufacturing skills in the United States are concentrated in chipmaking clusters in Texas, Arizona, Idaho, Oregon, and New York. Taiwan’s Hsinchu Science Park, one of the world’s most successful high-tech clusters, is a **magnet** for Taiwanese and foreign talent with relevant knowledge and skills. In many cases, industry-oriented universities are closely linked to the leading firms in the region and act as conduits for well-trained talent to support further growth.
- **Supplier linkages:** Manufacturers in clusters attract specialized supplier and service firms, whose proximity gives rise to scale economies with respect to transportation, supply chains, infrastructure, communications, and logistics. Manufacturing firms inside Taiwan’s Hsinchu Science Park, for example, **generate** an average value add (revenues minus costs as a percent of total revenue) of 50 percent, versus 30 percent for Taiwanese manufacturers located outside the park.
- **Knowledge spillovers and other positive externalities:** As **Marshall** put it, in a cluster, “mysteries of the trade become no mysteries; but are . . . in the air,” passing readily from person to person. Presence in a cluster enables firms to garner ideas for new designs and applications and to gather market intelligence, all of which **facilitates** technological advance.
- **Concentrations of tacit knowledge:** Clusters are rich sources of “tacit knowledge” or know-how: knowledge gained by actual operating experience, observation of results, and on-the-spot experimentation in a real manufacturing environment. This contrasts with “codified knowledge” derived from manuals, blueprints, and formal education. Tacit knowledge is thus a major source of competitive advantage for companies and the regions where these companies cluster. It is transmitted in person during real operations in a factory or laboratory. Such interactions closely **resemble** traditional apprenticeships under the supervision of a journeyman or master. The

conveyance of tacit knowledge is facilitated by the concentration of relevant manufacturing and research facilities and persons possessing such knowledge in a single geographic location.

Today, Taiwan's and South Korea's semiconductor clusters possess world-leading know-how on the manufacture of two-, three-, and five-nanometer semiconductors, knowledge that does not exist at the same level in the United States and even less so in Europe or Japan. Surpassing this competitive edge may not be impossible for the United States, but it will certainly be difficult. Whether Taiwan and Korea will eventually transfer their chipmaking know-how—or whether U.S., European, and Japanese chipmakers can develop such knowledge through their own efforts—represents a major challenge for the latter's firms and policymakers.

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Taiwan's Hsinchu Cluster

Semiconductor clusters that bring these features together offer substantial efficiencies in terms of innovation leadership and corporate health. The preeminent case in point is Hsinchu Science Park, which hosts many Taiwan Semiconductor Manufacturing Company Limited (TSMC) operations.

The Hsinchu complex **contains** a complete microelectronics industry chain—including wafer design and fabrication, electronic design automation tools, “fabless” (factory-less) design firms, chipmaking equipment manufacturing, lead frame manufacturing, and materials and services suppliers, as well as assembly, test, and packaging operations. These entities are frequently within walking distance of each other. U.S. semiconductor companies operating in Taiwan's science parks **observe** that “everything we need is right here” and that transactions and interactions requiring several days in the United States because of physical distances can be achieved within several hours in Hsinchu, enhancing efficiency and shortening cycle times.

About 150,000 people are employed in Hsinchu Science Park. Of the 130,000 **employed** in 2010, 65 percent had at least a junior college degree, around 17,000 had masters' degrees, and 1,200 had doctorates. Many, if not most, of these professionals had relevant work experience in some aspect of semiconductor manufacturing.

Immediately adjacent to the park are two world-class research universities, which turn out trained graduates for the companies and research organizations operating there. The first, National Chiao Tung University, supplies much of the engineering talent in the park. In 2012, **65 percent** of Hsinchu Park's CEOs, presidents, and general managers were graduates of this university. One of its professors, Simon Sze, wrote what is colloquially known as “the semiconductor Bible”: The Physics of Semiconductor Devices. The second, National Tsing Hua University (NTHU), is perhaps Taiwan's foremost research university—having produced Nobel laureates in physics and chemistry—and **holds** the highest citation rates for faculty papers in either Taiwan or mainland China. Researchers at NTHU have **achieved** multiple breakthroughs in microelectronics and nanotechnology.

Growing Clusters

Many clusters have grown organically, but policymakers have also deliberately created successful ones, though the effort often requires decades. These include North Carolina's Research Triangle, the Boston biotech cluster, and Taiwan's Hsinchu Science Park, although the scale and productivity of the latter is in a class by itself.

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Analyses of clusters reveal that establishing or “growing” a cluster in a particular industrial sector is most likely to succeed in regions that already have a history of relevant cultural, educational, and industrial activity in that field. Perhaps the most well-known is **Silicon Valley**, where chip technology emerged on the San Francisco Peninsula, already the home of many radio and electronics companies as well as Stanford University's Department of Electronic Engineering. These research and technological assets served as an experiential and human-resource base for the **developing** a radically new form of electronics technology.

Boston's Route 128 high-tech cluster grew out of an industrial milieu of electrical manufacturing companies that benefited from federal military funding during World War II, coupled with the proximity of **MIT's** engineering department, which turned out highly talented graduates with relevant electronics expertise. Boston's biomedical cluster initially evolved from research at MIT and Harvard, enjoyed substantial financial support from the National Institutes of Health, and received over **\$1 billion** from the state of Massachusetts. It also profited from a 1970s decision by the Cambridge City Council to legalize then-controversial recombinant DNA experimentation.

Cleveland, a third example, is the site of a biomedical innovation cluster that arose out of the presence of two well-established, first-rate medical institutions: Cleveland Clinic and Case Western Reserve University. These organizations **provided** the basis for a cluster specializing in healthcare fields such as medical imaging, medical devices, biotechnology, and pharmaceuticals.

Yet “greenfield” efforts in cluster creation remain a challenge. Experience has shown that attempts to establish new clusters in regions with no intrinsic historical advantages face an uphill climb. This is true even in states that have previously launched successful regional development initiatives. For example, in 2014 New York **announced** it would invest \$15 million to establish a movie-making hub near Syracuse, backed by offers of up to 40 percent in tax credits. Despite substantial tax advantages, no major films were ever produced there. The effort **lacked** scale, follow-on resources, trained labor, corporate interest, and the ongoing policy attention required for a new initiative to succeed.

Clusters and Regional Advantage

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In his 2012 book, *The New Geography of Jobs*, economist Enrico Moretti **points out** that “a handful of cities with the ‘right’ industries and a solid base of human capital keep attracting good employers and offering high wages.” Examples include Intel’s new semiconductor plants in Columbus, Ohio, which are **expected** to employ 3,000 workers—many without four-year degrees—at average annual salary of \$135,000 a year. Similarly, chip manufacturer **Micron’s** investments near Syracuse, New York, will draw on a rich educational infrastructure, a quality workforce, and advantages in power and water supply. Regions at the **other extreme**, with “traditional” industries and limited human capital, “are stuck with dead-end jobs and low average wages.”

Moretti further observes that benefits flow to regions not only due to the presence of major manufacturers, but also because of indirect employment by affiliated firms, which often employ highly skilled, well-compensated workers, adding to the strength of the cluster. These well-paid workers and the economic activity associated with manufacturing generate substantial induced employment in banking, housing, healthcare, hotels, and restaurants across the region.

Capturing these regional advantages of clusters also depends on the connections between these necessary assets. Such connections include regional workforce-training networks and partnerships that facilitate collaboration among universities, research laboratories, and firms.

New York Builds a Nanocluster

Creating a new cluster is possible, but it takes time, commitment, and major investments by both the state and industry partners. New York has **demonstrated** that developing a semiconductor cluster in a greenfield location is doable if the right combination of factors can be induced. With the reputational and financial support of IBM, New York succeeded in making greater Albany the site of the only U.S. semiconductor foundry, GlobalFoundries. The region has also become one of the **foremost centers** of applied nanotechnology research in the world, based around the College of Nanoscale Science and Engineering (CNSE, or the “Nano College”) at the State University of New York at Albany.

This was not an overnight effort. The facilities in and around Albany reflect 20 years of investment and around \$15 billion in equipment and facilities, including a unique, 300-millimeter fabrication facility that has become a **neutral** “Switzerland” of research for a wide range of leading companies in the semiconductor ecosystem.

Nor was progress self-evident. Thirty years ago, the Capital Region, like all of upstate New York, was **considered** part of the “Rust Belt” and was written off by some as an area with a hopeless economic outlook. State-level policymakers from both sides of the aisle did not accept this view and collaborated over many years and across party lines to steer a different course. A series of governors and capable leaders in the New York State Assembly and the New York State Senate worked together to capitalize on the region’s

advantages, which included superb educational institutions, availability of a large pool of skilled labor with manufacturing experience, and effective regional-development organizations. Crucially, the state backed these efforts through incentives—large and small—to build the infrastructure, attract a semiconductor manufacturing facility, and continue to support the CNSE’s outstanding collaborative research capabilities.

These long-term cooperative efforts were successful. Today, the Albany region hosts a thriving semiconductor cluster. Notably, **NY CREATES**—a joint institution by the State University of New York and Empire State Development, the state’s economic development arm—supports rapidly multiplying research and development (R&D) and commercialization partnerships with major private-sector companies. New York’s **multidecade experience** “has shown that regional competitive advantage can actually be grown and that public investments in research infrastructure can lead to a resurgence in well-paying manufacturing jobs.”

Ohio’s Cluster Strategy

Ohio is another example of a state that has made major investments in educational institutions and its workforce. It has tenaciously—and successfully—pursued the establishment of a semiconductor wafer-fabrication cluster near Columbus, an effort now considered major success. Attracted by a supportive policy environment and the prospect of both state and federal incentives, Intel is investing \$20 billion to establish two advanced wafer-fabrication facilities at a rural site in New Albany, Ohio, just outside Columbus.

Intel **claims**—perhaps hyperbolically—that this site will eventually become the “largest silicon manufacturing location on the planet.” It will certainly be massive. At first impression, **Intel’s choice** of Ohio might seem anomalous because “there has never been a history of Midwest or Ohio semiconductors.” However, the **press release** cites the region’s “proud heritage as an industrial and manufacturing powerhouse . . . it has a robust existing infrastructure with the capacity for future growth, and a strong talent pipeline sustained by world-class educational institutions.” Crucially, state and local government leaders also rolled out the welcome mat for Intel.

There are several specific factors supporting Intel’s decision to build semiconductor capacity in Ohio:

- **A “Can-Do” Attitude:** As Intel CEO Pat Gelsinger **explained** to an Ohio audience concerning his company’s decision to invest in the state, a key factor was that “Ohio has this tradition of manufacturing. You all like to build stuff. And that’s exactly what we’re going to do together.”
- **A Good Site:** Columbus put forward a viable site for wafer fabrication, and Ohio committed to building the necessary infrastructure there—itsself a huge undertaking involving hundreds of millions of dollars. Columbus envisions the site will provide 1,500 prime acres for Intel operations and 250 acres for suppliers—enough for an incipient cluster. Already, 30 companies that currently supply Intel are **expected** to begin business there. In addition, state economic-development authorities such as JobsOhio are **investing** in local firms that will be needed to support Intel’s local operations. The Columbus site is also within a day’s drive from every major city in the Midwest—thereby, **according** to an Intel executive, “making it possible to create an ecosystem across the entire region.”
- **A Strong Talent Pool:** Local and regional educational institutions have committed to introducing

curricula **designed** to produce graduates with the knowledge and skillsets to serve Intel's Columbus fabricators. For example, Columbus State Community College, which has become a regional leader in training students for manufacturing jobs, is establishing the Ohio Semiconductor Collaboration Network "to develop two-year pathways to semiconductor technician work." This project will engage all 23 of Ohio's community colleges and aims to **generate** 5,000 trained workers for Intel within three years.

- **Financial Incentives:** Ohio has **committed** \$600 million in grants to the Intel sites, plus \$700 million for infrastructure upgrades and \$650 million in income tax incentives over a 30-year period. The town of New Albany, Ohio, will provide a 100 percent property-tax abatement for 30 years for buildings constructed in its business park. These state incentives will be augmented by federal CHIPS and Science Act subsidies and tax credits. Intel **estimates** that the federal incentives will reduce the investment cost of each \$10 billion fabrication plant it is building in Ohio by \$2.5 billion.
- **Sustained State Investment in Innovation Linkages:** Ohio's comeback from the "Rust Belt" **arguably began** in 1983 when the state created the Thomas Edison Program, a state-funded initiative to link universities with businesses and startups through the creation of nine business incubators and statewide "seed development fund projects."

This initiative was augmented by other major economic development programs. In 2002, Ohio launched the Third Frontier Program, which provides funding to technology-oriented companies, startups, and nonprofit research organizations. With an initial budget of \$2.3 billion, this was the largest development fund in the history of the state. Amendments to the state constitution **approved** by Ohio voters in 2005 and 2010 lifted a long-standing state ban on public investments in private businesses and authorized the state to issue bonds to extend the program. Third Frontier funding, along with support from foundations, was **crucial** to the operation of the specialized nonprofit economic development organizations that were driving Ohio's economic turnaround effort. In 2012, the Third Frontier Program **reported** that since its launch, it had spent \$900 million in state funds to leverage additional investments of over \$8 billion, leading to the creation of 882 companies and nearly 100,000 direct and indirect jobs. Ohio's large-scale public investments in innovation and economic development **continue** to this day.

- **The crucial role of foundations:** In the 2000s, Ohio's philanthropic foundations helped rally the state's fragmented local governments to create and support successful statewide initiatives. They pooled their **funds** to establish a handful of small, high-quality, nonprofit economic development organizations to address the region's economic challenges. This created an economic development infrastructure with the expertise and resources to reach out to major manufacturers.

One of the most significant features of New York's and Ohio's efforts to establish high-tech industrial clusters is that they enjoyed bipartisan support from state leaders for a generation, ensuring that no administration defunded or otherwise undid the achievements of its predecessor. The resulting policy continuity, backed by substantial financial and human resources, is enabling the successful implementation of long-term industrial development—creating the jobs and growth that the nation needs.

Balancing Policy Objectives

Given the advantages of clusters for regional economic development, how can policymakers create more of them? A key challenge is that many regions have relatively thin innovation ecosystems, variously lacking relevant research, financial, workforce, and capital assets. Moreover, they often do not have viable partnerships or other collaborative mechanisms linking them to the complex semiconductor ecosystem. Without these pillars and supporting braces, isolated investment in physical capital is not likely to be effective in growing seed clusters.

This issue of a cluster strategy's sustainability and effectiveness comes to the fore as bipartisan efforts—through the CHIPS and Science Act and other legislation—seek to leverage technology clusters to renew the foundations of the nation's economy. Trying to bridge the gap between “elite” and “left behind” U.S. regions, the Biden administration aims for the benefits of its major legislative achievements to spread more widely, **noting that** “economic growth and prosperity over the past 40 years has clustered in a few regions on the coasts, leaving far too many communities behind. The CHIPS and Science Act will ensure the future is made in ALL of America, and unlock opportunities in science and technology for those who have been historically left out.” These are laudable objectives, but the exigencies of the semiconductor industry pose unique challenges.

Lacking rich ecosystems, disadvantaged regions will likely not reap the benefits of federal efforts to invest in these areas unless these are accompanied by a supporting state and regional growth strategy such as New York's or Ohio's. The success or failure of any particular effort may well be determined not by federal outlays, however important, but by the initiatives of states and regions themselves. Reviving federal-state partnerships does feature in the Biden administration's economic renewal agenda, but it is not a panacea—and the resources for the CHIPS and Science Act, while seemingly large, tend to pale in comparison to industry needs and expenditures, not to mention foreign competitors' investments.

In addition to realizing innovation-based regional growth, the cluster strategy found in recent legislation seeks to secure the nation's strategic strengths in the semiconductor industry. Unfortunately, the desire to spread the benefits more widely by establishing some chipmaking clusters in states with no established microelectronics capabilities runs up against the strategic need—starkly apparent in light of chip supply-chain disruptions precipitated by the Covid-19 pandemic—to rapidly add to an established innovation and production base. Existing facilities with the necessary high-cost equipment in place could be enlarged much more rapidly than greenfield investments due to lower capital costs and because new facilities confront additional environmental permitting challenges. In Albany, industrial partners are already active, protocols have been established, and a capable workforce is in place and ready to be enlarged—not created from scratch.

Clearly, a balance will have to be struck. To be effective, federal resources should be concentrated on the regions that already have strong engaged universities, major existing research facilities supported by existing industry partners, and a committed state government with major resources at its disposition. Only some states—such as Arizona, Texas, and New York—are likely to be able to assemble these components; even then, the timeframes for newer entrants such as Ohio are likely to be long. While the needs of different parts of the semiconductor ecosystem vary, from logic chips to memory circuits to advanced packaging, few have the advantage of New York's existing infrastructure, which

is further backed by the state government's ability to invest comparable funds. If the United States is to address pressing national security and competitive challenges soon, it needs to leverage existing facilities and concentrate resources where the technology requires it. Above all, the United States needs to recognize that reclaiming a larger position in semiconductor production is a long-term effort that will require sustained federal and regional support. ■

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