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Jeffrey Ding and Allan Dafoe

ABSTRACT
What resources and technologies are strategic? Policy and theoretical debates often focus on this question, since the "strategic" designation yields valuable resources and elevated attention. The ambiguity of the very concept, however, frustrates these conversations. We offer a theory of when decision makers should designate assets as strategic based on the presence of important rivalrous externalities for which firms or military organizations will not produce socially optimal behavior on their own. We distill three forms of these externalities, which involve cumulative-, infrastructure-, and dependency-strategic logics. Although our framework cannot resolve debates about strategic assets, it provides a theoretically grounded conceptual vocabulary to make these debates more productive. To illustrate the analytic value of our framework for thinking about strategic technologies, we examine the US-Japan technology rivalry in the late 1980s and current policy discussions about artificial intelligence.

In March 2018, when the Office of the US Trade Representative released its Section 301 report[1] on China's unfair trade practices—one of the first volleys in a trade war—astute observers noted that the report singled out one Chinese technology plan: "Made in China [*zhongguo zhizao*] 2025." Amid the bluster of tariffs on steel and soybeans, these analysts understood that "Made in China 2025," which prioritized ten "strategic industries [*zhanlüe chanye*]," posed the "real existential threat to U.S. technological leadership."[2] Indeed, competition over "strategic" goods and technologies has

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[1]Office of the US Trade Representative, *Findings of the Investigation into China's Acts, Policies and Practices Related to Technology Transfer, Intellectual Property, and Innovation under Section 301 of the Trade Act of 1974* (Washington, DC: Office of the US Trade Representative, Executive Office of the President, 22 March 2018).
[2]There were 116 mentions of "Made in China 2025" in the Section 301 report. The Chinese State Council first issued the plan in May 2015. The ten strategic sectors included high-end numerical control machinery and robotics, energy-saving and new-energy vehicles, biopharmaceuticals and high-performance medical devices, etc. Lorand Laskai, "Why Does Everyone Hate Made in China 2025?" *Net Politics* (blog), Council on Foreign Relations, 26 March 2018, https://www.cfr.org/blog/why-does-everyone-hate-made-china-2025.

become a focal point in the broader US-Sino rivalry, though the crucial step of clarifying what makes an asset "strategic" has often been neglected.[3]

This definitional vagueness is neither new nor limited to the US-China rivalry. For centuries policymakers and theorists have debated which goods and technologies deserve the "strategic" descriptor. These conversations matter. David A. Baldwin's 1985 characterization of the debates over strategic assets remains true today: "Widespread misunderstanding of the concept of 'strategic goods' is one of the biggest impediments to intelligent discussions of economic statecraft."[4] However, even as nations are increasingly concerned about strategies to build up technological advantages over their rivals, much more work needs to be done to understand the underlying logic of what makes an asset strategic.

How should national leaders identify strategic assets? In this paper, we present a unified theoretical framework based on an asset's connection to important rivalrous externalities, such that markets and individual national security entities themselves will not achieve optimal transactions involving these assets. Strategic assets are those that require attention from the highest levels of the state to secure national welfare against interstate competition.

Our theory of strategic assets offers a conceptual framework for clarifying policy debates over technology strategy. Mirroring Alexander L. George and Richard Smoke's characterization of deterrence theory's policy function, our theoretical work can best be understood as serving a "diagnostic function," providing "assistance to policymakers in assessing the configuration of a situation."[5] Instead of how to deter other states, we focus on how to identify strategic assets.

This framework is roughly captured in the following "strategic formula" for goods and technologies:

$$\text{Strategic level of asset} = \text{Importance} \times \text{Externality} \times \text{Nationalization}$$

[3]For instance, in October 2018 the US Department of Treasury established a pilot program that increased scrutiny of inward foreign investment in "critical technologies," a broad category that includes defense equipment and a similarly broad subcategory of "emerging and foundational technologies," which has not been defined. US Department of the Treasury, "Determination and Temporary Provisions Pertaining to a Pilot Program to Review Certain Transactions Involving Foreign Persons and Critical Technologies," 83 Fed. Reg. 197 (11 October 2018), https://home.treasury.gov/system/files/206/FR-2018-22182_1786904.pdf.

[4]David A. Baldwin, *Economic Statecraft* (Princeton, NJ: Princeton University Press, 1985), 214.

[5]Alexander L. George and Richard Smoke, "Deterrence and Foreign Policy," *World Politics* 41, no. 2 (January 1989): 180; Alexander L. George and Richard Smoke, *Deterrence in American Foreign Policy: Theory and Practice* (New York: Columbia University Press, 1974), 616–42. Our second section provides a longer explication of our method.

The strategic level of an asset is a product of the following three factors:

1. *Importance*: an asset's economic and/or military utility (some sectors, such as freight transport, contribute more to economic growth than others, such as high-end fashion).
2. *Externality*: the economic and/or security externalities associated with an asset, such that uncoordinated firms and individual military organizations will not optimally attend to the asset (for example, the positive externalities generated by research into foundational technologies, which private actors underinvest in because they do not capture all the spillover benefits).[6]
3. *Nationalization*: the degree to which these externalities are rivalrous between nations. Some assets, such as fundamental research in medicine, generate positive externalities that may easily diffuse to other rival nations, which limits their strategic level.[7]

Of these three factors in our framework, we focus on what we consider the most illuminating aspect of this equation: the existence and character of externalities that demand the state's attention. Typically applied to the behavior of private firms, externalities can also pertain to the actions of military entities, such as the navy, which have an incentive structure that does not wholly internalize other subnational actors' interests. Basing the framework on externalities also roots it in existing scholarship at the intersection of economics and national security.[8]

Externalities come in many shapes, but we distill three forms of these externalities—the cumulative-, infrastructure-, and dependency-strategic logics—that cover a substantial range of the strategic qualities of assets (see Table 1). The cumulative-strategic logic involves assets and sectors with high barriers to entry linked to cumulative processes, such as first-mover dynamics, incumbency advantages, and economies of scale. These high barriers to entry lead the market to underinvest, and military organizations to require explicit state support to achieve nationally optimal investments. Aircraft engines (1945–present) serve as a representative example. Even with government support, China's defense firms still lag the top producers of aircraft engines due to high research and development (R&D) costs and steep learning curves.[9]

[6]Even the most important assets, such as nuclear weapons, may score low in this factor if states have already internalized all the externalities associated with these assets.
[7]Nevertheless, such assets may still be worthy of government attention, as they provide absolute benefits.
[8]William J. Norris, *Chinese Economic Statecraft: Commercial Actors, Grand Strategy, and State Control* (Ithaca, NY: Cornell University Press, 2016); Andrew B. Kennedy and Darren J. Lim, "The Innovation Imperative: Technology and US–China Rivalry in the Twenty-First Century," *International Affairs* 94, no. 3 (May 2018): 553–72.
[9]Stephen G. Brooks and William C. Wohlforth, "The Rise and Fall of the Great Powers in the Twenty-First Century: China's Rise and the Fate of America's Global Position," *International Security* 40, no. 3 (Winter 2015/16): 38.

Table 1. The three logics of strategic assets.[11]

The logics	Description	Examples (economic)	Examples (military)	Examples (both)
Cumulative-strategic	Have high barriers to entry due to first-mover dynamics, incumbency advantages, economies of scale, or other cumulative dynamics.	Digital social networks (2000–present)	Stealth fighters (1945–present)	Aircraft engines (1945–present)
Infrastructure-strategic	Generates (diffuse) positive spillovers across the national economy or military system. These are often fundamental technologies that upgrade the national technological system.	Electricity (1890–1920)	Radar (1930–45)	Railroads (1850–90)
Dependency-strategic	Supply characterized by extramarket dynamics and few substitutes.	Platinum (1960–present)	Nitrates (1914–18)	Integrated circuits (1980–present)

The infrastructure-strategic logic involves assets that generate positive spillovers across the national economy or military system, in which subnational actors (for example, firms or military branches) underinvest because they do not appropriate all the associated gains. These are often foundational technologies that complement and upgrade the national technological system. A representative example is railroads (1850–90), which generated enormous positive spillovers for the US economy by enabling new patterns of labor mobility, economies of scale for manufacturing, and wholesale food distribution channels.[10]

The dependency-strategic logic involves assets a robustly open and competitive market does not supply, making such assets vulnerable to cutoffs. This often arises from physical, organizational, or national concentration in the supply chain, such that an adversary could plausibly intervene to reduce supply. These assets also must be essential, and thus have few substitutes. Nitrates (1914–18) are a representative example, as demonstrated by the British naval blockade's effect on Germany's supply chain for explosives, preventing nitrate imports from Chile, the world's principal supplier.

These logics illustrate that an asset's strategic level is not intrinsic to the good or technology itself. Not only is an asset's strategic level shaped by features of the international environment (for example, the rate of cross-border diffusion of technology); it is also affected by the particular strategy a state pursues (for example, one oriented around a land army, versus a navy, versus economic might, versus soft power). Motivated by the present environment of US-Sino rivalry, we focus on the strategy of a great power concerned about growing its economic and military strength vis-à-vis that of its peer competitors;[12] however, we also emphasize that our framework remains valid and useful for contexts in which states pursue different strategies.[13]

Bringing together scattered notions of strategic goods and technologies from international political economy and security studies, our framework

[10]Dave Donaldson and Richard Hornbeck, "Railroads and American Economic Growth: A 'Market Access' Approach," *Quarterly Journal of Economics* 131, no. 2 (May 2016): 799–858.

[11]Given date ranges represent our rough gauge of the period for which the asset remained at a high level of strategic significance for industrial great powers.

[12]For strategies pursued by nonmajor powers, see William I. Hitchcock, Melvyn P. Leffler, and Jeffrey W. Legro, eds., *Shaper Nations: Strategies for a Changing World* (Cambridge, MA: Harvard University Press, 2016); Thierry Balzacq, Peter Dombrowski, and Simon Reich, eds., *Comparative Grand Strategy: A Framework and Cases* (New York: Oxford University Press, 2019).

[13]Suppose, for instance, a state wants to base its strategy on soft power. Our framework gives an initial cut for where strategic assets may be positioned: sources of cultural capital dominated by a single country with high barriers to entry, such as the Hollywood film industry (cumulative-strategic); instruments, such as strict national standards against corruption, that prevent companies from undermining a nation's brand (infrastructure-strategic); and social media sites that dominate coverage for a particular country (dependency-strategic). Separately, a state's strategy may not give equal weight to economic and military might. For our framework, this would affect the "importance" of a particular asset but not the associated externality. We thank an anonymous reviewer for pointing this out.

contributes to the literature on the political economy of national security.[14] Existing scholarship on grand strategy rightly emphasizes the growing significance of technological instruments.[15] Although these studies offer insight into the relevant actors, doctrines, and consequences of various strategies, these discussions often neglect the objects themselves—that is, they fail to explicate how to determine which assets should be the target of statecraft.

Specifically, the designation of strategic assets drives at concerns about trading with the enemy, which is central to theories about economic interdependence and conflict.[16] However, "the analytical problem of how to distinguish strategic goods from others, particularly when the meaning of 'strategic' may vary across time and space" inhibits these ongoing debates.[17] Our framework provides a clearer conception of strategic goods by disentangling their military and/or economic utility (for example, the importance of having foodstuffs or weapons in a war effort) from the externalities associated with their production (for example, the extent to which supply of foodstuffs or weapons is concentrated in a particular country).

We also contribute to broader conversations over strategy and statecraft targeted at specific technologies, which increasingly extend beyond controlling trade.[18] In many cases, export restrictions on strategic assets hamper a nation's innovation system from "running faster," tradeoffs between two logics our framework captures.[19] By targeting externalities certain assets generate, our framework can help craft a more multidimensional and pragmatic technology strategy. This is in line with fifty years of research on scientific and technological competitiveness, which attributes success to a

[14]Michael Mastanduno, "Economic Statecraft, Interdependence, and National Security: Agendas for Research," *Security Studies* 9, no. 1–2 (1999): 288–316; Jonathan Kirshner, "Political Economy in Security Studies after the Cold War," *Review of International Political Economy* 5, no. 1 (Spring 1998): 64–91; Jonathan D. Caverley, "United States Hegemony and the New Economics of Defense," *Security Studies* 16, no. 4 (October–December 2007): 598–614.

[15]Kennedy and Lim, "The Innovation Imperative"; Mark Z. Taylor, "Toward an International Relations Theory of National Innovation Rates," *Security Studies* 21, no. 1 (January–March 2012): 113–52; Elizabeth Thurbon and Linda Weiss, "Economic Statecraft at the Frontier: Korea's Drive for Intelligent Robotics," *Review of International Political Economy* (2019): 1–25, https://doi.org/10.1080/09692290.2019.1655084.

[16]Jack S. Levy and Katherine Barbieri, "Trading with the Enemy during Wartime," *Security Studies* 13, no. 3 (Spring 2004): 1–47; Peter Liberman, "Trading with the Enemy: Security and Relative Economic Gains," *International Security* 21, no. 1 (Summer 1996): 147–75; Norrin M. Ripsman and Jean-Marc F. Blanchard, "Commercial Liberalism under Fire: Evidence from 1914 and 1936," *Security Studies* 6, no. 2 (Winter 1996/97): 4–50.

[17]Levy and Barbieri, "Trading with the Enemy during Wartime," 11.

[18]Beverly Crawford, *Economic Vulnerability in International Relations: The Case of East-West Trade, Investment, and Finance* (New York: Columbia University Press, 1993); Glenn R. Fong, "Breaking New Ground or Breaking the Rules: Strategic Reorientation in U.S. Industrial Policy," *International Security* 25, no. 2 (Fall 2000): 152–86; Nuno P. Monteiro, *Theory of Unipolar Politics* (Cambridge: Cambridge University Press, 2014), 124–42; Brooks and Wohlforth, "The Rise and Fall of the Great Powers in the Twenty-First Century."

[19]Hugo Meijer, *Trading with the Enemy: The Making of US Export Control Policy toward the People's Republic of China* (Oxford: Oxford University Press, 2016).

country's general commitment to solving market failures rather than to the role of any particular institution or doctrine.[20]

The paper proceeds in four sections. The first part reviews the literature on strategic goods and technologies, revealing the myriad and oft-confused understandings of the concept. We synthesize from this literature our three underlying logics of strategic assets: cumulative-strategic, infrastructure-strategic, and dependency-strategic. We fill out our externality-based framework of strategic assets in the second part, where we explain how firms and militaries fail to adequately internalize the benefits or risks of a good or technology. The next section illustrates the analytical value of our framework by examining the US-Japan technology rivalry in the 1980s and 1990s. Specifically, we highlight consistent missteps in US efforts to identify strategic assets, which failed to achieve purported goals. The final part applies our framework to artificial intelligence (AI), which has become central to current discussions about international technological competition.

Evolution of an Idea

In 1985, Baldwin wrote in his authoritative text on economic statecraft: "The controversy over what constitutes a 'strategic good' has been going on for thirty years."[21] Over thirty additional years later have passed, and scholars and policymakers still struggle with this ambiguous concept, leading many to abandon the exercise altogether and rely on gut feel—"they know a strategic industry when they see one."[22] Previous theorizing about strategic assets can be grouped into three camps, distinguished by whether the analytical focus is on: (1) military significance; (2) substitutability; or (3) strategic trade. Taking the perspective of a strategist concerned with the national interest, our framework for strategic assets highlights gaps and integrates insights from each camp.

Military Significance Camp

In the first camp, scholars emphasize the military significance of certain assets, arguing that military utility determines the strategic quality of goods

[20]Mark Zachary Taylor, *The Politics of Innovation: Why Some Countries Are Better Than Others at Science and Technology* (Oxford: Oxford University Press, 2016), 277. For an analysis of why the United States should adopt a more pragmatic approach to policymaking, which articulates the logic behind policy and yet eschews the rigidity of strategizing, see David M. Edelstein and Ronald R. Krebs, "Delusions of Grand Strategy: The Problem with Washington's Planning Obsession," *Foreign Affairs* 94, no. 6 (November/December 2015): 109–16.

[21]Baldwin, *Economic Statecraft*, 106. Baldwin traces this debate back to Yuan-Li Wu, *Economic Warfare* (New York: Prentice-Hall, 1952).

[22]David J. Teece, "National Support Policies for Strategic Industries: Impact on Home Economies," in *Strategic Industries in a Global Economy: Policy Issues for the 1990s* (Paris: Organisation for Economic Co-Operation and Development, 1991), 36.

and technologies.[23] The underlying assumption is that goods and technologies are "only strategic if they can be used for war, or converted for war, or processed into war-type goods."[24]

This view of strategic assets is prevalent in export control and defense industrial policy around the world, especially the United States. For example, from 1989 to 1992, the US Department of Defense (DoD) published annual critical technology plans, which designated twenty technologies as critical for US weapon systems' long-term qualitative superiority.[25] The US export regime is based on a conception of strategic assets tied to military end uses and users.[26]

From our framework's perspective, military assets often are strategic because they are often important and often exhibit one of the three strategic logics. However, notably, many military assets fail to meet one of these criteria, and thus by our framework should not be regarded as strategic. Some important military assets are readily supplied through global markets, or produced domestically through existing organizational capacity, and therefore do not require the high-level attention of the state because they do not exhibit rivalrous externalities. In the context of modern militaries, various types of missiles, machine guns, and other small arms are examples of assets that are militarily significant but not strategic under our framework.[27]

Substitutability Camp

The substitutability camp's view of strategic assets loosely corresponds to our framework's third logic (dependency-strategic). These thinkers base a good's strategic level on its substitutability, as captured by the degree to which it is critical to a significant economic or military process, as well as the availability of substitutes for the good. In line with the dependency-strategic logic, Theodore K. Osgood defines a strategic good as "an item for which marginal elasticity of demand is very low and for which there is no readily available substitute."[28]

[23]See, for example, Gunnar Adler-Karlsson, *Western Economic Warfare, 1947–1967: A Case Study in Foreign Economic Policy* (Stockholm: Almqvist & Wiksell, 1968), 3.
[24]Thomas C. Schelling, *International Economics* (Boston, MA: Allyn & Bacon, 1958), 500.
[25]Crawford, *Economic Vulnerability in International Relations*, 16–17.
[26]For an analysis of the challenges globalization and dual-use technologies pose for US export control policy, see Meijer, *Trading with the Enemy*.
[27]Using machine guns as an example, we expand on why military significance is insufficient for the designation of an asset as "strategic" in our second section. For evidence that US competitors have been able to catch up in missiles due to muted cumulative effects, see Brooks and Wohlforth, "The Rise and Fall of the Great Powers in the Twenty-First Century," 38.
[28]Theodore K. Osgood, "East-West Trade Controls and Economic Warfare" (PhD diss., Yale University, 1957), 89; Baldwin, *Economic Statecraft*, 215.

Elaborating this substitutability logic, Norrin M. Ripsman and Jean-Marc F. Blanchard's four-part "strategic goods test" is an exemplary, rigorous attempt to differentiate among classes of goods and technologies in Anglo-German economic relations before the First World War.[29] They first evaluate which goods were essential to national defense and economic well-being (*importance* in our equation) and then assess the impact of a supply cutoff by analyzing whether substitutes could have alleviated any disruptions (a particular kind of *externality* in our equation).

Primarily concerned about dependency risks, the substitutability camp does not look at other externalities that can give rise to strategic assets. Furthermore, the condition that the externality be rivalrous is rarely made explicit, plausibly because supply dependence is usually political, and thus can be made rivalrous. However, some dependence is in principle not rivalrous, such as two belligerents for whom a natural disaster disrupts their supply of oil, impacting them roughly equally.

Strategic Trade Camp

A third school of thought, the strategic trade camp, often lumps together the two strategic logics missed by the substitutability camp. Strategic trade theorists highlight the extent to which particular industries confer large first-mover advantages, present high barriers to entry, and/or yield enormous spillovers.[30] These considerations have risen in prominence alongside the liberalization of foreign direct investment flows, which enabled the consolidation of large-scale oligopolies.[31]

Strategic traders aim to ensure their national economy can both compete in industries with high learning curves and benefit from spillovers associated with the production of certain assets. Still, analysis from the strategic trade camp is largely limited to the economic domain and rarely differentiates between infrastructural and cumulative externalities; our framework rectifies both shortcomings.

Conceptual Framework

Under our framework, strategic assets are those for which there is an *externality* that is both *important* and *rivalrous*. As captured by the strategic formula in the overview, the strategic level of an asset is a product of these three factors, not a sum of three addends. Thus, these three criteria are

[29] Ripsman and Blanchard, "Commercial Liberalism under Fire."
[30] Paul R. Krugman, ed., *Strategic Trade Policy and the New International Economics* (Cambridge, MA: MIT Press, 1986).
[31] Wolfgang Michalski, "Support Policies for Strategic Industries: An Introduction to the Main Issues," in *Strategic Industries in a Global Economy* (Paris: OECD, 1991), 8.

Table 2. Tri-logic framework for strategic assets.

Strategic logic	$I \times E \times N$	$I \times E \times N$	$I \times E \times N$
	1, 0, 0	1, 1, 0	1, 1, 1
Cumulative	Steel (1990s–present)[a]	ITER (1985–present)[b]	Aircraft engines (1945-present)
Infrastructure	Real estate	Publications in basic science	Recombinant DNA tech (1980–present)[c]
Dependency	Wheat	Ozone	Integrated circuits (1980-present)

Note: I = importance; *E* = externality; *N* = extent to which externality differentially accrues to one nation vs. rival ones. 1 s and 0 s are a binary simplification. All three are continuous variables.

[a]Our third section explains why steel became less strategic.

[b]ITER is a thirty-five-nation project to demonstrate the large-scale feasibility of fusion. Any competitor project, whether a single-firm or multinational effort, faces enormous barriers to entry, but any accumulated gains from ITER will disperse across countries.

[c]For an empirical demonstration that recombinant DNA technology is a general-purpose technology, with the potential to improve productivity across many sectors, see Maryann P. Feldman and Ji Woong Yoon, "An Empirical Test for General Purpose Technology: An Examination of the Cohen–Boyer rDNA Technology," *Industrial and Corporate Change* 21, no. 2 (April 2012): 249–75.

each necessary and jointly sufficient for an asset to qualify as strategic (see Table 2).[32]

Consider two examples in the cumulative-strategic domain. First, assets that present externalities but have low levels of "importance" are not strategic. A new technology for brewing that exhibits strong "learning by doing" characteristics may generate barriers to entry, but the scale of the brewing industry does not have a substantial effect on the economic or military power of nations. Conversely, an asset can be extremely important but not strategic. M240 machine guns are essential equipment for infantry platoons and armored vehicles, but they are so easy for most nations to build or acquire that they do not exhibit strategic externalities.

This section further explores how these three strategic logics function in the economic and military domains. For each logic, we describe the mechanics of the externality, provide examples of strategic assets, and differentiate our interpretation of the logic from related, influential concepts (cumulative to Stephen Van Evera's "cumulative resources";[33] infrastructure to dual use; dependency to Albert O. Hirschman's "dependence"[34]). We conclude by highlighting the possible interactions between multiple logics, including scenarios in which assets are linked to multiple types of externalities or multiple logics conflict with each other.

[32]The concept of an asset's strategic level is a continuous one, as all three factors are continuous. Each condition must be present to a sufficient extent for the asset to have a high strategic level. Formally, this can be expressed as a product of the three conditions, or as these conditions being continuous versions of necessary and sufficient conditions. Gary Goertz, *Social Science Concepts: A User's Guide* (Princeton, NJ: Princeton University Press, 2006), 42. Our focus is on analyzing the positive and negative poles of the concept of strategic assets, though we acknowledge that gray zones exist where the cutoffs for the three criteria are unclear, as is the case with more theorized concepts, such as whether Switzerland is a corporatist or noncorporatist system, or whether Malawi qualifies as a democracy. We thank an anonymous reviewer for bringing up this point.

[33]Stephen Van Evera, *Causes of War: Power and the Roots of Conflict* (Ithaca, NY: Cornell University Press, 1999), 105–16.

[34]Albert O. Hirschman, *National Power and the Structure of Foreign Trade* (1945; repr., Berkeley: University of California Press, 1980).

Strategic Logic 1: Cumulative

The cumulative-strategic logic is underpinned by cumulative processes that entrench barriers to entry, a broad concept that covers long investment timelines, first-mover advantages, winner-take-all dynamics, learning by doing, etc. The potency of the cumulative effect can vary: a winner-take-all phenomenon, fueled by strong network effects, constitutes a strong version of the logic, whereas modest returns to scale generated by learning by doing evince a weak version of the logic.

The cumulative-strategic logic is relatively well understood in the economic domain. Most markets do not yield substantial rents because inter-firm competition moves the surplus to consumers. However, competition weakens in cases where cumulative effects characterize production, such as when returns only accrue after long time scales or risky bets, under strong economies of scale, and in the presence of other first-mover advantages.[35] Industries often identified as cumulative-strategic include semiconductors, commercial aircraft, and telecommunications.[36] As a byproduct of these cumulative processes, these strategic assets generate rents that accrue to the firms able to overcome the barriers.

Certain types of defense technology also exhibit the cumulative-strategic logic. For example, prime contractors (mostly based in the United States) benefit from network effects that come from controlling the arms-production industry's systems integration. Comparing systems integration technologies to "killer applications" and dominant standards such as Microsoft's Windows operating system, Jonathan D. Caverley highlights how customers/suppliers have an incentive to participate in weapons programs backed by US prime contractors since each new customer/supplier enhances the weapon's value for everyone in the network.[37]

Cumulative dynamics associated with learning by doing manifest in the interaction between some military technologies and the organizations that produce them. For instance, Andrea Gilli and Mauro Gilli argue that stealth fighters have not diffused to many countries since the required technical knowledge to make stealth fighters has become increasingly organizational in nature.[38] Since this organizational knowledge has accumulated in the collective memory of the US military, rival nations cannot acquire it through licenses, stealing blueprints, or even kidnapping engineers.

[35]On how the intervention of foreign governments affects the strategic calculus for cumulative gains in certain industries, see Marc L. Busch, *Trade Warriors: States, Firms, and Strategic-Trade Policy in High-Technology Competition* (Cambridge: Cambridge University Press, 2001).

[36]Helen V. Milner and David B. Yoffie, "Between Free Trade and Protectionism: Strategic Trade Policy and a Theory of Corporate Trade Demands," *International Organization* 43, no. 2 (Spring 1989): 239–72.

[37]Caverley, "United States Hegemony and the New Economics of Defense," 605–7.

[38]Andrea Gilli and Mauro Gilli, "Why China Has Not Caught Up Yet: Military-Technological Superiority and the Limits of Imitation, Reverse Engineering, and Cyber Espionage," *International Security* 43, no. 3 (Winter 2018/19): 162–63.

Lastly, it is important to relate our cumulative-strategic concept to Van Evera's conceptualization of "cumulative resources."[39] Van Evera defines a cumulative resource as one that "helps its possessor to protect or acquire other resources,"[40] and this concept has inspired research on the cumulativity of territory and conquest.[41] He specifies that a resource's cumulativity is a function of the utility of the resource for acquiring or protecting other resources, as well as the cost of extracting the resource from its territory.[42]

Under our framework, Van Evera's conception of cumulativity primarily factors into an asset's *importance*, whereas our notion of cumulativity (cumulative-strategic) functions as an *externality*. For instance, Van Evera asserts that uranium ore became more cumulative after the advent of nuclear weapons.[43] Our framework does not preclude the valuation of an asset's potential to enable the acquisition of other resources. However, the fungibility of resources means that most assets help their possessor protect another resource and thus qualify as cumulative under Van Evera's conception. We do view uranium ore as becoming more important in the nuclear age, but we do not consider it to be cumulative-strategic, as one nation's investment in uranium (short of trying to corner the global market) did not lead to barriers to entry for other countries to acquire uranium.[44]

Strategic Logic 2: Infrastructure

The second logic, which we call infrastructure-strategic, involves assets that generate large positive spillovers that cannot be internalized by the initial innovators. These assets typically upgrade the national technological system, thereby benefiting other firms in the same industry or related industries.[45] In the context of this logic, the *rivalrous* variable measures the degree to which these spillovers are largely contained within national borders or among allies (such as transportation networks), as opposed to being global (such as basic advances in medicine). Many technical advances, especially with increasingly rapid global diffusion, have global impacts, pushing out

[39]We thank Nuno P. Monteiro for pointing us to Van Evera's concept of cumulative resources. Van Evera, *Causes of War*, 105–16.
[40]Ibid., 105.
[41]Stephen G. Brooks, *Producing Security: Multinational Corporations, Globalization, and the Changing Calculus of Conflict* (Princeton, NJ: Princeton University Press, 2005); Richard Rosecrance, *The Rise of the Virtual State: Wealth and Power in the Coming Century* (New York: Basic Books, 2000).
[42]Van Evera, *Causes of War*, 106.
[43]Ibid., 107.
[44]The dependency-strategic logic may have applied to uranium for some countries, but over time it was discovered that uranium ore was plentiful and relatively widespread across countries. Jonathan E. Helmreich, *Gathering Rare Ores: The Diplomacy of Uranium Acquisition, 1943–1954* (Princeton, NJ: Princeton University Press, 1986).
[45]Michalski, "Support Policies for Strategic Industries."

the technological frontier to all parties' benefit.[46] However, even in a world of increased cross-border diffusion of technology, the spillovers from many infrastructure-strategic innovations cluster geographically, differentially advantaging some nations over others.[47]

Since this logic operates through interconnections that may benefit both the economic and military realm, infrastructure-strategic assets are often characterized as "dual use." Most of the time, economists are not trained to consider externalities in the national security domain, and military strategists do not focus on military technologies' effects in the economic realm. Of the three strategic logics we highlight, the infrastructure-strategic logic is most helpful in illustrating the value of a framework that accounts for assets' strategic qualities across both the economic and military domains.

Indeed, many dual-use technologies (for example, computers) can be considered infrastructure-strategic, as actors oriented toward maximizing benefits in either the security or economic domain do not internalize the cross-domain spillovers.[48] One particularly notable instance of spillover was the US military's investment in ARPAnet to secure the flow of information in the event of a nuclear attack, which stimulated development of technologies critical for the development of the internet.[49] Flowing in the opposite direction, spin-ons from the commercial sector to military applications have now become more important than spin-offs in the reverse direction. Advancements in fiber optics, for instance, play an important role in the modern economy by transmitting data at high speeds, but they also have spin-on effects for national security by improving missile-guidance capabilities.[50] In other domains, such as civilian and military aircraft technology, the linkages between some civilian and military assets are becoming more tenuous.[51] Thus, evaluating an asset's dual-use potential requires understanding how the connection between civilian and military assets is evolving.

In the economic domain, infrastructure-strategic assets are often foundational technologies that transform the outputs and production processes of

[46]We thank Theodore H. Moran for this point. Whether technological knowledge spillovers are global or local has been much debated in the empirical economics literature. One analysis has shown that although local spillovers are still important, the extent to which knowledge spillovers decline with distance has fallen by 20%, partly due to the increase in foreign R&D by technology producers. Wolfgang Keller, "Geographic Localization of International Technology Diffusion," *American Economic Review* 92, no. 1 (March 2002): 120–42.

[47]Michael Borrus, Laura D'Andrea Tyson, and John Zysman, "Creating Advantage: How Government Policies Shape International Trade in the Semiconductor Industry," in Krugman, *Strategic Trade Policy and the New International Economics*, 94. See also Busch, *Trade Warriors*.

[48]Michael L. Dertouzos, Robert M. Solow, and Richard K. Lester, *Made in America: Regaining the Productive Edge* (Cambridge, MA: MIT Press, 1989), 115.

[49]US military planners did not initially view ARPAnet as an infrastructure-strategic technology with possible spillover effects, as the internet was more a product of happenstance than intentional strategy.

[50]Richard J. Samuels, *"Rich Nation, Strong Army": National Security and the Technological Transformation of Japan* (Ithaca, NY: Cornell University Press, 1994), 30.

[51]Office of Technology Assessment [OTA], *The Defense Technology Base: Introduction and Overview* (Washington, DC: US Government Printing Office [GPO], 1988), 30.

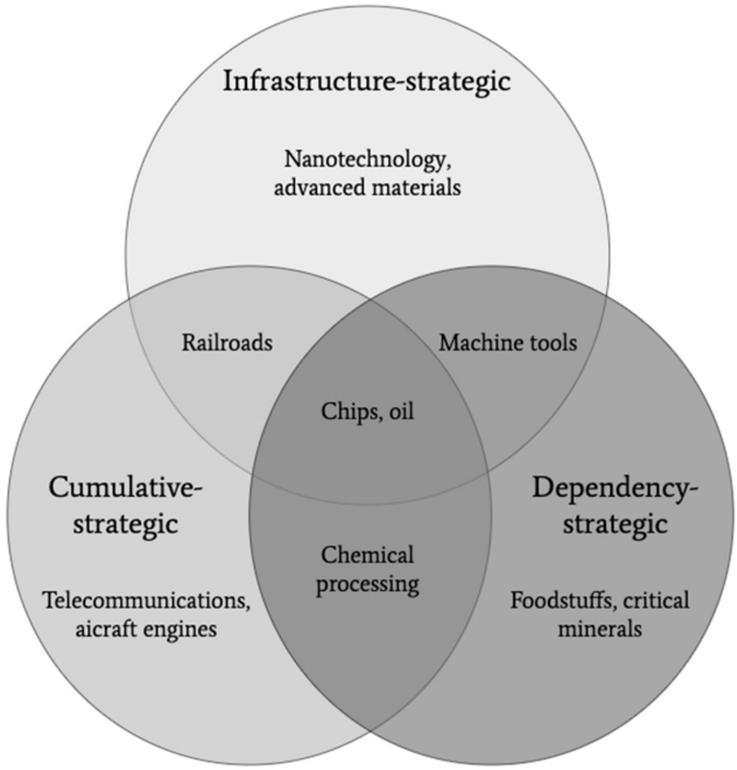

Figure 1. The strategic logics in combination.

a wide range of industrial sectors, and thus exert a profound effect on the competitiveness of national economic systems.[52] Railroads, for instance, generated enormous positive spillovers by increasing labor mobility, enabling economies of scale for manufacturing, and expanding transportation of perishable products and natural resources.[53] Additionally, the semiconductor industry is often characterized as providing extremely large spillovers to downstream electronics applications, though some scholars have questioned if private actors actually underinvest in this industry.[54]

In the military domain, the infrastructure-strategic logic characterizes technologies that can upgrade a wide range of military capabilities but are underappreciated due to entrenched organizational interests and lack of coordinated investment. As is often the case with market competition in the economic realm, competition between military services ("the

[52]Giovanni Dosi, Laura D'Andrea Tyson, and John Zysman, "Trade, Technologies, and Development: A Framework for Discussing Japan," in *Politics and Productivity: The Real Story of Why Japan Works*, ed. Chalmers Johnson, Laura D'Andrea Tyson, and John Zysman (New York: HarperBusiness, 1989), 8–10.
[53]Donaldson and Hornbeck, "Railroads and American Economic Growth."
[54]For a study that shows semiconductor firms can capture most of the spillovers from R&D, see Richard C. and Peter C. Reiss, "Cost-Reducing and Demand-Creating R&D with Spillovers," *RAND Journal of Economics* 19, no. 4 (Winter 1988): 538–56.

interservice model of military innovation"), or even within branches of the same military service ("the intraservice model of military innovation"), efficiently promotes military innovations.[55] However, competition also causes militaries to underinvest in infrastructure-strategic assets that provide benefits across branches and services and often require a common set of technical specifications. For instance, during the late 1980s, though the DoD recognized software's growing centrality across many military platforms, bureaucratic obstacles prevented standardization of programming languages and investments in advancing software technologies.[56]

Radar (1930–45) is another illustrative example. Despite possessing an early lead in developing radars more advanced than the British, Germany failed to realize radar's potential due to interservice rivalry. The German navy had started work on radar in the early 1930s but did not share any information with its air force. German leaders also failed to establish a liaison mechanism between radar units, fighter units, and the command organization. As a result, when the British conducted a bomber raid on Germany two days after declaring war, German radar detected the bombers, but no fighters were sent out to intercept them.[57] In contrast, the British rapidly integrated radar into a battle-ready air-defense system—a process that involved standardizing updates on the number, course, and heading of enemy aircraft—which took full advantage of its infrastructure-strategic attributes.[58]

Strategic Logic 3: Dependency

The dependency-strategic logic distills ideas from the substitutability camp into the language of externalities. Our framework highlights relations of dependence that private actors do not internalize, namely economic transactions involving goods and technologies where a concentration of foreign suppliers imposes a negative externality for the importing state, represented by the potential economic and security costs of being cut off from accessing these items.[59] Individual firms do not fully internalize the downside of a cutoff for the nation's economy or military, for which continued access to these dependency-strategic assets is at risk due to the lack of substitute goods and alternative suppliers. It is important to differentiate dependency-

[55]Adam Grissom, "The Future of Military Innovation Studies," *Journal of Strategic Studies* 29, no. 5 (October 2006): 905–34.
[56]Nance Goldstein, "Institutional Resistance to the Demands of a New Information Technology: Software R&D in the US Defense Department in the 1980s," *International Review of Applied Economics* 7, no. 1 (1993): 26–47.
[57]Azriel Lorber, "Technological Intelligence and the Radar War in World War II," *Royal Canadian Air Force Journal* 5, no. 1 (Winter 2016): 52–65, esp. 55–56.
[58]Stephen P. Rosen, "New Ways of War: Understanding Military Innovation," *International Security* 13, no. 1 (Summer 1988): 143–49.
[59]Many of these ideas were introduced in Hirschman, *National Power and the Structure of Foreign Trade*.

strategic assets from advanced technologies further downstream, such as nuclear weapons and stealth technology, which states do not need to purchase on an ongoing basis.

Dependency concerns affect both the military and economic domains. At the military end, dependency-strategic goods exist that enable important military functions. For instance, the German military's supply of explosives was severely hampered in the lead-up to World War I due to the British blockade, which cut off German access to nitrate exports from Chile, producer of almost 80% of the world's nitrates.[60] Other dependency-strategic assets fuel primarily economic functions. For instance, separate from other strategic stockpiles of materials for military needs, the US Geological Survey maintains a list of minerals critical to economic well-being.[61]

Some goods are critical for both economic and military processes. Oil, the "strategic commodity second to none," is the classic case of such an asset.[62] Before and during World War I, the British set fire to oil fields and the Germans torpedoed tankers, all to prevent the other side from powering their military industries.[63] In the lead-up to World War II, US grand strategy engineered conditions in which Japan was dependent on the United States for 80% of its oil supplies, meaning the 1941 US oil embargo inflicted devastating effects on Japan's military forces.[64] Additionally, because oil is crucial for industrial economies and consumed in such quantities that it is difficult to stockpile, countries have deployed the "oil weapon," that is, threatened to or actually cut off oil shipments to other countries, as a tool of economic coercion.[65]

This third strategic logic builds upon Hirschman's concept of dependence, which he defines broadly as "that part of a country's well-being which it is in the power of its trading partners to take away."[66] Hirschman centers his analysis of dependence on the concentration of a country's aggregate imports and exports to shed light on bilateral channels of influence. Expanding on this analysis, our framework examines supplier concentration

[60] Had it not been for Germany's development of synthetic nitrogen, Germany may have lost the war much earlier. William H. McNeill, *The Pursuit of Power: Technology, Armed Force, and Society since AD 1000* (Chicago: University of Chicago Press, 1982), 79–102.

[61] One of the twenty-three strategic minerals is platinum, for which 90% of production since 1990 has come from two countries: Russia and South Africa. Michael L. Zientek et al., "Platinum-Group Elements," in *Critical Mineral Resources of the United States: Economic and Environmental Geology and Prospects for Future Supply*, ed. Klaus J. Schulz et al. (Reston, VA: US Geological Survey, 2017), N1–N95.

[62] Daniel Yergin, *The Prize: The Epic Quest for Oil, Money, and Power* (New York: Simon & Schuster, 1990), 163.

[63] Ibid., 151–68.

[64] Timothy C. Lehmann, "Keeping Friends Close and Enemies Closer: Classical Realist Statecraft and Economic Exchange in U.S. Interwar Strategy," *Security Studies* 18, no. 1 (January–March 2009): 115–47. For a detailed analysis of the adaptive mechanisms that lessen the dependency-strategic concerns related to oil for American national security, see Eugene Gholz and Daryl G. Press, "Protecting 'The Prize': Oil and the U.S. National Interest," *Security Studies* 19, no. 3 (July–September 2010): 453–85.

[65] Roy Licklider, "The Power of Oil: The Arab Oil Weapon and the Netherlands, the United Kingdom, Canada, Japan, and the United States," *International Studies Quarterly* 32, no. 2 (June 1988): 205–26.

[66] Hirschman, *National Power and the Structure of Foreign Trade*, 18–19.

for specific goods. These assets highlight not just bilateral power relations but also situations of dependence on suppliers that are politically unstable or vulnerable to natural disasters.

The Logics in Combination

Although we have largely analyzed these strategic logics in isolation, in any given case these logics can overlap, complementing, attenuating, or complicating each other. States should pay especially close attention to those technologies and goods that exhibit multiple strategic logics. First, if multiple logics are operative, then the asset is, all else equal, more strategic. Second, multiple logics may call for a diverse set of policy responses to address each externality, complicating the policy problem.

Strategic assets can be characterized by multiple complementary logics (Figure 1). Oil, for instance, is the prototypical strategic asset because it activates each of these strategic logics in a powerful way. Oil is cumulative-strategic, in that it gives rise to a valuable industry characterized by an oligopolistic global market structure. It is infrastructure-strategic: its integration leads to a broad upgrading of economic and military systems, for which no substate actor has full incentives to adequately provide. It is dependency-strategic: it serves as a critical flow input that is vulnerable to being cut off.

Chips also exhibit all three of our framework's logics as an asset.[67] For large portions of its history, an oligopolistic structure defined the semiconductor industry. Only a few firms can invest the high capital and R&D expenditures and accumulate the experience required to keep pace with constant technical iterations. In addition, investments in integrated circuit development feed into advances in computers, machine tools, and robots, thereby generating diffuse productivity across the entire electronics value chain.[68] Finally, chips are dependency-strategic in both domains. Only a small group of foundries can design and/or fabricate the microchips that power a range of crucial military platforms, including aircraft, electronic warfare systems, and radar. These foundries also make the chips that are a critical input across a wide range of information industries.[69]

A second type of relationship arises when the logics trade off with each other. States seeking to capture a positive externality from one strategic logic may expose themselves to a negative externality from another strategic logic. Winston Churchill encountered such a tradeoff between the

[67]Chips refers to integrated circuits, which constitute a large segment of the semiconductor industry.
[68]Crawford, *Economic Vulnerability in International Relations*, 53.
[69]Masaru Yoshitomi, "New Trends of Oligopolistic Competition in the Globalisation of High-Tech Industries: Interactions among Trade, Investment, and Government," in *Strategic Industries in a Global Economy*, 19.

infrastructure-strategic and dependency-strategic logics when deciding whether to convert the Royal Navy to oil-burning ships. On the one hand, oil-powered ships presented a significant upgrade in operational efficiency, speed, and radius of action, which would provide a spillover boost to the entire military's range and capabilities. On the other hand, the transition away from ships powered by steam coal, which was abundant in British mines, would make the navy reliant on oil imports from distant countries.[70]

These tradeoffs underscore that goods and technologies can be strategic in more than one sense. Whereas the existing literature on the economics of national security has examined these logics separately, we package them together under a comprehensive framework that can inform a state's overall technology strategy. The following case study of US-Japan technological rivalry, and the application to current strategizing about AI, demonstrate the value of our approach.

In advance of the empirical analysis, it is important to clarify how the case study supports our framework. Our diagnostic theory for strategic assets uncovers logical inconsistencies in the end-means chain by which national strategists target specific technologies (means) to accumulate power and plenty (end). In principle, our theory makes positive causal claims that can be tested, given sufficient auxiliary assumptions: if a state better identifies strategic assets, then, all else equal, it will tend to better accrue wealth and power. However, similar to deterrence theory, which George and Smoke state is "best understood as a contingent policy theory," these claims cannot be fully tested due to many confounders.[71] Technology policy is one of many instruments (that is, many end-means chains), and strategic asset identification is only one step in the implementation of technology policy (that is, many other steps in the end-means chain). Thus, empirics' role in this work is not to conduct systematic evaluation of causal relationships but rather to illustrate the framework's utility for improving the identification of strategic assets.[72]

Strategic Assets in the US-Japan Technological Rivalry

In the 1980s and 1990s, the United States confronted a changing international landscape of power. As the Soviet Union neared its fall, Japan emerged as a challenger to US technological preeminence, sparking concerns over the United States' ability to remain a leader in critical fields.[73]

[70]Yergin, *The Prize*, 156.
[71]George and Smoke, "Deterrence and Foreign Policy," 181.
[72]George and Smoke, *Deterrence in American Foreign Policy*, 622.
[73]From a list of twenty technologies, the DoD's critical technologies plan identified five technology groups critical to military superiority in which Japanese firms had the lead. US DoD, *Critical Technologies Plan*, report to the Committee on Armed Services, US Congress, 1990.

Alarmed by Japanese technological ascendancy, the US government, independent academics, and industry associations published dozens of major lists of critical technologies. Labeled as a "critical technologies movement," these efforts aimed to identify strategic assets in a systematic and comprehensive manner.[74]

Our case study focuses on the rationale behind technology assessments in the United States during the 1980s and 1990s for a variety of reasons. First, as evidenced by the critical technologies movement, there is a rich literature and empirical record to pore through. Compared to other potential cases, US-Japan competition generated a disproportionately large amount of deliberation over strategic goods and technologies, making it a crucial test of our framework's analytical value.

In addition, commentators note the parallels from this case to the current period. China's rising challenge to American technological dominance has raised similar concerns in US policymaking circles about protecting strategic assets.[75] Thus, the case is substantively important for strategy related to US-Sino competition. Lastly, it is important to select a case where enough time has passed, enabling us to better assess the wisdom of labeling certain assets as strategic. The US-Japan case fits the bill.

To preview the results, the case study evidence confirms the analytical value of our conceptual framework. By feeding into ineffective industrial policy and flawed assessments of relative technological capabilities, misidentification of strategic assets hampered US economic and military competitiveness in this period. We also present evidence that the underlying logics of our framework informed US policymaking in isolated cases. However, the critical technologies movement's failure to integrate all three logics hindered its effectiveness. These missteps, if our framework has diagnostic value, should consistently involve the identification of an asset as "strategic" that our framework would have excluded (false positives) and the failure to identify an asset as "strategic" that our framework would have included (false negatives).

[74]Mary Ellen Mogee, *Technology Policy and Critical Technologies: A Summary of Recent Reports* (Washington, DC: National Academies Press, 1991), 24; Caroline S. Wagner and Steven W. Popper, "Identifying Critical Technologies in the United States: A Review of the Federal Effort," *Journal of Forecasting* 22, no. 2–3 (March–April 2003): 113–28.

[75]Stephen S. Roach, "Japan Then, China Now," *Project Syndicate*, 27 May 2019, https://www.project-syndicate.org/commentary/for-america-china-is-the-new-japan-by-stephen-s-roach-2019-05. We also considered the US response to the Sputnik in the late 1950s, which also generated spirited debate over which technologies contribute disproportionately to national security. Ultimately, we decided the dynamics of the US-Japan case, especially the enmeshing of economic competitiveness and national security concerns, were a better test of our framework's applicability to the current period.

False Positives and Negatives

To demonstrate our theoretical framework's utility, we highlight examples of false positives and false negatives in the assessment of strategic assets, for which our three-logic framework could have improved technology strategy. Regarding false positives, US thinkers used the "high-tech" designation as a blanket label for strategic industries, a fixation that Sylvia Ostry and Richard R. Nelson describe as "high-tech fetishism."[76] Although some of the "high-tech" sectors could be justified as cumulative-strategic (for example, supercomputers, which are discussed below), the designation was overly broad and produced flawed indicators of US competitiveness. For example, a 1986 report by the Department of Commerce (DoC) claimed the United States had a $2.6 billion[77] trade deficit in high-tech industries, resulting in the creation of a potpourri of councils, commissions, and institutes to study all varieties of strategic technologies.[78] But when this high-tech trade deficit was measured in high-tech products rather than high-tech industries, a deficit of $17 billion (1985–88) turned into a surplus of $3.5 billion. In this case, analysts had included trade in scales, cash registers, and similar products (which did not generate cumulative-strategic externalities) in the indicator deficit because they fell under the DoC's "Office and Computing Machines" high-tech industry classification.[79]

In their attempts to apply the infrastructure-strategic logic, analysts treated biotechnology as an industry rather than a set of techniques that affect a wide range of industries. Four influential technology reports identified biotechnology—largely framed toward biomedical applications—as a critical technology.[80] However, none of these reports assessed whether existing federal funding for biotechnology was sufficient. In fact, a separate Office of Technology Assessment (OTA) assessment recommended that, given the success of existing private efforts, Congress consider reducing federal funds for basic biomedical research and redirecting them to biotech applications in other sectors, such as agriculture, chemicals, and waste management.[81] These recommendations underscore the need to clearly specify the contexts in which a set of techniques qualifies as infrastructure-strategic.

[76]Sylvia Ostry and Richard R. Nelson, *Techno-Nationalism and Techno-Globalism: Conflict and Cooperation* (Washington, DC: Brookings Institution Press, 1995), 60.
[77]All currency values are in US dollars.
[78]Benoît Godin, "The Obsession for Competitiveness and its Impact on Statistics: The Construction of High-Technology Indicators," *Research Policy* 33, no. 8 (October 2004): 1217–29.
[79]Thomas A. Abbott III, "Measuring High Technology Trade: Contrasting International Trade Administration and Bureau of Census Methodologies and Results," *Journal of Economic and Social Measurement* 17, no. 1 (1991): 17–44.
[80]Mogee, *Technology Policy and Critical Technologies*, 25–29.
[81]OTA, *Biotechnology in a Global Economy* (Washington, DC: US GPO, 1991).

Finally, US policymakers misdiagnosed the dependency-strategic logic in numerically controlled machine tools, marking a failure to zoom into the key technologies of a general sector and a failure to gauge the extent to which supply was concentrated in a particular country. In 1986, the US government designated the entire industry of machine tools as strategic, negotiating a voluntary restraint agreement (VRA) with Japan and other countries to limit their machine tool exports to the United States for a period of five years. The implementation of VRAs was relatively insulated from factors unrelated to the strategic assets framework, such as domestic machine tool firms' lobbying or labor conditions in the industry.[82] Rather, national security concerns, related to the importance of machine tools for the US defense base, were the main driver of protectionism.

A fuller appreciation of dependency concerns would have better qualified which machine tool assets were most strategic for enhancing US national security. At the time, the general category of machine tools also included mature, standardized product models for which production was not concentrated in any country, limiting the dependency-strategic logic's salience. In fact, new suppliers in Belgium, Denmark, Italy, and Spain were beginning to further reduce the United States' dependence on Japan in some types of machine tools. Counterproductively, the VRA restricted the expansion of these new suppliers. Instead, analysts should have focused their attention on key subsectors of machine tools, such as grinders of ceramic and other nonmetallic materials, where Japan dominated US imports.[83]

Because of interest groups and policymakers' tendency to deploy the "strategic" descriptor broadly, uncovering the existence of false positives represents a relatively easy test of our theory. We also find evidence of false negatives, which constitute a harder test. For instance, military planners neglected dependency-strategic risks associated with rayon fibers. In November 1988, the American apparel company Avtex announced it was shuttering due to foreign competition, sending shockwaves through the US military and space community, as Avtex was the only producer of rayon fibers, critical to the production of missiles and rockets.[84] Alternative sources could have been certified and other fibers adapted into substitutes, but this process would have taken longer than the period of time the available rayon supply would support production.

[82]The US machine tool industry was neither highly concentrated nor composed of a small number of firms, which reduced its capacity to organize and lobby for protection. In addition, it was relatively easy for machine tool builders to find jobs in other industries, which means that adjustment assistance concerns cannot explain protectionist actions. For a systematic analysis of the causes of VRAs in machine tools, see Elias Dinopoulos and Mordechai E. Kreinin, "The US VER on Machine Tools: Causes and Effects," in *Empirical Studies of Commercial Policy*, ed. Robert E. Baldwin (Chicago: University of Chicago Press, 1991), 113–34, esp. 114–21.

[83]Theodore H. Moran, "The Globalization of America's Defense Industries: Managing the Threat of Foreign Dependence," *International Security* 15, no. 1 (Summer 1990): 87–88.

[84]OTA, *Holding the Edge: Maintaining the Defense Technology Base* (Washington, DC: US GPO, 1989), 33.

Though US government and aerospace industry officials eventually negotiated a deal to keep Avtex open, the case illustrates that the defense community undervalued risks with relying on sole-source supplies for key inputs.[85] Considerations of military utility dominated discussions of strategic assets. The DoD's annual critical technology plans defined the criticality of technologies based on their importance to US weapons systems' long-term qualitative superiority.[86] Under this framework, cases such as Avtex fell through the cracks because, as the US Defense Science Board concluded, "neither DoD nor industry ha[d] the means of measuring the scope of [foreign] dependence or of identifying the systems and components which are affected."[87]

The US military also overlooked infrastructure-strategic aspects of software technologies. There was no question that both the United States and Japan recognized the growing importance of software for national security. In 1990 the DoD identified "software producibility" as one of twenty technologies "most essential" to US weapon systems' long-term superiority.[88] Software codes were also at the heart of a 1989 controversy over the US-Japanese codevelopment of the FSX fighter aircraft.[89]

It was the infrastructure-strategic characteristics of software that deserved more attention. By the mid-1980s, escalating software costs and uncoordinated software development—four hundred different programming languages and variations were used across the DoD's weapons systems—led the US military to acknowledge it was facing a "software crisis."[90] Across major weapon systems, software development issues contributed to cost overruns, fielding delays, and even entire program cancelations.[91] In response, the DoD launched a software initiative in an effort to create a central software authority and promote a standard programming language called Ada.[92] But the budget of the office in charge of integrating Ada across the Pentagon peaked at $7 million, and "software R&D was the first to go" amid late-1980s defense cuts.[93]

[85]A concentration of foreign suppliers in a particular asset is not necessary for the dependency-strategic logic to be in play. For instance, relying on a sole-source domestic supplier could also present a negative externality if that source were vulnerable to natural disasters, cyberattacks, and other disruptions.

[86]Crawford, *Economic Vulnerability in International Relations*, 16–17.

[87]Defense Science Board, *Summer Study on the Defense Industrial and Technology Base* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, 1988), 51.

[88]US DoD, *Critical Technologies Plan*, A-30–A-32.

[89]Michael Mastanduno, "Do Relative Gains Matter? America's Response to Japanese Industrial Policy," *International Security* 16, no. 1 (Summer 1991): 84–93.

[90]Goldstein, "Institutional Resistance to the Demands of New Information Technology," 30; OTA, *Holding the Edge*, 170.

[91]Henry Attanasio, "Contracting for Embedded Computer Software within the Department of the Navy" (Master's thesis, Naval Postgraduate School, 1990), 11–13.

[92]Goldstein, "Institutional Resistance to the Demands of New Information Technology," 30–32.

[93]Ibid., 32.

The DoD neglected the infrastructural aspects of software development regarding two undertakings in particular: taking advantage of commercial software spillovers and overcoming individual military services' autonomy over their software projects. Regarding the first factor, the Pentagon's Ada initiative, though attuned to infrastructure-strategic concerns in the military domain, actually limited convergence with US commercial software applications, which were advancing much more quickly. One Office of the Secretary of Defense (OSD) executive admitted that "the Department would have improved cost and quality performance more by standardizing on any existing programming language instead of creating Ada."[94] A 1989 OTA report concluded that divergence between government and commercial software development had produced "separate defense and commercial businesses that often do not share technology."[95]

As for the second factor, without special attention to the needs for major organizational reforms to adapt software across the military, individual services "ferociously resisted" the standardization of software development practices.[96] When the OSD convened defense contractors to enforce cross-service software standardization, the US Air Force sent no representatives to the conference, essentially removing the development of the advanced tactical fighter, one of the most complex software systems to date, from the standardization effort.[97]

The Logics in Isolation

In many instances, US policymakers and analysts reasoned in line with our three logics, with varying degrees of clarity and explicitness. Based on amplified cumulative gains in supercomputers compared to steel, US policymakers more actively protected the former. Despite their small market relative to steel, the production of supercomputers was highly dependent on learning by doing, in which experience developing previous generations transferred to developing the next generation, and early market share enabled the development of unique software libraries.[98] In contrast, steel production technology was more easily diffusible as the technology had

[94]Ibid., 40. Technically savvy officers would program in the C++ language instead of Ada. See Jon R. Lindsay, "'War upon the Map': User Innovation in American Military Software," *Technology and Culture* 51, no. 3 (July 2010): 632.
[95]OTA, *Holding the Edge*, 35.
[96]Goldstein, "Institutional Resistance to the Demands of New Information Technology," 36.
[97]Ibid. The advanced tactical fighter was one of the five largest military software systems in 1990. US DoD, *Critical Technologies Plan*, A-26.
[98]By 1993, American firms were able to draw on these cumulative gains to dominate most markets, including 85% of the European public sector market—though they failed to penetrate Japan, which realized its industry could not compete without substantial protection. See John C. Matthews III, "Current Gains and Future Outcomes: When Cumulative Relative Gains Matter," *International Security* 21, no. 1 (Summer 1996): 130–34.

become standardized,[99] which was partly why the United States was more willing to make concessions on trade disputes over steel.[100]

US policymakers also appropriately attended to the infrastructure-strategic logic in some cases. An influential Council on Competitiveness report published during this period, titled *Gaining New Ground: Technology Priorities for America's Future*, emphasized support for "critical generic technologies" that could potentially enable growth across a range of industries.[101] Of these, microelectronics were a prime target for technology policy, such as the Strategic Computing Initiative. This was justified because advances in microelectronics provided "infrastructural support for all computer development."[102] In a widely read text, Laura D'Andrea Tyson, who later served as chair of President Bill Clinton's Council of Economic Advisers, articulated a "cautious activist" policy toward industries in which "the returns to technological advance create beneficial spillovers for other economic activities, and barriers to entry generate market structures rife with first-mover advantages and strategic behavior."[103] This reflects the infrastructure- and cumulative-strategic logics, respectively.

US technology policy was most attuned to dependency concerns. During this period, the US government produced a total of sixteen different studies that assessed the globalization of US defense production.[104] Defense industrialists pinpointed America's increased reliance on foreign suppliers for key components of weapon systems. For instance, Japanese companies such as NEC and Mitsubishi dominated the production of gallium arsenide (GaAs), a key material used in field-effect transistors that enabled higher computing speeds and radiation resistance for missile guidance and radar.[105]

Addressing the vulnerability to supply cutoffs was not straightforward. With a defense technology base that increasingly relied on globalized, dual-use industries, the military faced a tradeoff between taking advantage of these infrastructure-strategic dual-use assets or "going it alone" to avoid

[99]Generally, cumulative advantages fade as a technology matures, design parameters become standardized, and greater competition emerges through channels such as incremental refinement, distribution, and marketing. One exception is integrated circuits, for instance, where the number of transistors on a chip has doubled every two years while the costs have halved ("Moore's Law"). See Borrus, Tyson, and Zysman, "Creating Advantage," 104.

[100]Matthews, "Current Gains and Future Outcomes," 140–42.

[101]Council on Competitiveness, *Gaining New Ground: Technology Priorities for America's Future* (Washington, DC: Council on Competitiveness, 1991).

[102]Alex Roland with Philip Shiman, *Strategic Computing: DARPA and the Quest for Machine Intelligence, 1983–1993* (Cambridge, MA: MIT Press, 2002), 33.

[103]Laura D'Andrea Tyson, *Who's Bashing Whom? Trade Conflict in High-Technology Industries* (Washington, DC: Institute for International Economics, 1993), 3.

[104]Stephen G. Brooks, "Reflections on *Producing Security*," *Security Studies* 16, no. 4 (October–December 2007): 637–78, esp. 667.

[105]Seventy-five percent of the GaAs material for field-effect transistors were obtained from foreign sources, mainly Japanese companies. National Research Council, *Foreign Production of Electronic Components and Army Systems Vulnerabilities* (Washington, DC: National Academies Press, 1985), 26.

dependency-strategic risks. Indeed, the technologies where foreign dependence was most pronounced—for example, advanced semiconductors, structural materials, and fiber optics—were also those driving innovation and qualitative improvements in critical military systems.[106]

Although the above examples illustrate how isolated aspects of US technology strategy did heed the three logics, they were not integrated into identifying strategic technologies. One systematic review of six reports on critical technologies, all published between 1987 and 1991, found that the lists relied on broad definitions of technology and different criteria, time horizons, and methodologies.[107] The National Critical Technologies Panel—established in 1990 as the principal instrument for the federal government to answer the question: "What is a critical technology?"—was the source of one of these assessments, but it gave no criteria for determining what was critical, thereby leaving the matter in the hands of thirteen individuals from government and industry.[108] This was the case for other efforts to identify critical technologies. "Most of the reports involve little or no serious original research or data collection and little or no guiding theoretical framework," writes Mary Ellen Mogee.[109]

Absent a guiding theoretical framework, efforts to identify strategic assets fell prey to familiar traps. The principal purpose of exercises to name key technologies turned toward evaluations of an asset's absolute utility (*importance*) for US national security and economic prosperity rather than the level of intervention an asset demands from the federal government (*externality*). Caroline S. Wagner and Steven W. Popper conclude that the "critical technologies reports must be held to have had little formal effect on US federal policy towards technology development."[110] Of course, it has to be recognized that there were many other factors at play, including the United States' decentralized technology system and its ideological orientation against picking technology winners. But the evidence above does point to confusion over how to define critical technologies being a key part of the explanation for the limited usefulness of critical technology identification in this period.

One last note about how the above case should be interpreted—our framework elaborates three logics that can make an asset worth attending to. Our theoretical claim is that when these logics are operative, states who attend to the assets and adopt appropriate policies will gain in power and

[106]At the time, the OTA issued a series of annual reports that focused on this trade-off: OTA, *Holding the Edge*; OTA, *Arming our Allies: Cooperation and Competition in Defense Technology* (Washington, DC: US GPO, 1990); OTA, *Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base* (Washington, DC: US GPO, 1991).
[107]Mogee, *Technology Policy and Critical Technologies*, 37–38.
[108]Wagner and Popper, "Identifying Critical Technologies in the United States," 117–18.
[109]Mogee, *Technology Policy and Critical Technologies*, 37.
[110]Wagner and Popper, "Identifying Critical Technologies in the United States," 123.

plenty. Ideally, we could construct a counterfactual for the US-Japan case in which decision makers fully adopted our view of strategic assets, and thereby isolate the effects on US economic and military might. One could imagine a world where, for instance, the US military appropriately identified the infrastructure-strategic aspects of software advances in the commercial realm and standardized its programming language accordingly. This preventative approach could have mitigated software bottlenecks, which continue to plague military systems decades later.

Given the complexities of the end-means chain from strategic asset identification to end goals, the above empirics are not intended to prove the theoretical claim. A counterfactual in which the United States addressed dependency-strategic concerns in machine tools, along the lines of our framework, must also grapple with other factors that outweigh the benefits of improved strategic asset identification. For instance, Japan's macroeconomic struggles hampered its machine tool industry, which nullified the long-term vulnerability of the United States in this domain. Still, our findings illustrate the importance of strategic asset identification across a range of domains and scenarios, and they show how conceptual clarity could have improved policy around strategic assets.

Implications

How should strategists identify the strategic assets of the current era? We conclude by applying our theoretical framework to the contemporary case of AI, a technology that has drawn so much high-level attention from states that the World Economic Forum (WEF) has published a framework to help governments create "minimum viable" national AI strategies.[111] The WEF framework describes AI as the "engine that drives the Fourth Industrial Revolution."[112] Others note AI's potential to transform the military balance of power.[113] In sum, the governance of advanced AI systems "may be the most important global issue of the 21st century."[114]

Strategic Assets in the AI Era

While most agree on AI's importance, there is less clarity over the strategic aspects of developments in AI. Though all three strategic logics are present

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[111]WEF, *A Framework for Developing a National Artificial Intelligence Strategy* (Geneva: WEF, August 2019), https://www.weforum.org/whitepapers/a-framework-for-developing-a-national-artificial-intelligence-strategy.
[112]Ibid., 4.
[113]Kenneth Payne, "Artificial Intelligence: A Revolution in Strategic Affairs?" *Survival* 60, no. 5 (October–November 2018): 7–32; Michael C. Horowitz, "Artificial Intelligence, International Competition, and the Balance of Power," *Texas National Security Review* 1, no. 3 (May 2018): 36–57.
[114]Allan Dafoe, "AI Governance: A Research Agenda" (Future of Humanity Institute, Governance of AI Program, University of Oxford, 27 August 2018), 5, https://www.fhi.ox.ac.uk/wp-content/uploads/GovAI-Agenda.pdf.

with AI, and in some cases trade off against each other, infrastructural considerations are most central to what makes AI strategic. Described by leading economists as a new general-purpose technology (GPT), AI advances can potentially transform a wide range of economic sectors.[115] If the trajectory of previous GPTs holds, the effective diffusion of AI will take decades and many complementary innovations.[116] For example, the introduction of the steam turbine, which occurred about a decade after the invention of the dynamo, was crucial to the spread of electric power across manufacturing industries.[117]

The breadth of spillovers and prolonged payoff period associated with AI makes it difficult for private investors to capture most of the gains. One study of six GPTs' evolution found that large-scale, long-term government investment was necessary in accelerating their commercial development.[118] Thus, recognizing the strategic implications of AI as a GPT is the first step to realizing its potential for economic transformation.

The general-purpose nature of AI should also guide defense industrial policy. If AI is "much more akin to the internal combustion engine or electricity than a weapon," as Michael C. Horowitz argues, then military strategists should pay more attention to the organizational adaptations that advances in AI may demand.[119] A recent study warns that the DoD "has not yet adapted its enterprise processes to effectively support the rapid and widespread adoption warranted by the potential benefits [of autonomous capabilities]."[120]

These organizational challenges have been raised by previous GPTs. After all, AI systems are still built on software, so many of the lessons from the US military's attempt at software standardization in the 1980s still hold. According to a recent submission to the National Security Commission on Artificial Intelligence's (NSCAI) call for ideas, military AI projects are isolated from best practices in the civilian sector. Either the DoD adapts its software ecosystem to better cross-pollinate with the private sector's software ecosystem or it "risk[s] losing out to China and Russia."[121]

[115]Erik Brynjolfsson, Daniel Rock, and Chad Syverson, "The Productivity J-Curve: How Intangibles Complement General Purpose Technologies" (working paper 25148, National Bureau of Economic Research [NBER], Cambridge, MA, October 2018); Iain M. Cockburn, Rebecca Henderson, and Scott Stern, "The Impact of Artificial Intelligence on Innovation" (working paper 24449, NBER, Cambridge, MA, March 2018).

[116]Brynjolfsson, Rock, and Syverson, "The Productivity J-Curve"; Thurbon and Weiss, "Economic Statecraft at the Frontier," 18.

[117]Vaclav Smil, *Creating the Twentieth Century: Technological Innovations of 1867–1914 and Their Lasting Impact* (Oxford: Oxford University Press, 2005), 33–97.

[118]Vernon W. Ruttan, *Is War Necessary for Economic Growth? Military Procurement and Technology Development* (Oxford: Oxford University Press, 2006).

[119]Michael C. Horowitz, "The Algorithms of August," *Foreign Policy*, 12 September 2018, https://foreignpolicy.com/2018/09/12/will-the-united-states-lose-the-artificial-intelligence-arms-race/.

[120]Defense Science Board, *Report of the Defense Science Board Summer Study on Autonomy* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, 2016), 98.

[121]James Ryseff, "How to (Actually) Recruit Talent for the AI Challenge," *War on the Rocks*, 5 February 2020, https://warontherocks.com/2020/02/how-to-actually-recruit-talent-for-the-ai-challenge/.

The interaction of AI with all three logics is partly what makes strategic thinking about the technology so difficult, so strategists should not neglect the other two logics. Regarding the cumulative-strategic considerations in the economic domain, big data platforms, such as Facebook and Amazon, appear to benefit from a virtuous circle that links access to data, improvements in machine learning models, and the attraction of more users and data. Some regulators, who believe these platforms are exploiting this market power, are exploring options to restore competition in this domain.[122] As for military applications, cumulative-strategic dynamics vary by application—a nuance lost in the narrative of an AI arms race.[123] It may be much harder for advanced militaries to sustain large first-mover advantages in military applications of AI that build directly off of open research in the civilian sector, such as image recognition for reconnaissance and predictive analytics for logistical planning.[124] For advanced weapon systems for which autonomous capabilities demand the integration of AI into more complex systems, the cumulative-strategic dynamics may be much more salient.[125]

Of the three logics, the dependency-strategic logic has drawn a disproportionate share of the attention when it comes to AI. This may be partly due to the overwhelming focus of the existing statecraft literature on tools such as trade and financial sanctions.[126] In particular, analysts and policymakers have identified AI hardware as a strategic asset for US-China technological competition. As Tim Hwang writes, "The extent to which the U.S. is able to successfully deny China access to advanced computing power, and the extent to which China is able to develop it domestically or acquire it otherwise, remains to be seen."[127]

Statecraft targeted at the dependency-strategic aspects of the AI supply chain is complicated by tradeoffs between various logics. Take, for example, US policy debates over the strategic asset of semiconductor manufacturing equipment (SME), an integral piece of the supply chain in hardware for training and execution of AI algorithms. One of the four initial consensus judgements in NSCAI's first report was that the US government should continue to use export controls to protect American advantages in AI hardware, particularly those in SME.[128]

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[122]Jerrold Nadler and David N. Cicilline, *Investigation of Competition in Digital Markets: Majority Staff Report and Recommendations*, report for the Subcommittee on Antitrust, Commercial and Administrative Law of the Committee on the Judiciary, 2020; Steven Weber, "Data, Development, and Growth," *Business and Politics* 19, no. 3 (September 2017): 397–423.

[123]Remco Zwetsloot, Helen Toner, and Jeffrey Ding, "Beyond the AI Arms Race," *Foreign Affairs*, 16 November 2018, https://www.foreignaffairs.com/reviews/review-essay/2018-11-16/beyond-ai-arms-race.

[124]Horowitz, "Algorithms of August."

[125]Gilli and Gilli, "Why China Has Not Caught Up Yet," 189.

[126]Thurbon and Weiss, "Economic Statecraft at the Frontier," 5.

[127]Tim Hwang, "Computational Power and the Social Impact of Artificial Intelligence," SSRN, 23 March 2018, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3147971.

[128]NSCAI, *Interim Report* (Arlington, VA: NSCAI, 2019).

On the one hand, export controls would leverage the dependency-strategic aspects of SME, since US firms occupy around 50% of the global market. However, the SME industry is also strategic in the cumulative sense, for which the optimal policy involves maximizing global revenues. Thus, exploiting the dependency-strategic externalities of SME to gain leverage over China (for example, restricting China's military advances) could enable cumulative-strategic gains for US competitors, as SME vendors in Europe and Japan could benefit from the loss of US SME sales to China.[129]

Extending the Logic of Strategic Assets

As revealed by our preliminary analysis of the strategic aspects of AI, our framework aids strategic asset identification by assessing how a particular technology's characteristics interact with the surrounding context. Most studies of economic statecraft and defense industrial policy concentrate on relevant actors, strategies, and consequences. Significantly less emphasis is placed on the objects themselves—the strategic assets that are often the target of military competition and foreign economic policy. The fundamental contribution of this article is toward resolving a tension in the international landscape today: even as nations are increasingly concerned about building up their advantage in strategic goods and technologies, much more work needs to be done to understand the underlying logic of what makes an asset strategic.

Future research could expand the scope of our framework. A continuing issue with determining strategic technologies is the level of aggregation. Does "strategic" apply to specific technological innovations, classes of techniques, technological systems, or entire sectors? Theoretically, strategic assets could even encompass things other than goods and technologies. For example, governments compete to attract highly skilled talent in science and technology in what the International Organization for Migration has labeled a "human capital accretion 'sweepstakes.'"[130]

Moreover, our theory can encompass more than just three strategic logics. Consider a brief sketch of the "poisoned-chalice logic," which highlights the externalities associated with hardware hacks from upstream parts and components. While closely related to risk from supply disruptions, the poisoned chalice refers to an adversary's access to the asset in an upstream

[129]John VerWey, "The Health and Competitiveness of the U.S. Semiconductor Manufacturing Equipment Industry" (working paper ID-058, Office of Industries, Washington, DC, 2019), 19; Jade Leung, Sophie-Charlotte Fischer, and Allan Dafoe, "Export Controls in the Age of AI," *War on the Rocks*, 28 August 2019, https://warontherocks.com/2019/08/export-controls-in-the-age-of-ai.

[130]High-skilled migrants provide "free" knowledge assets to receiving states since sending states bore the costs of education and training. This relates to our framework, as global talent flows can be considered a positive externality for the receiving state. Fiona B. Adamson, "Crossing Borders: International Migration and National Security," *International Security* 31, no. 1 (Summer 2006): 186.

portion of the supply chain. For instance, datasets can be "poisoned" to attack the integrity of the AI systems that are trained on them, such that an adjustment to just a single observation can produce a "backdoor" that can later be exploited.[131] If the complexity of supply chains and the number of suppliers for many advanced technology systems continues to increase, this externality will grow in relevance.[132]

Although many extensions are possible, one consistent element of our framework is that mapping the logic behind strategic goods and technologies is only a starting point. It would be a mistake to leap from the identification of a strategic asset to the implementation of industrial policy targeted at that asset. There are many reasons to be skeptical of technological planning, forecasting, and selection by central authority. Cost overruns, wasteful rent seeking, and crowd-out from "picking winners" all contribute to "government failure," which could outweigh the benefits of correcting market failures.[133]

Still, our effort to bring conceptual rigor to the discussion of strategic assets is a prerequisite to effective strategy. One assessment of national efforts to enhance scientific and technological competitiveness, which synthesized over fifty years of research on national innovation rates, found that the one common trait among successful countries is "their dedication, not to particular institutions or policy designs, but to solving market failures and network failures in general."[134] In essence, our paper translates this insight into a framework for the identification of strategic assets.

Fred Halliday called international relations the capstone discipline of the social sciences in part because it is tasked with integrating concepts from all the other sciences.[135] An economist may identify strategic assets as the civilian technologies of greatest economic importance; a military planner may think of strategic assets as those most essential to military operations; a historian may understand strategic assets as those that have had the most significant effects in shaping the development of society. Our paper offers a framework for how a grand strategist should conceive of strategic assets.

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[131] Ali Shafahi et al., "Poison Frogs! Targeted Clean-Label Poisoning Attacks on Neural Networks" (paper presented at 32nd Conference on Neural Information Processing Systems, Montreal, Canada, 2018), 1–11.
[132] For studies of risks to the DoD's supply chain related to this logic, see Brooks, "Reflections on *Producing Security*," 671–72.
[133] Kirshner, "Political Economy in Security Studies after the Cold War," 77.
[134] Taylor, *The Politics of Innovation*, 277.
[135] Andrew Hurrell, "Towards the Global Study of International Relations," *Revista Brasileira de Política Internacional* 59, no. 2 (November 2016), http://dx.doi.org/10.1590/0034-7329201600208.

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