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Does America Really Need Manufacturing?

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PHOTOGRAPH: MARGARET BOURKE-WHITE/TIME LIFE PICTURES/GETTY IMAGES: AT THE INDUSTRIAL RAYON CORP. FACTORY, 1939

Too many American companies base decisions about how to source manufacturing largely on narrow financial criteria, never taking into account the potential strategic value of domestic locations. Proposals for plants are treated like any other investment proposal and subjected to strict return hurdles. Tax, regulatory, intellectual property, and political considerations may also figure heavily in the conversation. But executives, viewing manufacturing mainly as a cost center, give short shrift to the impact that outsourcing or offshoring it may have on a company's capacity to innovate. Indeed, most don't consider manufacturing to be part of a company's innovation system at all.

The result, as we've argued before, has been an exodus of manufacturing from the United States. (See "Restoring American Competitiveness," HBR July–August 2009.) That mass migration has seriously eroded the domestic capabilities needed to turn inventions into high-quality, cost-competitive products, damaging America's ability to retain a lead in many sectors. In recent decades a number of U.S. industries, including flat-panel displays, advanced batteries, machine tools, metal forming (such as castings, stampings, and cold forgings), precision bearings, optoelectronics, solar energy, and wind turbines, have paid the price. And in other industries, such as biotechnology, aerospace, and high-end medical devices, the U.S. lead is now endangered.

Part of the problem is that it's devilishly difficult to determine when manufacturing is critical to innovation and when it can be safely outsourced to lower costs and reduce capital outlays. In this article we'll provide a framework that will help business leaders and government policy makers navigate this issue. Our hope is that it will lead to better sourcing decisions that will reinvigorate America's innovation-driven economy.

A Framework for Sourcing Decisions

How can you tell if moving production halfway around the world, far from R&D operations at home, will hurt a company's ability to innovate over the long term? You need to look at two things: the ability of R&D and manufacturing to operate independently of each other, or their *modularity;* and the *maturity of the manufacturing technology.*

Modularity.

When R&D and manufacturing are highly modular, the major characteristics of the product (features, functionality, aesthetics, and so on) aren't determined by the production processes, and the two activities can be located far apart without any consequences. When modularity is low, the product design can't be fully codified in written specifications, and design choices influence manufacturing choices (and vice versa) in subtle and difficult-to-predict ways. In these cases keeping manufacturing near R&D is valuable.

Two basic questions will help you determine the degree of modularity:

1. How much must product designers know about the production process to carry out their task?

In some contexts, like biotech and advanced materials, every conceivable product design requires a unique manufacturing process. So designers cannot do their jobs without deeply understanding the process choices. In these contexts, product innovation often involves process innovation.

At the other extreme are contexts in which it's technically and economically feasible to use the same process technology to manufacture just about any product design. That means designers can blissfully create without thinking about—or even understanding—the process. Writers of text, software, and music operate with this freedom. Some industries lie in between; they have developed formal approaches for incorporating process considerations into product development. They establish "design rules"—a set of product specifications that will work with a particular process recipe. As long as designers stay within those boundaries, they can be pretty confident that the given manufacturing process will work. In general, process constraints intensify as product designs move closer to or try to go beyond those boundaries.

2. How difficult is it for a product designer to get relevant information about the production process?

Process technologies run along a spectrum from pure art to pure science. Processes at the pure-art end have unclear and difficult-to-describe parameters. To understand them, you need to see them—and even then, they may be hard to replicate. In these contexts, product innovation typically requires intense iteration between product and process development and feedback during actual production.

Maturity.

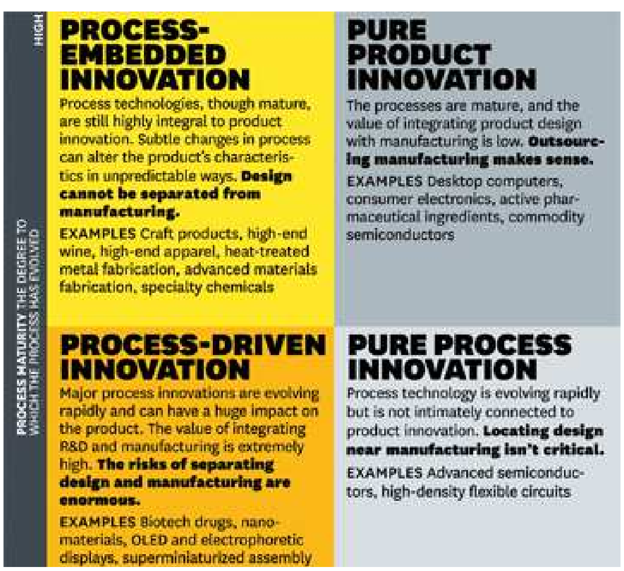
By this we mean how much a process has evolved rather than the age of a technology, although obviously the two tend to be correlated. Immature processes offer the greatest opportunities for improvement. In the 1960s, after scientists at DuPont discovered Kevlar, the polyaramid fiber used in body armor and other high-strength applications, the company spent

15 years and $500 million commercializing the manufacturing process and learning how to weave the material. As processes mature, the opportunities for improvement usually become more incremental.

When manufacturing technologies are immature, companies can thrive by focusing on process innovation. In the early 1980s Japanese semiconductor companies exploited many opportunities for improving manufacturing techniques that their U.S. competitors had missed, and took a commanding position in memory chips. Today, in sectors like advanced flat-panel displays, biologics, and advanced materials, the process-technology frontiers are moving so quickly that world-class innovation is a must to stay in the game.

Viewed through the modularity-process maturity lens, relationships between manufacturing and innovation fall into four quadrants (see “The Modularity-Maturity Matrix”):

The Modularity-Maturity Matrix



Pure product innovation.

Here, the value of tightly integrating product innovation with manufacturing is low, and the opportunities for improving processes are few. Outsourcing manufacturing makes a lot of sense.

Many segments of the semiconductor industry fit into this quadrant. This explains why there is a thriving sector of “fabless” semiconductor firms (such as Qualcomm), which specialize in design but own no production facilities, and a thriving sector of firms that just manufacture (such as Taiwan Semiconductor Manufacturing Company).

Pure process innovation.

Here, process technology is ripe for improvements and advancing rapidly but isn't intimately connected to product innovation. Because sufficient design rules have been established, neither vertical integration nor locating R&D near manufacturing is critical, and it makes sense for specialized contract manufacturers to provide custom production to firms that focus on design. However, before ceding manufacturing to others, companies should keep in mind that process innovation can be a significant source of value in these contexts.

High-density flexible circuits, which connect electronic components like the circuit boards in iPads, fall into this category. They have thousands of tiny holes ("vias") to connect wires at different layers, and making the microscopic wiring and vias requires significant innovation. But design rules embodied in the engineering specifications for the flex circuits ensure independence of the design from manufacture.

Process-embedded innovation.

In this quadrant process technologies, while mature, are highly integral to the product-innovation process. Small changes in the process can alter the characteristics and quality of the product in unpredictable ways. Product innovation is incremental and comes from tweaking the process. (Think wine.) So the value of keeping R&D and manufacturing organizationally integrated and geographically close is high.

Many traditional creative businesses, such as high-end fashion, fit into this quadrant. How a fabric is cut or how a seam is sewn can affect the way a garment drapes in subtle ways that matter. One European producer of luxury apparel that we studied has worked only with local fabric suppliers because the suppliers' manufacturing engineers and the company's product designers need to exchange information almost constantly.

Process-driven innovation.

In sectors developing breakthrough products at the frontiers of science, the major process innovations are evolving rapidly. Since even minor changes in the process can have a huge impact on the product, the value of closely integrating R&D and manufacturing is extremely high, and the risks of separating them are enormous.

Managers, investors, and analysts haven't always recognized this danger. Viewing manufacturing as a distraction and a drain on capital, they often push companies in this quadrant to outsource production or move it to lower-cost locations far away from R&D. The results can be disastrous because, to put it simply, when you lose your manufacturing competence, you lose the ability to create new commercially viable products.

Biotechnology offers a good example. Drugs derived from genetic engineering techniques consist of large protein molecules that are too complex to be chemically synthesized—the approach used to make drugs for over a century. Without major advances in process technology (such as mammalian-cell-culture processes), blockbuster drugs like Amgen's erythropoietin, for treating anemia, or Genentech's Herceptin, a therapy for breast cancer, would never have made it out of the laboratory.

Manufacturing Strategies for Innovators

Our framework does not obviate the need for rigorous financial analysis of manufacturing investments. Nor does it override other considerations that might influence sourcing decisions, such as proximity to customers, political barriers to market entry, taxes, and regulations. Rather, it's designed to help managers think more strategically about the consequences of geographically separating R&D and manufacturing.

To devise an appropriate manufacturing strategy, you have to determine which quadrant your business falls into. We have developed some questions and guidelines that can help you. (See the sidebar "The Design-Manufacturing Relationship: What to Ask.") But no simple formula can tell you whether the manufacturing technology is mature and the product design and process technology are modular. A lot of judgment is required.

The Design-Manufacturing Relationship: What to Ask

Assessing Process Maturity

If a process technology hasn't changed in quite some time (or if the changes are largely incremental) and current performance (in terms of yields, quality, and costs) appears to meet the market's demands, your business is

When was the last major change in basic process technology in your business?

What has the rate of change in process technology been over the past five years?

How much process R&D is being conducted by companies in your industry, including equipment vendors and other suppliers?

How well do current process technologies meet commercial requirements (costs, yields, quality, and so on)?

What is the likelihood that a major upheaval in process technology will occur in the next five years?

Assessing Modularity

To what extent are product-design choices constrained by process technology and manufacturing capabilities?

How much impact would a minor variation in the manufacturing process have on the product's crucial characteristics?

How well understood are the underlying relationships between product parameters and process parameters?

To what extent can a product design be described without referencing the manufacturing process?

To what extent can the product design and process design be codified?

probably in a mature sector. If costs are falling, yields are increasing dramatically, processes are changing rapidly, and you expect competitors or equipment vendors to continue to invest heavily in process R&D, your business is probably in an immature sector. Talking to vendors and even to companies from other industries may help you identify whether significant process innovations are on the horizon.

Process parameters that are difficult to codify, process changes that significantly affect product characteristics, and a lack of standardized processes are all telltale signs of low modularity, but an in-depth discussion among product designers, process engineers, and manufacturing personnel is often needed. People from different functions can have very different perspectives on this issue. Product designers frequently underestimate the degree to which their design choices impact manufacturing processes. Likewise, process engineers and manufacturing personnel often do not realize how changes in a process or operation might affect a design.

In too many companies, the people who actually know the most about how manufacturing location choices might influence innovation have no say in the

Are there standardized process platforms that are compatible with specific ranges of product designs?

decisions. One biotech firm we spoke with during our research decided, with virtually no input from its process-development scientists, to outsource production to a supplier halfway around the world. The decision was based strictly on an analysis of capital costs and financial returns. Even though the company used an experienced and competent contractor, the contractor had problems scaling up production and improving yields. Serious product shortages damaged the company's stock price. Ultimately, the firm was acquired.

When using these guidelines, it's important to consider not only where things stand today but also where they're going. In assessing trends, keep the following in mind:

Manufacturing technologies can be rejuvenated.

When a company operates in a sector where the process technology is mature, it's tempting to dismiss the possibility of process innovation and try to reduce costs by outsourcing or offshoring production. But game-changing process technologies sometimes can emerge. Established players that underestimate this possibility may find themselves struggling to compete or unable to pursue new opportunities. This has happened in industries such as steel, textiles, contact lenses, and consumer electronics.

> Game-changing process technologies can emerge even in mature sectors. Firms that dismiss this possibility may falter.

Beware of "demodularization."

Sometimes new technologies can also make product design and manufacturing processes much more interdependent. Consider jetliners. For decades their design and manufacture were highly modular. Boeing could outsource major chunks of its aircraft development and manufacturing to subcontractors around the world and then assemble the planes in its factories in the state of Washington. But in the 787 Dreamliner program, the shift from aluminum alloys to carbon-fiber-composite materials changed things. The old modular design rules could not fully account for stress transmission and loading at the system level—something that Boeing did not get right initially. As a result it encountered problems assembling the pieces (such as the horizontal stabilizer from Alenia Aeronautica in Italy and the wing box from Mitsubishi Heavy Industries in Japan). Significant redesign and rework were required, and the program suffered major delays.

Don't squander an advantage created by low modularity.

Many companies fail to recognize that the deep integration of their product-design and manufacturing processes actually poses a major barrier to entry for newcomers, who must master the product technology, the process technology, and the interactions between the two. Therefore, incumbents shouldn't outsource production.

It's generally much easier to reverse-engineer a product design than to figure out someone else's proprietary manufacturing process. This is why companies in the fashion business, like Zegna, Armani, Ferragamo, and Max Mara, keep the bulk of their high-end production in Italy despite the costs. By doing so, they can better protect their proprietary designs and reduce the risk of imitation.

Manufacturing capabilities are hard to acquire and easy to destroy.

It can take decades for a company to build up its manufacturing capabilities and associated supply chains. Precisely for this reason, they provide a powerful advantage. The manufacturing-outsourcing road is often a one-way street: Once companies go down it, they may never be able to return. Today American companies are talking about "in-sourcing" more production back to the United States. We're skeptical that this can be done easily. In many places, elements of the industrial commons that are essential to support manufacturing—the suppliers, skilled workforce, and managers with operations experience—evaporated long ago.

What Washington Should Do

Innovation-based competition will only become more intense as countries such as China, India, Brazil, and the nations of Eastern Europe nurture their own capabilities. If the United States hopes to retain its edge, changes in how companies are managed won't suffice; changes in government policies are crucial too.

Public policy discussions of ways to stimulate innovation have focused heavily on investments in scientific research and education, taxes, and regulation. All of those are important. But manufacturing rarely makes the agenda, because of the wrongheaded view that it isn't integral to innovation. That attitude must change. An explicit focus on manufacturing is essential to innovation policy—especially since the exodus of any manufacturing that's tightly linked to product design is certain to pull R&D abroad as well.

What should such policies look like? Let's start with what they should not be. We oppose a heavy-handed industrial policy that calls for the government to try to pick winners. Governments do a lousy job of playing banker or venture capitalist, as demonstrated by the recent brouhaha over federal and state loans and subsidies to solar-panel companies that then failed or closed some U.S. operations.

Once critical capabilities have migrated, trying to prop up domestic companies through subsidies or other targeted support is not a solution. Consider the situation in solar photovoltaics. American solar PV firms argue (correctly) that their Chinese competitors have an unfair advantage because of subsidies from the Chinese government. But Chinese competitors have another edge: Solar PV shares much of its technology infrastructure and supply chain with the electronics industry, which is now centered in Asia. No amount of government aid will help European and American PV firms overcome that disadvantage.

While we oppose targeted industrial policies, we do believe that government has a key role to play in supporting innovation, including innovation related to manufacturing. Here are two policy approaches that history suggests will be productive:

Build capabilities through research in manufacturing sciences.

In the past, government funding of basic and applied research has helped greatly strengthen the country's foundations of innovation. In the 20th century, the United States made sizable investments in science, technology, and education via such agencies as the National Science Foundation, the National Institutes of Health, the Department of Agriculture, and the Department of Defense and its Defense Advanced Research Projects Agency. These initiatives laid the groundwork for the internet, electronic design automation, advanced computer graphics, the explosion in agricultural productivity, and the revolution in genetics-based drug discovery.

The government has also played a major role in financing the development of important manufacturing technologies. Today most advanced jet engines employ esoteric metals and ceramics capable of operating under extreme heat and pressure. Manufacturing those materials is extremely difficult. Much of the science underlying the processes used to make them was spawned by government-funded basic research in metallurgy in the 1960s. But over the past two decades, funding for metallurgical research—and for other process-related sciences—has largely dried up.

> The deep integration of product-design and manufacturing processes can actually pose a major barrier to entry for newcomers.

The President's Council of Advisors on Science and Technology recently called for the federal government to create an "advanced manufacturing initiative" that would invest $500 million annually (and eventually increase that amount to $1 billion) in basic and applied research in such technologies as robotics, nanoelectronics, materials, and biomanufacturing. That would be a good first step toward redressing the deficiency in research funding for manufacturing-related science. And even $1 billion a year is relatively modest when compared with the government's total annual R&D budget of $143 billion or the $31 billion NIH budget. (Of course, in today's budgetary environment the likelihood that the council's recommendation will be adopted is low.)

Private-sector R&D is generally most productive when focused on problems directly related to a company's specific markets, customers, or manufacturing processes. Developing solutions in these areas requires commercial insight that government agencies lack. But companies are not well positioned to invest in basic or applied research. The payoffs are too far in the future and too diffuse. Unless the government takes the lead, a U.S. manufacturing renaissance is unlikely.

Create fertile conditions for manufacturing at home.

A full-blown exposition of tax and regulatory policies is well beyond the space limits of this article, but it's clear that high corporate tax rates and complex, ever-changing regulations discourage investment in U.S. manufacturing. Beyond getting the basics right in those areas, the most important way government can encourage domestic manufacturing may be by supporting training. We've heard the same refrain from many executives we've talked with: "We would love to do more manufacturing in the U.S., but we can't find people with the right technical skills." Tool and die makers, maintenance technicians, operators capable of working with highly sophisticated computer-controlled equipment, skilled welders, and even production engineers are in short supply.

The reasons for such shortages are easy to understand. As manufacturing plants closed or scaled back, many people in those occupations moved on to other things or retired. Seeing fewer job prospects down the road, young people opted for other careers. And many community and vocational schools, starved of students, scaled back their technical programs.

Government policy makers have a mind-set that manufacturing is a good sector for people with less education and less training. As a result, the United States—unlike, say, Germany—spends little on training people in the specialized skills needed in manufacturing. That has to change.In a global economy where knowledge and capabilities drive growth, competitive advantage is shaped by both managers and policy makers. The notion that the United States and other advanced countries are not supposed to be good at manufacturing has no basis in any theory and no empirical evidence to support it. It is dangerous folklore. The United States has been conducting a multidecade experiment testing the hypothesis that it can thrive as a post-industrial economy. American business leaders and policy makers must abandon that experiment now—before it's too late.

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