

Correspondence

Military-Technological Imitation and Rising Powers

Michael C. Horowitz
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Andrea Gilli and
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To the Editors (Michael C. Horowitz writes):

Andrea Gilli and Mauro Gilli should be lauded for making clear how the growing complexity of capital-intensive military platforms such as fighter jets hinders states, such as China, seeking to mimic the United States.¹ Gilli and Gilli join a long line of thinkers, myself included, who argue that military technology does not always diffuse easily and that the characteristics of technologies matter in driving how those technologies spread and influence international politics.² Although there is much to like about Gilli and Gilli's article, their analysis has some theoretical limitations with implications for policymaking.

First, because Gilli and Gilli evaluate only military technology adoption, they miss the broader ways that human capital, tacit knowledge, and organizational practices shape military power. Gilli and Gilli's unit of analysis is military-technological superiority (p. 145), suggesting a technologically determinist view of military power. Technology, however, is only a subset of how states generate military power. More important for victory and defeat, on average, is how states develop and employ their capabilities on the battlefield.³

Gilli and Gilli's ignoring of the organizational component of military power is relevant because another reason why a country such as China might struggle to adopt some of today's key military capabilities involves a lack of tacit organizational and

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1. 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*, Vol. 43, No. 3 (Winter 2018/19), p. 145, doi.org/10.1162/isec_a_00337. Further references to this article appear parenthetically in the text.

2. Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences for International Politics* (Princeton, N.J.: Princeton University Press, 2010), pp. ix, 3, 9, 26–27, 33.

3. Stephen Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, N.J.: Princeton University Press, 2004).

operational knowledge. Moreover, explaining how countries use their military equipment, not just their military technologies, requires understanding the varying organizational capacity requirements for those technologies.⁴

Second, Gilli and Gilli's key conceptual advance is to show how the growing complexity of military technologies slows technology diffusion. However, they incorrectly bundle multiple things into their concept of complexity. The level of difficulty in copying technology changes depending on its absolute complexity—the number of intersecting components, challenges in machining them, systems integration, and the like—and on the number of players with the capability to produce those systems.

My adoption capacity theory argues, for example, that the resource and organizational requirements of a particular innovation influence the number of players who can adopt a technology, in addition to broader innovation adoption rates.⁵ Technology diffusion slows as unit costs for the applicable systems increase and when the relevant technology has exclusively military applications.⁶ These factors help explain, for example, why stealth (part of Gilli and Gilli's F-22 case) has spread so slowly. Stealth technology is expensive and has only military purposes, which also causes it to spread slower than less expensive technology based on commercial products.⁷ When the underlying basis of a technology is commercially oriented, more actors get involved, for reasons involving market forces, and technology can spread via more pathways.

When Gilli and Gilli argue that more complicated technologies are inherently harder to copy, they also imply that the diffusion rate for all complicated technologies should be the same—whether an exclusively military technology such as an F-22 or a dual-use technology such as a smartphone. Smartphones have spread around the world, however; F-22s have not. Moreover, contrary to their argument, some complex military technologies, including cruise missiles and armed uninhabited vehicles, have spread widely.

Finally, I feel compelled to correct Gilli and Gilli's repeated misrepresentation of my research. Gilli and Gilli selectively quote my work to imply that I argue that all military technology diffuses easily.⁸ As described above, this is incorrect. For example, they quote me as saying "it is [not] difficult to copy . . . specific technologies" (p. 188). Here is the quote in context: "Organizational capital is a critical element of firms' success, helping businesses survive during periods of change by giving them the institutional capacity to shift practices without being blocked by bureaucratic obstacles. Because it is difficult to copy business processes, as opposed to specific technologies, organizational assets are difficult to duplicate. Darby and Zucker find a ten- to fifteen-year gap be-

4. Horowitz, *The Diffusion of Military Power*, p. 7.

5. *Ibid.*, p. 3.

6. *Ibid.*, pp. 30–33.

7. *Ibid.*, pp. 217–219. See also Michael C. Horowitz, "Military Robotics, Autonomous Systems, and the Future of Military Effectiveness," in Dan Reiter, ed., *The Sword's Other Edge: Trade-Offs in the Pursuit of Military Effectiveness* (New York: Cambridge University Press, 2017), pp. 162, 166.

8. For a systematic review of their citations of my work, email the author at horom@sas.upenn.edu.

tween the beginning of the biotechnology revolution and widespread knowledge of the practices necessary to take advantage of the evolution for business purposes.”⁹

Clearly, Gilli and Gilli edited the quote. The sentence is about research on changes by businesses in the corporate world, not militaries. It is also only about technological change in the context of organizational change—it is a relative claim, not an absolute claim. Gilli and Gilli cherry-picked that quote, ignoring the litany of evidence about what my theory actually says.

In conclusion, Gilli and Gilli should be commended for their contribution in helping explain how military power spreads. A key question is what will happen moving forward. It is possible that the advances in artificial intelligence and robotics that Gilli and Gilli reference will manifest themselves in low-cost, high-volume systems that are complex, but that are based in private-sector research that will be easier to mimic than technologies such as stealth. For understanding the future of warfare, it will therefore be critical to assess how many factors influence the diffusion of military technologies, including system complexity, unit costs, and whether the underlying technology comes from private-sector or military research.

—Michael C. Horowitz
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To the Editors (Shahryar Pasandideh writes):

In their article, Andrea Gilli and Mauro Gilli make a major contribution to the study of international security and advance the literature on the diffusion of military technology.¹ In it, they argue that the increasing complexity of military technology makes imitation and reverse engineering much more difficult than it was in the past (p. 142). As such, the rate of diffusion is slower in the contemporary era, thereby helping to sustain the advantages of technological first movers such as the United States.

Although Gilli and Gilli’s underlying theory is largely persuasive, there are two reasons to be skeptical about their most policy-relevant finding: that a rising China is “not catching up,” thus helping to sustain the United States’ military-technological superiority. First, Gilli and Gilli devote extensive attention to whether China can produce “fifth-generation” fighter aircraft that can match the capabilities of the U.S. F-22 fifth-generation fighter. By doing so, they forgo examination of a wider set of military technologies to ascertain whether China is “catching up” with technological first movers, the overarching question that they seek to address. Consequently, Gilli and Gilli not

9. Horowitz, *The Diffusion of Military Power*, p. 34.

1. 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*, Vol. 43, No. 3 (Winter 2018/19), pp. 141–189, doi.org/10.1162/isec_a_00337. Subsequent citations to this article appear parenthetically in the text.

only overlook the impressive progress that China's defense industry has made in recent decades, but they also utilize a largely inappropriate test for both their theory and the question of whether China can compete with the United States in military technology.

Gilli and Gilli argue that "China has benefited from massive access to foreign technological knowledge in its attempts to imitate U.S. advanced jet fighters" (p. 180). As evidence for how doing so has not helped China in a manner similar to that of second movers in the past, Gilli and Gilli point to the ongoing difficulties that China is reportedly experiencing in developing and fielding the fifth-generation J-20 jet fighter. Although China's ability to master fifth-generation fighter aircraft technology is undoubtedly important, it is an inappropriate test of their theory. That is, Gilli and Gilli are essentially asking why China's licit and illicit access to the designs of foreign fourth-generation fighter jets has not helped it build fifth-generation fighter jets with which to compete against the F-22.²

A more suitable test would be to examine China's experience in producing progressively more capable variants of two fourth-generation fighter aircraft designs, the indigenous J-10 and the many Chinese derivatives of the Soviet-Russian Su-27/Su-30 "FLANKER" family. If Gilli and Gilli had examined the results of Chinese efforts to develop the technological capacity to field these advanced fourth-generation combat aircraft, they would have found strong evidence that China is catching up quickly to the United States, and that its efforts at defense industrial espionage and technology transfer have paid off handsomely. And had they looked beyond China's aviation sector, Gilli and Gilli would have found that China has been producing progressively more capable and increasingly world-class warships, missile systems, and defense electronics, such as radar.

Second, throughout their article, Gilli and Gilli implicitly assume that imitation is the primary, if not the only, way through which China can counter the military power of the United States and erode its military-technological superiority. For example, they write that "although countermeasures and counter-innovations can be very effective, they permit countries only to negate the benefits an enemy gains from its innovations. When countries seek to remain or become regional or global powers, or when they aim to deploy certain capabilities, however, they have to acquire specific military platforms, such as aircraft carriers for long-range power projection, jet fighters for air superiority, or submarines for sea denial" (p. 146). But irrespective of the impressive capabilities offered by the U.S. F-22, there are only some 180 of them in service, with the rest of the United States' land-based and carrier-based fighter aircraft being considerably less capable.³

It is unclear why Gilli and Gilli assume that China must engage in a like-for-like

2. Although Gilli and Gilli claim that China has obtained access to the technology of U.S. fifth-generation aircraft, their evidence here is less convincing and more contestable than the evidence for their claims that China has licit and illicit access to foreign fourth-generation combat aircraft technologies.

3. "F-22 Raptor," fact sheet (Washington, D.C.: U.S. Air Force, September 2015), <https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104506/f-22-raptor>.

competition with the United States and why its J-20 fighter must match the performance of the F-22. Modern warfare is increasingly about the conflagration of complex systems of systems versus other systems of systems. The end result of a conflict between the United States and China is therefore a question not of the outcome of a clash between fifth-generation fighter aircraft—the United States' F-22 fighters and China's J-20 fighters—but of the outcome of a clash of the aggregate matrix of U.S. and Chinese anti-aircraft and anti-surface capabilities in a regionally contextualized conflict.

Finally, because Gilli and Gilli focus on like-for-like military and military-technological competition, they do not consider the possibility that China may intentionally seek to supplement the J-20 with other capabilities. For example, in addition to fourth- and fifth-generation fighter jets, China may continue its long-standing investment into long-range ground-based air defense systems, a capability area that the United States has largely forgone. Given the geographic realities of the western Pacific theater—the vast distances across which the United States must deploy its military forces, including the F-22—China appears to view ballistic and cruise missiles as a means with which to blunt, if not negate, U.S. airpower deployed in its region. Through such dissimilar capabilities, coupled with advanced fourth-generation fighter aircraft such as the J-10C and J-16, as well as the fifth-generation J-20, China may have identified another approach, or perhaps multiple alternative approaches, with which to counter U.S. airpower.⁴

—Shahryar Pasandideh
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Andrea Gilli and Mauro Gilli Reply:

In our article, we argued that over the past century, the complexity of military technology has increased dramatically and that, as a result, the imitation of advanced weapons systems such as attack submarines and combat aircraft has become much more difficult.¹ Today, even countries that have access to foreign designs or weapon systems are likely to encounter technological challenges that will frustrate their efforts, if they lack the required technological capacity or experience. We tested our theory by comparing Wilhelmine Germany's imitation of *Dreadnought* with China's efforts to imitate U.S. fifth-generation fighters.

In their letters, Michael Horowitz and Shahryar Pasandideh argue that by focusing on the imitation of advanced weapon systems, our article ignores important factors that

4. Jiayao Li, "China's Fighter Jets Hold 'Perfect Combination' Training," June 3, 2018, http://eng.chinamil.com.cn/view/2018-06/03/content_8049150.htm.

1. 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*, Vol. 43, No. 3 (Winter 2018/19), pp. 141–189, doi.org/10.1162/isec_a_00337. Further references to this article appear parenthetically in the text.

determine the outcome of wars as well as many strategies and technologies that China could pursue to compete with the United States. They are right. The goal of our article was not to provide a comprehensive assessment of the many factors that affect the U.S.-China military competition. We focused instead on a question that the field of international relations has not investigated, despite its policy and theoretical significance: whether the imitation of advanced weapon systems—a form of internal balancing—is easier now than it was in the past given globalization, the emergence of dual-use components, and advances in communication technologies. We did not assume, as Pasandideh incorrectly concludes, that the imitation of fifth-generation jet fighters is the only or the best strategy for China. We chose this case because it offers a hard test of our theory, given that, for example, China's massive cyber espionage campaign yielded more than 50 terabytes of data that included blueprints and technical specifications of U.S. fifth-generation fighters (pp. 170–185).²

Pasandideh incorrectly asserts that we investigated whether China's access to data on foreign fourth-generation fighters has helped it build fifth-generation fighters. In fact, we examined whether access to data on both fourth-generation and fifth-generation fighters has helped China replicate these technologies (ibid.). Pasandideh further argues that we should have analyzed Chinese imitations of Russian fourth-generation fighters; but we did, as a robustness test (pp. 184–185 and online appendix, pp. 54–55). Consistent with our theory, China has struggled much more in replicating this mature technology than Imperial Germany did in imitating a cutting-edge technology, despite significantly more favorable conditions. Overall, China's fourth-generation fighter programs have been slow and plagued by problems—the most extreme case being the repeated crashes of the J-15, a reverse-engineered version of a Russian fighter.

Horowitz, who has written one of the seminal works on military innovations, argues that to understand the diffusion of advanced weapon systems, one has to focus on their unit cost and on whether their underlying technologies have commercial applications. Accordingly, he argues that the wide diffusion of smartphones, in contrast to the absence of diffusion of the F-22 Raptor, confirms his theory and undermines ours. There are three problems with Horowitz's claims. First, in his letter and in his book, Horowitz treats the indigenous production and foreign acquisition of a weapon system as equivalent and hence as alternative options that states can pursue.³ The most important U.S. weapon systems, however—including the F-22, the B-2 Spirit, and the Virginia-class and the Ohio-class submarines—are not for sale. Therefore, if China wants to acquire these capabilities, it must produce them indigenously or try to imitate U.S. technologies through cyber espionage or reverse engineering.

2. See also Gilli and Gilli, "Why China Has Not Caught Up Yet," appendix, pp. 43–45, <https://css.ethz.ch/content/dam/ethz/special-interest/gess/cis/center-for-securities-studies/pdfs/Gilli-and-Gilli.pdf>.

3. Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences for International Politics* (Princeton, N.J.: Princeton University Press, 2010), pp. 28, 46.

Second, Horowitz's focus on unit costs underappreciates the technological challenges of imitation: it assumes that inexpensive (and commercial) technologies are relatively easy to imitate, and that devoting more resources will translate into the successful imitation of expensive weapon systems. These assumptions are unwarranted: China has found it extremely hard to copy commercial and dual-use technologies with low unit costs such as superconductors (\$500–\$5,000), single-crystal turbine blades (\$30,000–\$50,000), and turbofan engines (\$10 million), despite the billions of dollars it has poured into these sectors, to say nothing of its espionage efforts and opportunities for reverse engineering.⁴

Third, Horowitz's comparison of smartphones to the F-22 paradoxically highlights the very limitations of his theory. Although smartphones have been sold widely, the capacity to produce them has not diffused. As Andrew McAfee and Erik Brynjolfsson have observed, smartphones "are incredibly complicated devices that must be designed well and built reliably. The engineering expertise...required...[is] so formidable that only a handful of companies in the world ever try."⁵ In other words, Horowitz's theory cannot explain why the production capabilities of an inexpensive (\$800) commercial technology have not diffused and why even very advanced companies such as Intel ultimately failed in this market (appendix, p. 6). Conversely, the case of smartphones is consistent with our theory, thereby indicating the applicability of our framework beyond its scope conditions.

Finally, our article aimed at questioning the widely shared assumption that to imitate today's most advanced weapon systems, states need only mobilize the necessary financial resources. We argue that by accepting this assumption, the international relations literature has underestimated the inherent challenges of imitating modern technologies (pp. 143, 147, and 188). This problem can be found even in works, such as Horowitz's book, that purport to explain the limits to the diffusion of military innovations.

In his letter, Horowitz asserts that for one out of two quotations we draw from his work, we altered the meaning of his words. It is unfortunate that Horowitz feels we misrepresented his views: he should not. Horowitz's original sentence, "It is difficult to copy business processes, as opposed to specific technologies," means what we attributed to him: that "it is [not] difficult to copy... specific technologies." That sentence comes from the theoretical chapter of his book and serves to justify his focus on the organizational constraints to diffusion. Indeed, that financial and organizational factors—rather than technological ones—constrain the spread of military innovations is the

4. Andrew Erickson and Gabe Collins, "The 'Long Pole in the Tent': China's Military Jet Engines," *Diplomat*, December 9, 2012; and James A. Lewis, *Learning the Superior Techniques of the Barbarians: China's Pursuit of Semiconductor Independence* (Washington, D.C.: Center for Strategic and International Studies, 2019).

5. Andrew McAfee and Erik Brynjolfsson, *Machine, Platform, Crowd: Harnessing Our Digital Future* (New York: W.W. Norton, 2017), p. 204.

central message of Horowitz's book.⁶ Moreover, in his book, Horowitz explicitly states that the challenge of imitating military innovations entails mobilizing sufficient financial resources.⁷ This is the very assumption that the literature in international relations shares and that our article criticized.

The second quotation, with which Horowitz does not engage in his letter, captures a second key message of his work: that inexpensive and commercial technologies can be more easily imitated.⁸ As the cases of semiconductors, single-crystal blades, smartphones, and turbofan engines discussed above show, this claim is unwarranted. Most importantly, these cases show that our representation of Horowitz's theory is, again, correct: like the literature in international relations more generally, it underestimates the challenges of imitating modern technologies. As to the memo Horowitz has drafted about our "repeated" misrepresentations of his work, we welcome a copy so that we can reply in a public debate.

—*Andrea Gilli*
Rome, Italy

—*Mauro Gilli*
Zurich, Switzerland

6. Horowitz, *The Diffusion of Military Power*, pp. 4, 11, 14–17, 27–28, 34, 44–45, 48–50, 218–222.

7. *Ibid.*, pp. 3, 30–31.

8. *Ibid.*, pp. 4, 14–17, 218–222; and Michael C. Horowitz, "Information-Age Economics and the Future of the East Asian Security Environment," in Avery Goldstein and Edward D. Mansfield, eds., *The Nexus of Economics, Security, and International Relations in East Asia* (Stanford, Calif.: Stanford University Press, 2012), p. 223.