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Preventing The Next Shortage: A Framework For Industrial Policy

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Executive Summary

Throughout our series on semiconductors, we have used the semiconductor industry to explore big questions in economic theory and industrial policy. So far, we have refrained from giving specific policy recommendations, instead providing historical examples to illustrate prior policy successes and missteps. But with the looming threat of climate change, and its attendant supply chain disruptions, we can view the semiconductor industry as a sandbox for testing out the kind of large-scale industrial policy that will only become more necessary as time goes on. So today, we offer a positive account. While our suggestions are organized around the present disruptions to the semiconductor supply chain, the underlying principles are broad enough to remain relevant in almost any sector.

This framework outlines four steps to a successful industrial policy program:

(1) a robust system of supply chain monitoring;

(2) specification of clear high-level and low-level goals;

(3) the use of fiscal policy to smooth financial uncertainty; and

(4) the creation of dedicated, enduring institutions.

Many of the proposals currently on the table — the Endless Frontiers Act[1] (EFA), the CHIPS Act,[2] the Biden Administration infrastructure plan[3] — solve some important parts of the problem. However, no proposal we've seen offers a comprehensive strategy to address the entire problem.

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Four Steps

The first step is the implementation of a robust public system for industrial capability monitoring, with a focus on understanding supply chains. As it stands, supply chains are incredibly complex and opaque. Even successful businesses rarely know who supplies their suppliers, and the government is even further behind. To prevent future shortages and bottlenecks, industrial policy must be formulated to address the specific deficiencies and granular needs of existing supply chains. Without a clear view of the initial situation, government agencies will have a difficult time identifying policy goals, judging policy success or failure, or appropriately targeting investment.

The next step: the specification of clear goals. This is deceptively simple. Since the role of science policy is to push forward the frontier of research, goal setting is often left to industry and researchers. Industrial policy, in contrast, is much more closely tied to macroeconomic management than research, and requires a different goal-setting approach. Successful industrial policy forms a bridge between cutting-edge research and large-scale commercialization, but that can only happen if we gather and carefully use data to establish clear goals to that effect.

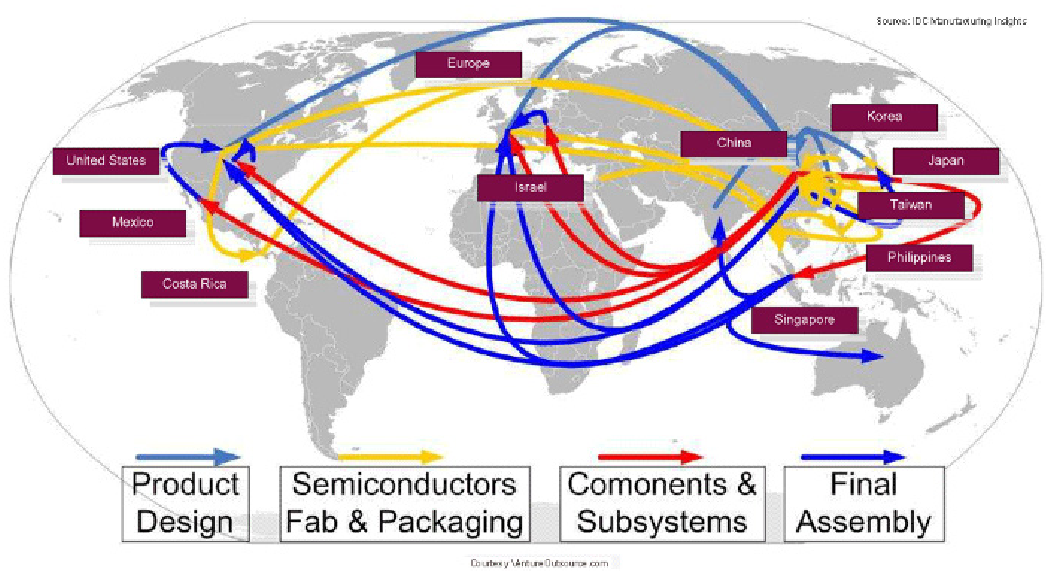
The third step, where the rubber hits the road, is to use the fiscal power of the state to smooth financial uncertainty for both workers and investors in the semiconductor industry. Industrial policy means more than just targeting investment in capital goods, it also requires targeted investment in our workers. This goes far beyond the kind of skills transfer and training programs already in place, and focuses on providing a safe, stable work environment where careers can be built. The semiconductor industry in particular has faced relatively severe brain drain and attrition since the dot-com bubble burst. At the same time, firms have cut investment and focused on an asset-light model that reduces their need to carry expensive labs and fabs on their own balance sheet. An industrial policy approach helps resolve both of these issues. Even better, it can provide the stability necessary for the US to durably regain the technological frontier while creating robust and sustainable lagging-edge supply chains for the rest of the economy to rely on.

The final step is to create durable institutions that bring together investors, workers, and policymakers to iterate on the goals and methods of policy as the industry grows and changes. Consistency and long-term planning are critical for innovation, and flexible industrial policy ensures that policymakers and the industry alike are able to think on longer time horizons. Rather than waiting on individual congressional approvals, industrial policy should fund dedicated departments and offices. There is no need to ask representatives to understand and anticipate the highly technical minutiae of the semiconductor industry. At the same time, independent institutions with a strong understanding of supply chain structures will best be able to engage the private sector and ensure that industrial policy is not a mere giveaway to incumbent firms.

The goal of this policy framework is to achieve the kind of robust competitive ecosystem that we have advocated for throughout this series. These principles provide a roadmap to reduced volatility, enhanced industrial capacity, broad-based experimentation, and the creation of resilient supply chains. The exact goals and actions, the line-by-line policy prescriptions, are necessarily outside the scope of this paper; it's impossible to choose between loan guarantees or price and purchasing programs without a clear view into the existing supply chain dynamics and input-output of the industry. However, by following the steps outlined here, choices like these, and many others, will become clear and actionable.

Step 1: Understanding and Monitoring Semiconductor Supply Chains

Modern information technology and advances in global shipping have allowed companies to construct incredibly complex and opaque supply chains. If you include every step involved in producing an iPhone, the supply chain passes through 43 countries,[4] each making incremental steps in the value chain. For a complex product like the iPhone, even its inputs will have their own entire supply chains. The following diagram gives a sense of this complexity for a modern semiconductor:



Source: Venture Outsource[5]

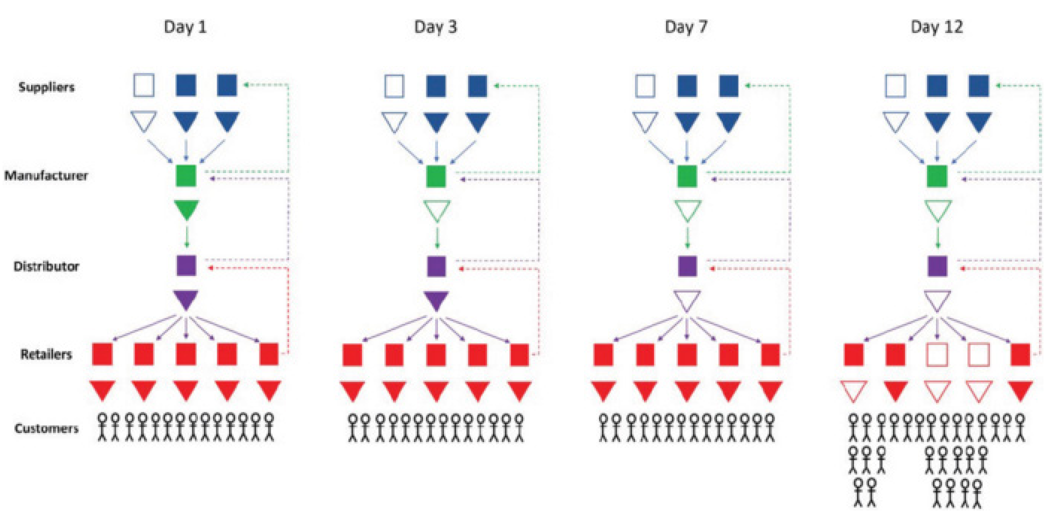
As we are seeing with automakers now, even large firms rarely know who supplies their suppliers. When something goes wrong somewhere in the supply chain, firms have minimal immediate visibility into what happened and how to fix it — all they know is they're missing some critical input. Over the last 30 years, many final goods producers have spun off what used to be in-house chip-making facilities into separate companies. These separate companies have in turn been rolled up and rationalized into larger fabrication firms, recreating the single point of failure.

To give a sense of how quickly a breakdown in one supplier can spread through the chain, Barry Lynn quotes[6] an auto industry consultant:

> ***"What vehicle manufacturers are finding are parts within parts within parts within parts that are sourced from a single-source Japanese manufacturer."***

Today's chip shortage — and the resultant shutdowns of auto manufacturing plants — are not driven by leading edge chips. Instead, much humbler ICs — that often retail for as little as $1 — are causing dramatic assembly line snarls. These inputs are nested deeply inside the bill of materials for Ford's touchscreen's supplier, not something Ford purchases directly. However distant a missing semiconductor is from Ford's actual assembly line matters little. The current chip shortage was in no small part caused by this complexity, which helped to hide just how fragile the system was.

Since supply chain management and organization is a key competitive strength for successful firms, it makes sense that no individual actor takes responsibility for the health and resilience of the supplier ecosystem as a whole. This has created a situation reminiscent of the "tragedy of the commons," where an unregulated resource — in this case, the existence of spare capacity in a supplier network — is over-harvested to the detriment of everyone involved. Each firm worries about their immediate upstream suppliers, and assumes that those companies are taking responsibility for their upstream suppliers in turn. However, with globalized firms competing over every step of production, the failure to understand supply chain governance in a macro sense has led to a hollowing out of secondary or even marginally higher-cost producers. This in turn creates a systemic fragility to which every producer is vulnerable. Competition may appear to produce an efficient supply chain, but if every firm converges on that same "efficient" supply chain, the competition itself disappears. If anything happens along those supply lines, everyone is exposed.



Source: National Academies Press.

"An example[7] of cascading failure in a supply chain: filled shapes represent normal flows, empty shapes represent breakdowns at nodes. The supplier breakdown on day 1 turns into a manufacturer breakdown on day 3 and a shortage for consumers on day 12."

In semiconductors in particular, the pressures to cut excess capacity against flagging demand[8] have led to a particularly fragile supply chain ecosystem. When an external shock disrupts these supply chains, it's not immediately obvious how to pull the system back together. In fact, firms have incentives to be secretive about their procurement structure and much of global competition today is merely a competition in assembling an incrementally faster or more efficient supply chain.[9]

Rather than functioning like a direct line for each good, where each product has its own independent path from raw material to finished good, supply chains operate more like a web. This web has starting points at raw materials, thousands of factories as nodes, and end points at final consumers. A breakdown at one of these nodes may affect a single final goods industry, or it may affect hundreds. Without good data on supply chain infrastructure, it's impossible to know beforehand which industries will be impacted, and how severely.

The absence of expertise in understanding and monitoring global supply chains has greatly hampered the government's response to the present semiconductor shortage. There have been many calls to "do something" about the shortage, but these have yet to result in any concrete action. Unless policy begins with a clear understanding of supply chains as they exist, and with an eye to how they could shift, it will be unable to meaningfully engage with the problem. Semiconductors are a natural place to start building this administrative capacity.

To summarize:

(1) The complexity of today's supply chains masks their underlying fragility.

(2) No public datasets with sufficient granularity to understand potential future supply chain bottlenecks currently exist.

(3) Government institutions, primarily within the Department of Defense, do have existing competencies that we can leverage to build sector-level understandings of industry capacity and supply chain structure.

Complexity and Fragility

As we have written about extensively,[10] concentration in the global value chain for the semiconductor industry has created an overly fragile system, vulnerable to even minor disruptions. However, we cannot discuss a single semiconductor value chain. Individual product markets within the industry encompass a wide range of technological capabilities and economic circumstances. Successful supply chain monitoring must differentiate between frontier, emerging, and mature technologies. At the lagging edge, this is a question of examining the balance between profitability and redundancy in production to find where government intervention could enhance resilience.

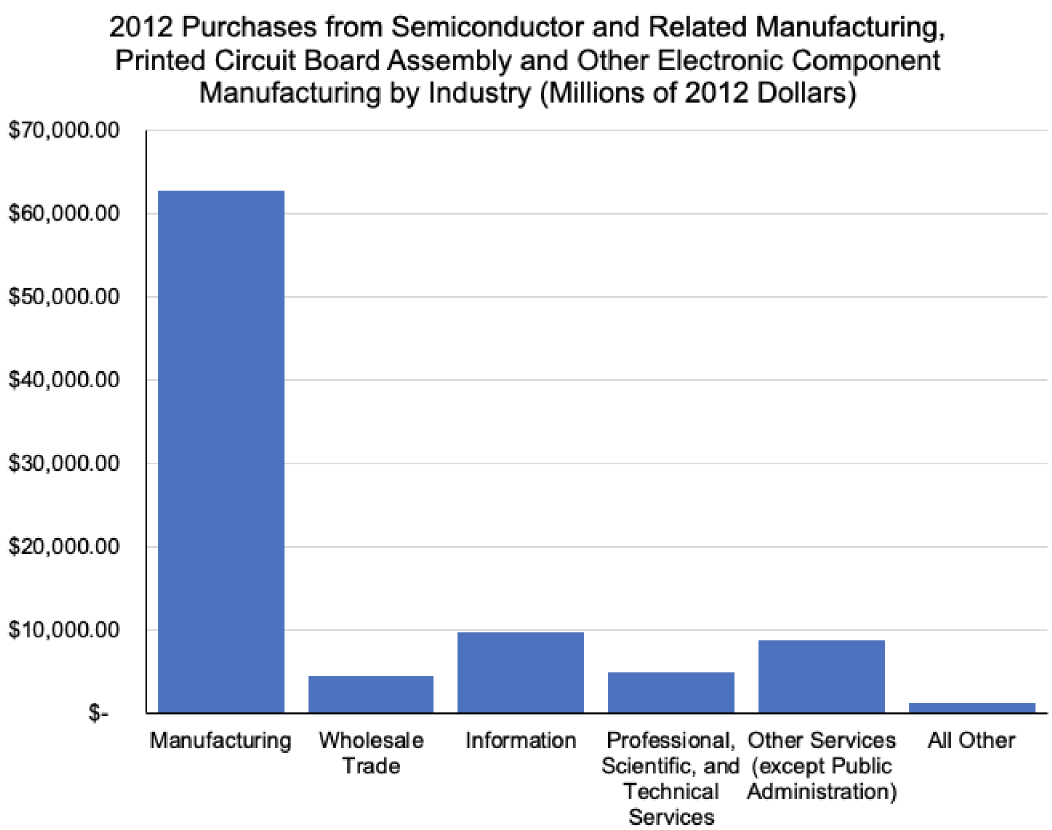
At the leading edge, this is a question of ensuring the dissemination of cutting-edge production techniques to ensure that firms aren't tied to a single supplier for a particular task. This is a real problem, as limitations of worker know-how and the sheer cost of investing in large scale capacity has driven substantial consolidation on the technological frontier into too-big-to-fail "Champion Firms." For example, anyone who wants to produce chips at the 5 or 7 nanometer node today is single-sourced[11] with the Dutch company ASML, the globe's only supplier of Extreme Ultraviolet (EUV) lithography equipment, a necessary process for leading-edge manufacturing. Furthermore, only three firms are even capable of manufacturing at that process node, producing chips so small that billions could fit in a single coffee mug.

While reshoring production could play a role in creating more resilient supply chains, it's not nearly sufficient. A resilient supply chain must be able to operate unimpeded over a wide range of adverse events: floods, wars, financial crisis, port disruption, pandemics. Reshoring all production merely shifts exposure entirely to domestic problems, like the Texas grid failure or California wildfires. Given the climate disruptions to come, geographic dispersion is a key component of resiliency. However, the system we have today developed its geographic dispersion on the basis of tax optimization and cost minimization, not resiliency. When a single source falters, the effects are the same whether the firm is domestic or foreign. Successful supply chain monitoring will take into account the benefits that a globally distributed but structurally resilient supply chain can have, especially against natural disasters.

Sourcing Data

Supply chain monitoring requires a lot of data that the government does not currently have. The Input-Output Tables prepared by the Bureau of Economic Analysis[12] (BEA) are the closest in spirit to the data we would need. These tables do a good job explaining aggregate inter-industry linkages and provide an easy handle on who buys what from whom.

The BEA also uses these Input-Output tables to produce "Requirements" tables, which show even more complex interlinkages.[13] In these we can see that although a furniture manufacturer may not buy products directly from semiconductor manufacturers, they remain reliant on intermediate goods that use semiconductors. The furniture manufacturer may purchase machinery and other capital goods from a firm that purchases directly from a semiconductor manufacturer. At the same time, the mill that produces the lumber may rely on computerized precision lathes that in turn rely on a semiconductor firm. Though the linkages are not direct, they structure the economy as a whole.



Source: BEA Input-Output Tables

However, this data is highly aggregated, and offers little insight into firm-level decision-making or inter-firm linkages of the type we highlighted here.[14] To understand supply chains, the government must be able to produce much more granular datasets that reveal the nature of existing ecosystems.

Ideally, these would show flows between suppliers, and map out — in both geographic and production process terms — where bottlenecks may exist. This would allow us to identify choke points, where a crisis in a single factory or single country could produce significant downstream disruption. Thankfully, on both the public and private side, there is a substantial literature on supply chain analysis[15] and supply chain risk[16] profiling that we could use to structure our intervention.[17]

Ultimately, the supply chain monitoring program should provide sufficient data to examine a variety of risks and vulnerabilities. Data collection will be its core competency and responsibility. Ideally, we start with granular Input-Output data at a firm level that allows researchers to break into the black box of "technology." Next, we use that granular data to examine market concentration in intermediate inputs and raw materials. It is also critical to examine geographic concentration, to assess vulnerability to both adverse climatic conditions and adverse geopolitical developments.

At an economy-wide level, this data should be able to tell us what kinds of semiconductors are widely shared across key industries, to allow for better overall economic strategy. If a certain type of microcontroller is used to produce phones, automobiles and medical equipment, the government has an interest in ensuring that the supply lines for that chip don't fracture.

Existing Competencies

While assembling a supply chain monitoring office for key industries is a heavy lift, some existing approaches point the way towards what government supply chain monitoring could look like.

The Department of Defense, as a longtime swing purchaser in a variety of markets, has developed offices with competencies similar to those we would be interested in. The Office of Industrial Policy[18] coordinates its efforts to prevent single-sourcing for key strategic inputs. The National Counterintelligence and Security Center (NCSC) has established a strategic initiative[19] to secure semiconductor supply chains. The Space Industrial Base Working Group[20] tackles similar problems in the domain of aerospace engineering. The Defense Production Act[21] also authorizes the blocking of key mergers based on national security interests. To justify these, they complete wide-ranging studies of the affected supply chains to demonstrate national security impact.

Supply chain monitoring is the critical first step on which the rest of an industrial policy program relies. Without this, policymakers can only swing wildly in the dark. Not only will mistakes and misfires hamper attempts to create resilient supply chains, they may make future industrial policy less politically viable.

Step 2: Establishing Clear Goals for Policy

Once the government has developed an understanding of existing supply chains and the threats they face, the next step is to decide the goals of intervention. While this may seem obvious, it can be challenging to link high-level goals like "supply chain resiliency" to specific interventions in specific industries. Some circumstances may merit direct investment by the government, while others may only require only loan guarantees or institutional coordination and guidance.

In fact, a central tenet of the US Science Policy approach is to provide funding without specific policy goals, but rather to provide funding based on the expert decisions of scientific panels. This approach has been tremendously successful at expanding our nation's scientific capabilities at the frontier. However, it has few tools to ensure that those scientific capabilities translate into industrial capabilities and commercial successes. At the same time, an overwhelming focus on funding for R&D and design alone has implicitly subsidized the offshoring of the actual production of chips. As we have noted elsewhere,[22] this has cost domestic industry process improvements, and Intel is at risk of losing[23] its process lead to Taiwan Semiconductor (TSMC) on an increasing range of chips.[24] This was not an intentional policy outcome, but rather, an accident of poorly specified goals. R&D is important, but a system that only subsidizes research implicitly penalizes production.

Moreover, in recent years, firms have reduced their own investments in basic research. As this trend proceeds, the linkages between scientific capabilities and industrial capabilities which underpinned the rationale of much of this investment may be changing. The latter trend's impact is further exacerbated by increasing industrial concentration. Within a given sector, only a few firms operate at the leading edge and their strategies and investment decisions become de facto national technological and industrial development paths. When technological capabilities are a core component of national competitiveness these champion firms in effect become "too big to fail." If their development path turns fruitless, there is no other cutting edge firm ready to take the lead on a different path. National policy is leveraged tightly to company policy.

Our approach is not to abandon Science Policy for Industrial Policy. Instead, we see the two approaches as symbiotic and mutually-reinforcing. Scientific funding and institutions explore novel phenomena, lay the groundwork for identifying new scientific and technical directions and provide fertile training ground for the next generation of workers, but they cannot enumerate specific production targets for industry to hit. Industrial policy steps in to guide the question: given our scientific capabilities, and the structure of this industry's global value chain, which interventions best ensure our domestic capabilities are sufficiently robust to maintain a competitive edge. We will argue later that coordinating this hand-off between two policy approaches requires standing-up dedicated institutions on the industrial policy side to match those on the science policy side.

Learning From China and Japan

East Asian countries have in the past successfully leveraged the Industrial Policy toolkit to play catch-up because the already-mature semiconductor market provided them clear targets to aim at. However, Industrial Policy critics will rightly point out that these countries have largely been unable to translate those successes into durable advantages at the leading-edge. We build on lessons from those countries and argue that the US starts with its own major advantage: the US already has a rich vein of institutions dedicated to — and successful at — advancing the technological frontier. All that needs to be done now is to assemble a coherent industrial policy program to support them.

In the 1980s, when the Ministry of International Trade and Industry (MITI) helped orchestrate Japan's ascendance in the global semiconductor industry, most major producers had already consolidated their designs around a few standard chips. Since these chip designs were well understood, policy goals could focus expressly on production targets. Companies could then optimize around those goals,[25] minimizing cost and capturing market share. Greenfield development of fabs and government-directed mergers helped rationalize the whole domestic industry towards a common and well-specified goal. This is the ideal strategy for an industrial policy approach: using the levers of government power to organize production of well-understood products.

However, when MITI began setting new targets — especially in its Super-Speed project[26] — it faltered. After dominating chip production for a few years, Japan began to pursue what we have been calling "Science Policy," focusing R&D funds on new technologies, rather than process improvements in production. While this created a lot of anxiety[27] in the US at the time, the project was largely a failure. Industrial policy and science policy use different tools and methods, and cannot compensate for one another.

China has followed Japan's footsteps in this story: hitting industrial policy targets with speed that terrified the international community, before stumbling in setting its own technological goals. In the late 80s, under Deng Xiaoping, much of southern China began to open to foreign markets.[28] By the mid-2000s, commodity semiconductor production had become a major part of the region's economic strategy.[29]

Today, many critical chips are sourced from China, and Chinese manufacturers have proven incredibly adept at cutting costs in the production of well-understood technologies. This has steadily driven lower-tech Western fabs out of those markets, as was the case with Japanese dominance in the 1980s and early 1990s.

However, companies like Huawei have floundered when trying to set new technological standards for hardware production.[30] In fact, China has had real[31] trouble[32] establishing leading edge fabs, owing in part to an absence of the kind of scientific base the US has long cultivated. In many cases, they simply lack the technological know-how to push forward the frontier. This has led to an extreme anxiety[33] on the part of American commentators and policymakers about Chinese industrial espionage, but in fact shows that the US remains dominant on the technological frontier of chip design.

Goal-Setting in Science Policy and in Industrial Policy

As we argued previously, US policy towards semiconductors erred due to a myopic focus on scientific progress. This funneled money towards frontier research but neglected to maintain the competitiveness of our industrial base. Industrial Policy and Science Policy approaches differ on the basis of their goals. While Science Policy institutions focus on expanding frontier capabilities, successful Industrial Policy must establish goals for industrial capability throughout the value chain. Goal setting in science policy is driven by scientific panels of reviewers from institutions like the NSF and NIST in determining what to fund. By contrast, Industrial Policy goal setting is informed by supply chain monitoring and driven groups of key stakeholders.

At a macro level, all of this illustrates the key difference between the Science Policy regime that has dominated US intervention into semiconductors and the Industrial Policy regime that many international competitors have used to successfully enter the space. Industrial Policy is focused on developing tools to hit specific production targets reliably and well, at low cost and efficiently. Science Policy instead provides tools for deciding where that target that Industrial Policy aims at can be, or even where it should be. The two practices are symbiotic, and a move to add an Industrial Policy approach would support the US's broadly successful Science Policy approach.

However, the Industrial Policy approach demands its own goal-setting and will be ill-served by the methods of existing Science Policy-focused institutions like the National Science Foundation[34] (NSF) and the National Institute of Standards and Technology[35] (NIST). Science Policy is closest in spirit to research, while Industrial Policy is closer in spirit to engineering.

At a macro level, the policy goals for a successful Industrial Policy program are clear:

On the low-tech side, we want to create robust supply chains that prevent final goods producers from single-sourcing critical chips and to capture the process improvements that can only come from iteratively increasing capacity incorporating the latest techniques.

On the high-tech side, we should ensure a broad and differentiated competitive ecosystem, where large and small firms coexist and iterate near the technological frontier. Rather than a few champion firms setting the direction of technology policy for the nation as a whole, the government should work to maintain a competitive landscape with diverse and innovative approaches to production, robust supply chains, and ***sufficient labor and capital to support both.*** It is also critical, at every level, to assess degrees of industry concentration when considering supply chain impacts.

However, without a good understanding of existing supply chains, it is difficult to translate these big-picture goals into concrete action. Nonetheless, some of the tools explained below may provide a good starting point for thinking about how to translate large-scale goals of resilient supply chains into firm-level intervention and coordination.

Step 3: Smoothing Financial Uncertainty

With data gathering processes firmly in place and actionable goals established, policymakers can next outline the tools for intervening in these supply chains.

As we have discussed in previous pieces in this series, the semiconductor industry has a long history[36] with Industrial Policy. In the early years of its development, direct funding by the Department of Defense, second-source contracts, mandatory licensing and technology sharing, as well as price and purchasing guarantees helped motivate investment into what was a promising but highly uncertain space. However, today's market is dramatically different and production processes have changed accordingly. We have to adapt this earlier playbook to a radically changed industry.

We can break things down by looking first at the investment side of the industry, and then looking at the employment side. Both are critically important: as we have argued, much of the stagnation since the dot com bust may be due as much to worker attrition as to a failure to invest.[37]

Under an industrial policy regime, the government has ecosystem-level, rather than firm-level, goals. Policy is meant to support supply chains that all firms rely on. The government's comparatively soft budget constraint means it has the resources to take responsibility for the smooth operation of economically critical supply chains.

Investment-side Strategies

As outlined previously, weak demand and a policy regime that implicitly supported the outsourcing of production have together created a situation of substantial underinvestment in capacity in the US semiconductor industry. A well-executed Industrial Policy program will reverse that trend by making strategic investments in semiconductor supply chains.

As others have addressed at length, there are a number[38] of techniques[39] that the government[40] can use[41] to achieve these goals.

One of the most common is loan guarantees. The US has used these in the past to support targeted industries, especially when encouraging investment related to climate change.[42] These work by allowing firms to issue debt to finance operations or investment. If the firms are unable to pay back those loans, the government will step in to make lenders whole. By de-risking investment into a volatile sector, government policy can encourage more entrants and greater capacity buildout. Financing will become less of a constraint for private actors.

Another important set of tools are price and purchasing guarantees. The Department of Agriculture uses these to support commodity prices in a variety of key industries,[43] particularly corn and dairy. More recently — and more germane to our present disruptions — price and purchasing guarantees for vaccines played a key role[44] in incentivizing rapid buildout of new capacity. The basic idea is that the government picks a cornerstone commodity and guarantees a price at which it will buy these. If the market price lands above the government price, they don't need to buy anything, but if the market price is below, then producers know they can still move product and cover their costs. Ultimately, the government is using its balance sheet to smooth financial uncertainty in private markets and guarantee production of critical commodities.

While milk and eggs are substantially different from semiconductors, the Department of Defense, under the Defense Production Act Title 3,[45] offers some similar guarantees to firms that produce rarely-needed but vital semiconductor products.

A more intensive approach may be for the government to outright purchase equity stakes in companies engaged in producing critical components, to allow them to diversify their operations along strategic grounds. This approach offers the government more control over the investment process, as well as setting it up to absorb any loss or benefit incurred by the company. This approach might be most successful in supporting infant companies working to innovate near the technological frontier. In-Q-Tel,[46] the wing of the Department of Defense, arguably does a version of this already.

At the most aggressive, the government could itself directly invest in the buildout and maintenance of key facilities. National Labs and National Fabs could be established and fully funded within the institutions charged with directing Industrial Policy and provide both a location for targeted investments as well as provide an employment backstop for workers in the industry.

On the mature technology side, the government can support the production of the low-profit-margin chips needed to enhance the reliability of the ecosystem as a whole. On the high-tech side, these interventions might take the form of mission-oriented public/private labs dedicated to building pilot lines for next-generation fabs (e.g. advanced packaging,[47] 3nm[48]). The government could also jointly fund pilot plants with larger firms to train researchers and students. To ensure a public mission, firms would agree on information-sharing and technology transfer for innovations developed onsite.

Each approach has its unique upsides and downsides, and different approaches may be better suited to different situations. It's hard to say with any degree of certainty before the relevant data has been produced.

However, it is important to remember that Industrial Policy involves not just carrots, but sticks as well. Government support comes with reciprocal obligations.

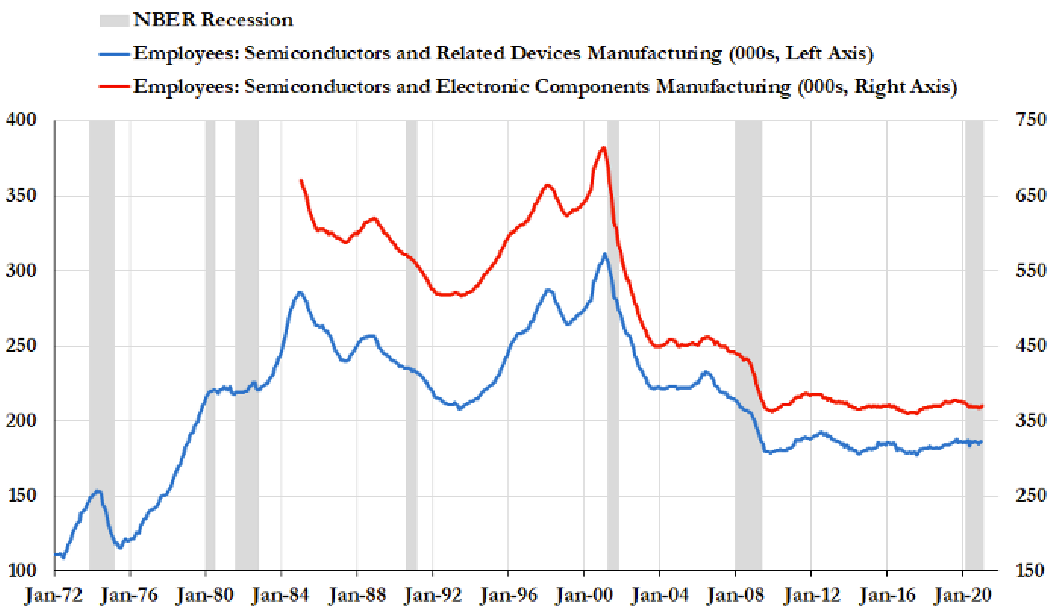
One of the most important of these is continued access to data on supplier relationships to support the supply chain monitoring efforts described in Step One. This information is often a competitive advantage for firms, and it may take some coaxing to get them to give it up, as well as benefits for doing so.

As a result, the government should have leeway to negotiate with private firms on needs as well as terms. Without a dedicated industrial policy, the government can be limited to "throwing money at the problem." They identify a problem and ask firms how it should be solved. The firms suggest some sweetheart deals that the government can either accept or reject. In the absence of government-side supply chain knowledge, government negotiators are wholly reliant on information provided by private actors while bargaining for the public interest. While this dynamic can be seen in regional squabbles like the siting of Amazon HQ2,[49] it also covers broad strategies, like TSMC and Intel's requests for gargantuan sums[50] in exchange for reshoring production.

The data from a supply chain monitoring system will allow government actors to construct models of the ecosystem, and negotiate with private firms over these models. They will be able to bargain effectively and thereby ensure that public funds serve public purposes. In fact, with the data gathered above, the government as a whole will be in a better position to negotiate with important economic actors, by virtue of having a better grip understanding of the supply chain ecosystem as a whole.

Employment Strategies

On the employment side, industrial policy can correct the problems that decades of underinvestment in retaining and upskilling workers have created. As we have shown,[51] the industry's connection to broader macroeconomic trends has meant substantial attrition and hiring declines in recent years.



Source: BEA Input-Output Tables

We know from studies[52] that workers in this industry have many portable skills, and when they are laid off, they often shift to a different industry that can provide better job security and benefits. As such, an Industrial Policy program focused on retaining the technological frontier while enhancing our productive capacity across the technological spectrum requires a substantial engagement with labor.

Both the design and production aspects of semiconductors rely heavily on what some economists refer to as "human capital." On the high-tech design side, many of the top workers in the field are highly sought after internationally. These are highly educated workers with unique talents working on the cutting edge. An Industrial Policy approach needs to ensure that these workers are able to stay and build careers at US companies.

On the lower-tech side, workers utilize a different set of highly-context-specific skills. Semiconductor manufacturing is part chemistry, part physics, part nanotechnology, and part artistry. Speeding up production requires people who have a deep and intuitive understanding of existing processes that can often only be gained through years of experience.

When these workers — though some may be considered blue collar — are forced out of the industry, that process knowledge leaves with them. Much of Industrial Policy is concerned with process improvement, and as such, workers at every level of the technological and skill spectrum need job security, regardless of the broader macroeconomic winds.

Naturally, some of these labor benefits will accrue through the programs described in the investment section. Increased investment in capacity means bringing on more workers, and upskilling existing ones to meet new targets. Increased demand through government purchasing programs will likely mean the same.[53] What is most important though, is for Industrial Policy to learn from the mistakes of Science Policy, and not restrict its reach to highly-credentialed workers and experts.

The labor market programs associated with a strong Industrial Policy program must be durable, coherent and consistent. Using the fiscal power of the state to smooth uncertainty for workers as well as for firms is a natural way to confront this problem.

Failure to do so, like we saw when the National Institutes of Health temporarily had its budget doubled,[54] can actually be worse than not increasing funding at all. For the few years that funding was doubled, researchers started many new projects and added many new workers. Once that expanded funding expired — something no one in the field expected — the response[55] was a predictable winnowing down of existing projects, and the shedding of key workers and know-how.

For this reason, we include our fourth step: building durable institutions. Without these, an Industrial Policy program is likely to degenerate into a collection of barely-related subsidies, or a few underfunded programs.

Step 4: Building Durable Institutions

Keeping Industrial Policy democratically accountable while also ensuring that it is sufficiently flexible to achieve its goals is a tricky balancing act. Individual politicians can't be expected to keep up to date on incremental advances in rarefied high-tech fields. At the same time, policy decisions can't be handed off entirely to private firms and their representatives. Regulatory capture is already a serious issue in many industries.

Why New Institutions?

As we discussed above, the US has a rich history and expansive ecosystem of Science Policy institutions for guiding and facilitating research at the technological frontier. These institutions have been so successful that some have suggested organizing our Industrial Policy program within those existing institutions. As we hinted at in step 2, this approach is less than ideal. Industrial Policy should come with a new set of dedicated institutions.

Many existing government departments have Industrial Policy divisions related to the goals of their departments. For the Department of Defense, these are oriented narrowly towards procurement.[56] In the Department of Energy,[57] these concerns often take the form of ensuring access to resources and the existence of supply chains to extract and process those resources. However, in both cases, these departments of industrial policy are inwardly-focused and look to make sure that the areas governed by each department are able to get the economic provisioning they need.

Since a core motivating factor behind the push for industrial policy to address issues in the semiconductor industry is the semiconductor's status as a critical "general purpose"[58] technology, this inward-looking approach is not appropriate. While those departments may best achieve their goals by using the methods of industrial policy to ensure their own needs are met, our goal is for the needs of the broader economy to be met. As such, our industrial policy program should take a broader scope and seek broader visibility than the kinds of industrial policy offices structured under specific departments.

Embedding industrial policy for semiconductors under the auspices of the NSF or NIST may make sense on first look, but unduly limits the scope of the program, and may hamper attempts to widen the aperture of industrial policy to other industries. As John Alic writes:[59]

> ***"The distinguishing feature of industrial policy lies in efforts to provide some form of goal-directed analysis and decision-making for whatever it is that government ends up doing that affects business decisions and behavior, directly or indirectly, and thus national economic performance."***

This is clearly different from the "set and forget" approach to funding Science Policy institutions, where day-to-day operations and strategy are handled by researchers and scientists, rather than government officials.

Ultimately, Industrial Policy institutions do Industrial Policy, and Science Policy institutions do Science Policy. The staffing, culture, toolkit and overall approach are markedly different between the two. The path of scientific development can't be made to exactly follow the dictates of policymakers, and Science Policy recognizes this. Policymakers can give broad, vague directives attached to open-ended spending that is then directed by scientists and industry experts.

The path of economic development, in contrast, has always been guided to a certain extent by policy. In times when it has been explicitly directed — wartime mobilization, for example — the result has been mammoth success in capacity buildout. Rather than deference to scientists and experts, the goals and approach of an industrial policy program should be explicit and democratically accountable. Policymakers are much more directly responsible for the success or failure of directed investment programs than they are in fostering scientific progress. This requires a different set of skills, a different culture, and a different approach from the Science Policy approach, and the institutions we establish should reflect that difference.

Making Institutions Work

A key ingredient to successful industrial policy is participation by key stakeholders. Industry buy-in is absolutely necessary. The goal of industrial policy is to enhance their productive capabilities: if they aren't on board, the program has already lost. Input and involvement from labor is critical to ensuring that these new policies help with retention and upskilling. At the same time, equity considerations demand that we give labor a seat at the table in determining industrial policy. Last, policymakers are required to ensure that the institution, though independent, is accountable to the demands of a democratic country.

Policy must become more flexible the closer it gets to the technological frontier; "disruptive innovations" like those described by Clayton Christensen[60] may create rapid shifts in supply chain structures. At the same time, changes in technology trajectories change the linkages between universities, firms, and suppliers. For example, we might need to quickly grow the capacity of our labor force in solar panel construction[61] to meet growing demand as well as ecological goals. Policy flexibility also helps with adaptation to changing crises, such as the present shortage brought on by the COVID-19 pandemic.

These two needs are best fulfilled by creating institutions dedicated to the practice of industrial policy that also build relationships and facilitate communication between key stakeholders. Science Policy[62] succeeded by building a diverse array of institutions centrally linked to the National Science Foundation. Institutions like this provide a natural clearinghouse for an array of policy approaches, and allow iteration of technique without having to go through the process of legislative approval for each particular change.

Perhaps most importantly, institutions are important locations for "Learning-by-Doing." Embedding these insights and processes in institutions will help ensure they are iterated and passed on, while also providing proof of concept for doing industrial policy as climate change forces us to adopt this strategy for a wider range of industries.

In Conclusion

The principles outlined above offer a roadmap to the development of a successful Industrial Policy strategy for semiconductor production but are widely applicable to many industries. While engaging with existing legislative proposals — the Endless Frontiers Act, the CHIPS Act, the Biden Infrastructure Plan — is beyond the scope of this present piece, all of them solve critical parts of the problem while ignoring others. The solution to this chip shortage, and the way to prevent the next shortage in the next industry, is to build out a large-scale, comprehensive, and enduring Industrial Policy program to reinforce and protect our fragile supply chains.

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