Paradoxes of Global Value Chains: (Im)possibilities of Decoupling

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For decades, global value chains (GVCs)[1] were lauded for their deflationary benefits for consumers, for higher margins for companies, and for enhancing international cooperation. Recently, however, they have become new sources of insecurity for consumers, labor, companies and countries. While impacts on labor are well-known[2], deep skepticism towards GVCs began in earnest with American-initiated trade and technology frictions in 2018, followed by the massive disruptions of COVID-19, and most recently, the unprecedented sanctions imposed on Russia. These darker aspects of interdependence compel us to seriously re-think some foundational concepts, including globalization, interdependence, and economic and national security.

These new vulnerabilities have popularized de-globalization narratives and spawned a slew of new GVC terminology, like re-shoring, near-shoring, friend-shoring, stockpiling, diversifying, trusted partnerships, sustainable domestic production, and ecosystem-building, among others. All of these options should be considered to achieve goals in the public interest, and that satisfy cost-benefit analysis for government intervention.

This paper makes two primary arguments. First, while the broad policy goal is value chain "resiliency," the meaning of resiliency (and by extension any policy interventions) differs by country, actor, and, most problematically, by GVC and even product. Second, some GVCs have become so functionally integrated that they are not amenable to reshoring or nearly any policy intervention. Because they ignore complex GVC interdependencies, well-meaning policy interventions are likely to fail, such as recent initiatives to re-shore semiconductor manufacturing. These complex GVCs have evolved into "massive modular ecosystems" (MMEs), and dominate in many critical industries with geopolitical implications, such as information-communication technologies (ICTs).[3] The paper offers brief empirical illustrations of MMEs.

A Simple Policy Framework for GVC Resiliency

Two basic factors are important for policymakers. First, GVCs vary enormously. While it is now clichéd to say that value chains are complex, what matters more is that each GVC is complex in its own way, and so there are no one-size-fits-all policy recommendations. While there may be some broad similarities between GVCs at the industry-level, ultimately, each product is uniquely organized. This became evident during the COVID-19 pandemic when shortages of personal protective equipment (medical masks, medical gowns, gloves, ventilators, etc.) had to be managed differently by hospitals and governments due to their unique GVC structures.[4] Even within products, each "lead" firm that manages a GVC varies in size, organization, and mode of governance. Second, the definition of resiliency will vary enormously according to a product's importance for national security, military, health, energy, employment, or consumer welfare. Resiliency also differs based on a country's priorities, which drives each government's resource commitments. The politics of business lobbying makes this all the more complex.

Figure 1 offers a simple framework to determine which products are most critical to consider policy intervention. First, only products with important public interest should be considered, whether for national security, health, food, or energy. A country's key task is not to achieve perfect supply security (an impossibility), but to differentiate the circumstances creating unacceptable risk from tolerable or benign risk.

Second, if an important product is provisioned through resilient GVCs, such as diversified sourcing, liquid markets, and product substitutability, then in most cases, GVCs are likely to adapt effectively, perhaps with the exception of a truly systemic global crisis, like COVID-19. Finally, even in more rigid GVCs, such as in highly oligopolistic industries or with high reliance on single-country sourcing, it is possible that post-crisis time to recovery is short, and again GVCs can adapt. Thus, policy intervention should be considered only for products of high public importance, in rigid GVCs in which there is a long time to recover after a crisis, whether economic or political.

Despite the simplicity of this decision tree, the list of products that qualify for policy intervention is certainly very long. Furthermore, it remains complicated to decide on the most appropriate and cost effective policy intervention for each GVC. Both problems will require enhancing state capacity, such as extensive new data collection on GVCs, training of personnel across government agencies and new public-private partnerships given the private sectors' knowledge advantages. Several U.S. executive orders and ongoing (though uncoordinated) efforts at the Bureau of Industry and Security (BIS), National Institute of Standards and Technology (NIST), Department of Defense (DoD), Cybersecurity and Infrastructure Security Agency (CISA), and United States Geological Survey (USGS) indicate recent progress.

Massive Modular Ecosystems and the Policy Paradox

One primary argument of this paper is that GVC governance and organization are critical factors when countries consider policy intervention. In essence, GVCs are amalgams of interfirm linkages which vary by mode of governance. An enormous literature considers markets, hierarchies, and various intermediary forms of inter-firm ties. One prominent analysis of GVCs classifies five ideal types of interfirm governance linkages, with perfect markets and hierarchy (internalization) at the extremes, and with three intermediary forms—modular, relational, and captive. [5]These five governance types derive from distinct combinations of three variables: informational complexity, ability to codify complex information, and firm capabilities.

While too complex to explain in full, among the five, only modular ties are able to combine all virtues—the codification of very complex information and highly capable suppliers. This unique combination allows for an exceptional degree of complexity in building broader, interlinked ecosystems with complex interdependencies. Although most GVCs contain combinations of all five types of governance, industries that are predominantly stitched together by modular ties (like ICTs) can achieve unprecedented complexity, which evolve into MMEs, with important geopolitical and industrial and technology policy implications.

Very briefly, modularity is the partial decomposability of a complex system into distinct sub-systems which interoperate through standard interfaces, and thereby maintains system-level coherence and functionality. It is especially prevalent in ICTs due to digitization, and it can occur in large-scale systems (internet) and micro-systems (semiconductors). Massive modularity generates three paradoxes: (1) products can be both extremely complex and produced at scale; (2) they create extreme component-level industry concentration and high industry-level fragmentation; and (3) they combine intense geographic clustering and dispersion. Interoperability standards are the "glue" that allows for such fragmentation by codifying very complex information. Together, this produces a fourth policy paradox: MMEs create intense economic and security vulnerabilities and hence pressure to decouple, while simultaneously creating incentives towards international cooperation.

To illustrate, the following data examines the ubiquitous smartphone and probes layer-by-layer deeper into the MME. Figure 2 offers a simplified schematic of the mobile phone MME, and the following data reflect a small sample of nested layers (#1 to #5) composing the MME.

Figure 3 (Layer #1) reflects countries where smartphones are manufactured and exported, and it confirms China's centrality as an export powerhouse. However, Figure 3 does not reflect the headquarters of the contract manufacturers (such as Foxconn in Taiwan), nor the headquarters of the brand company (such as Apple). Such an additional layer would offer quite different perspectives on China's position in the GVC.

Inside a smartphone, there exists a hodge-podge of about 1,500 tightly packed hardware components. These components are grouped together into major sub-systems or "modules," such as memory, touchscreen, camera, CPU, etc. Figure 4 demonstrates most sub-systems are heavily concentrated in a single country and dominated by one or two firms. For instance, in 2019, 72% of CPUs and 69% of radio frequency module chips come from U.S.-headquartered firms (like Qualcomm and Qorvo), while 81% of displays and 79% of memory chips come from South Korea firms, such as Samsung and SK Hynix. Since a sub-system is worthless unless integrated into a smartphone, these figures reflect intense country and firm interdependencies. Furthermore, each module can be further disassembled, revealing greater specialization.

Operating systems are platforms that contain standardized interfaces (called APIs) which are partially "open," through which other companies interconnect to create and optimize their products. Platforms also undermine traditional GVC conceptualizations. Nevertheless, all sub-systems suppliers in Layer #2 engage with the operating system (OS), as do the innumerable app developers who create millions of apps worldwide. Figure 5a shows that after 2014, Apple and Google created a global duopoly, due to powerful network effects of platforms. However, Apple iOS and Google's Android differ dramatically. While iOS is mostly proprietary, Google has constructed a very complex open-source software platform which allows any company in the world to participate in, contribute to, download, use, and even modify and customize the Android OS—completely for free. Figure 5b reflects the country origin of the companies, non-profits, and individual programmers who have contributed to Android's open-source software. While Google predictably contributed the most (23%), U.S.-based software programmers contributed another 33%. Chinese organizations contributed only 0.4%.

Semiconductors are the core of the sub-systems of Layer #2. Figure 6 contains data on all semiconductors (not just mobile chips), and is roughly organized as a linear supply chain. The chain starts at the top where the most upstream EDA software and IP core firms provide critical inputs to fabless design houses.[6] Then, designs are passed off to manufacturing companies, which encompasses "semiconductor equipment," "materials," and, ultimately, "wafer fabrication." The final firms do "assembly, packaging, and testing." Again, Figure 6 shows extensive country concentration with U.S. firms dominant in the upstream research and development (R&D), design, and software-intensive segments, like EDA & IP (74%) and logic designs (67%). However, these data mask intense firm concentrations for specific chips. For instance, a single company (Taiwan's TSMC) dominates 85% of manufacturing for the most advanced semiconductors (5-10 nm), with Samsung taking the remaining 15%.

Each "bar" in Figure 6 roughly corresponds to a "link" in the semiconductor GVC. Of course, each link can be further disaggregated in various ways. For instance, "manufacturing equipment" contains a large basket of machines through which silicon wafers pass through their long journey to become finished chips. Figure 7 shows just two sequential tasks in semiconductor manufacturing: deposition and lithography. Figure 6a shows U.S. firms dominant in various "deposition" machines, and Figure 6b shows European and Japanese firms dominant in distinct "lithography" machines. Each machine itself is composed of thousands of parts (extreme ultraviolet (EUV) lithographs contain 100,000 parts), each with its own suppliers. Thus, the MME only deepens further.

The point of this exercise is to ask a simple question: what should policymakers target and how? In the United States, European Union, and Japan, policymakers are poised to spend many billions, targeting only leading-edge "wafer fabrication" (Figure 6), dominated by TSMC and Samsung. However, fabrication depends on over 1,000 distinct suppliers that are similarly concentrated (similar to Figure 7). Given TSMC's overwhelming dominance, suppliers are deeply clustered in Taiwan, and, most are unlikely to relocate only to supply a single new Arizona fab. Thus, "reshoring" fabs may appear to reduce domestic vulnerabilities at the targeted fabrication link, but in reality, aggregate vulnerabilities (including all supply links) will increase. Government must understand the complex interdependencies of GVCs, not simply target perceived "chokepoints."

Given the complexity of MMEs, there are few good policy options. More extreme versions—such as China's dream of technological self-reliance—are bound to fail. China will either have to be content with old generation chips or will have to cooperate in the existing global MME. This is the final policy paradox: the greater the vulnerabilities, the greater the incentive to cooperate. For this reason, in complex industries, current efforts at friend-shoring (such as US-EU Trade and Technology Council) is the only plausible policy option.

Appendix: Figures

Figure 1

Figure 1: Simple framework for determining policy relevance to enhance value chain resiliency

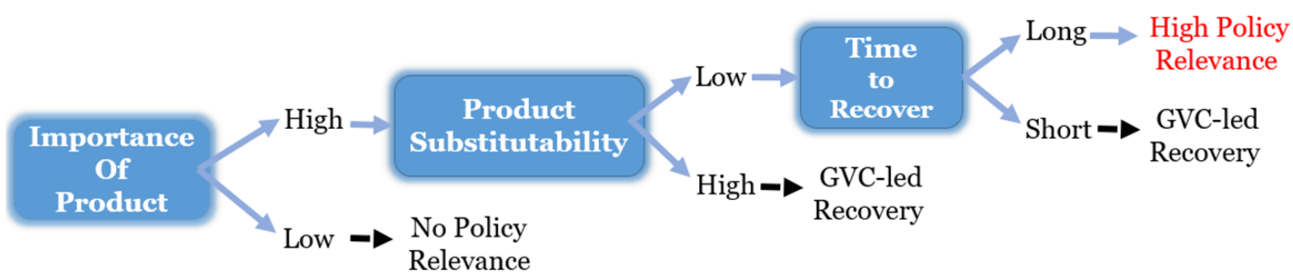
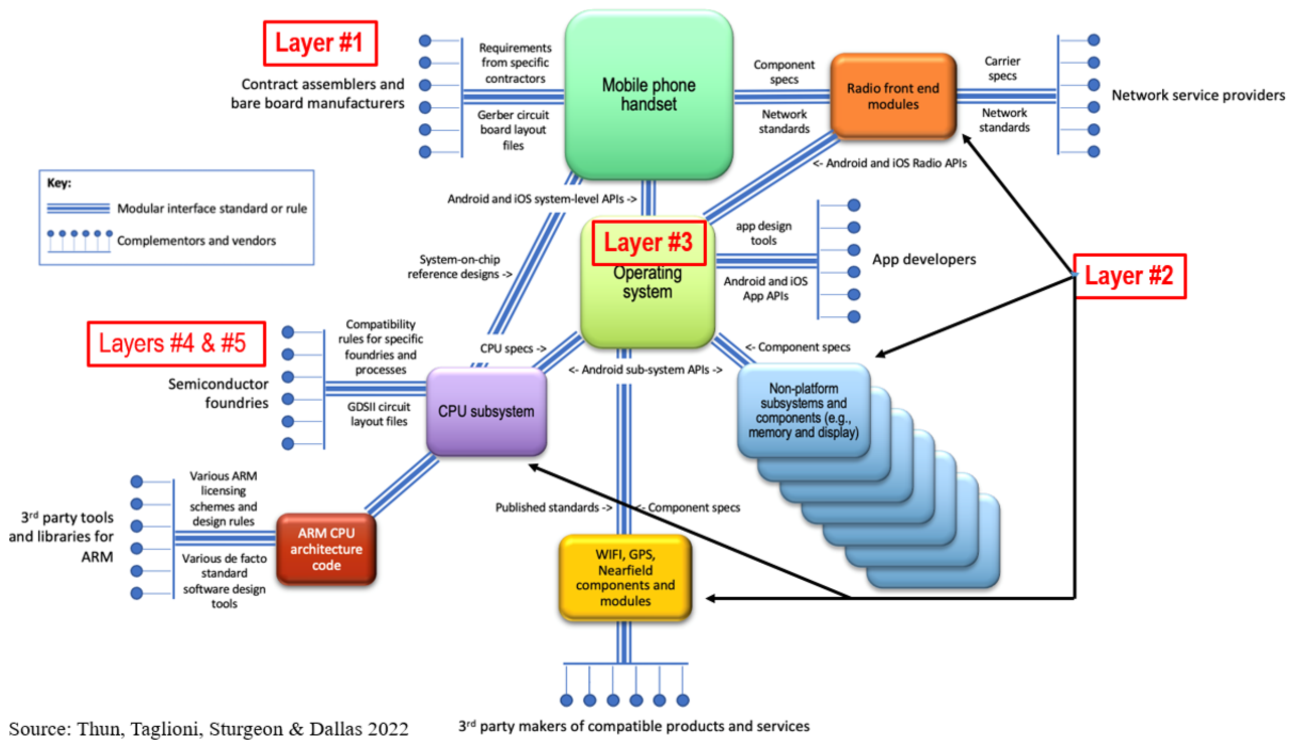


Figure 2

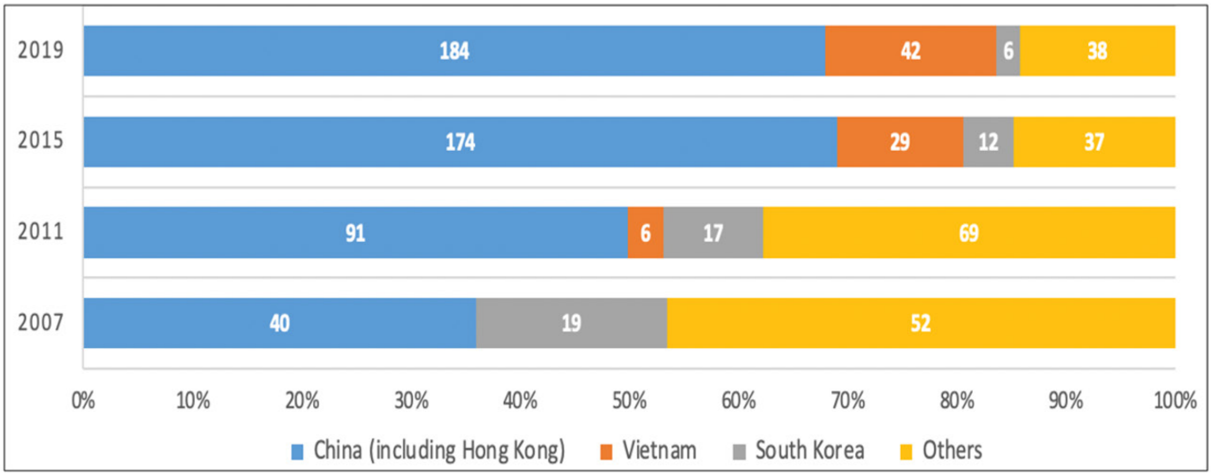
Figure 2: Simple Schematic of Mobile Phone MME



Source: Thun, Taglioni, Sturgeon & Dallas 2022

Figure 3

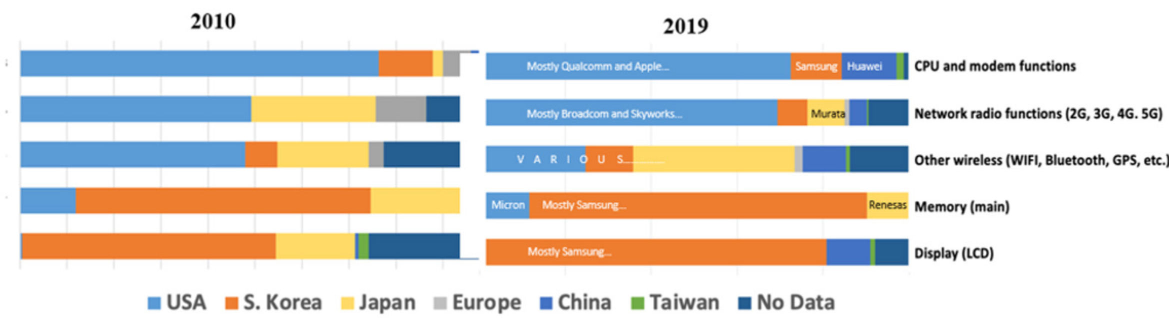
Figure 3: Layer #1 – Top mobile handset export shares and values, 2007-2019, US$ billions



Notes: China includes Hong Kong based on the assumption that most handsets exported from Hong Kong are imported from the Mainland and re-exported, even though they are not reported as such. Export values are calculated are made by summing imports from all trade partners of each reporter.
Source: UN Comtrade, HS 851712 (Telephones for cellular networks or for other wireless networks), from Thun, Taglioni, Sturgeon & Dallas 2022

Figure 4

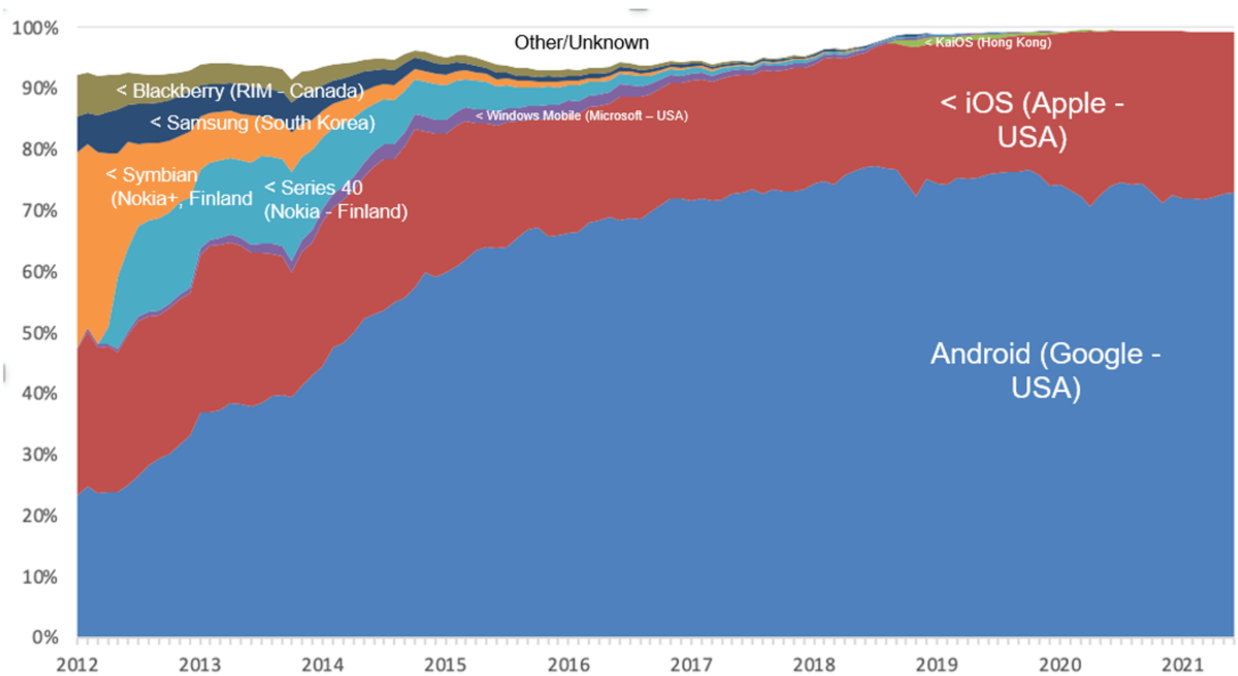
Figure 4: Layer #2 – Mobile phone sub-systems value and share by country, 2010 and 2019



Source: IHS Markit based on teardown reports of 456 handsets (average 38 reports per year)
From Thun, Taglioni, Sturgeon & Dallas, "Massive Modularity: Understanding Industry Organization in a Digital Age," 2022.

Figure 5

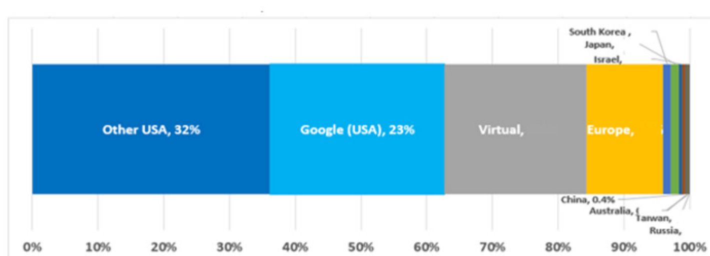
Figure 5a. Layer #3 – Global Mobile handset OS market share, January 2012 – April 2021



Source: Statista based on StatCounter, which calculates OS data based on more than 1.7 billion page views per month worldwide. StatCounter defines a mobile device as a pocket-sized computing device - tablets are not included.
From Thun, Taglioni, Sturgeon & Dallas 2022

Figure 5b

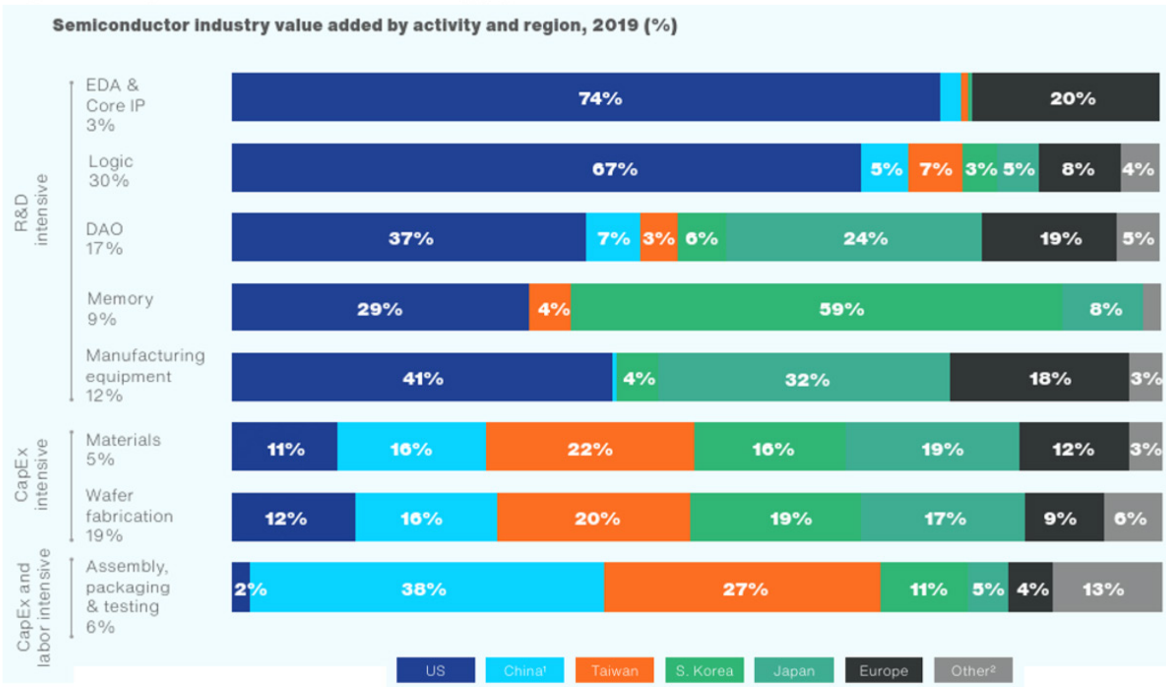
Figure 5b: Contributions (software code "commits") to Google's Android Open-Source Project
(about 10 million commits since 2008)



Note: 'Virtual' includes private individuals and individuals who contribute to open-source organizations, but who do not have a formal employment relationship with the organization, such as Linux contributors.
Source: Android Open-Source Project (https://source.android.com/). Courtesy of Jing-Ming Shiu (National Cheng Kung University, Taiwan)

Figure 6

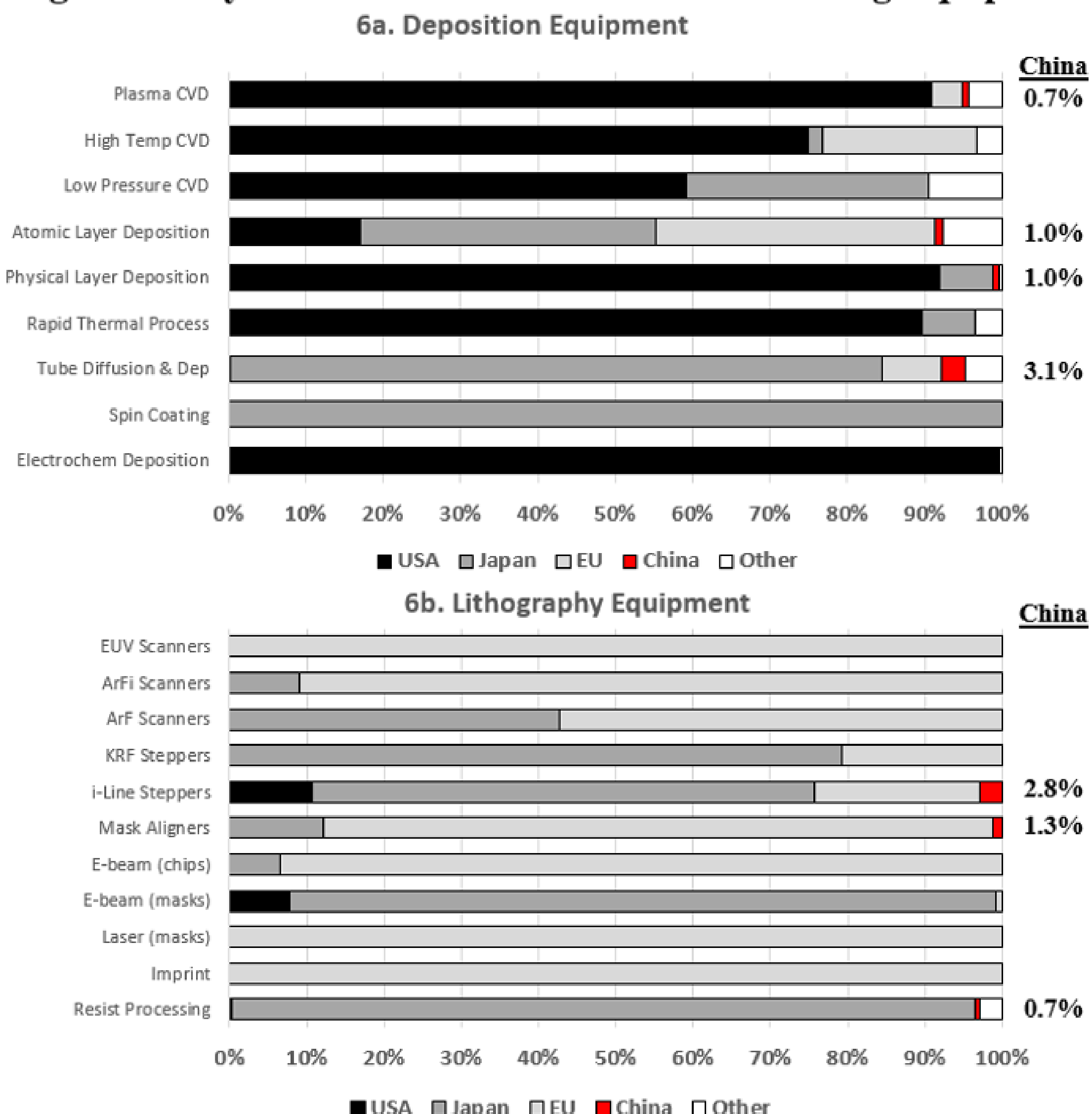
Figure 6: Layer #4 – Semiconductor Supply Chain



Source: Semiconductor Industry Association & Boston Consulting Group, 2021

Figure 7

Figure 7: Layer #5 – Semiconductor Manufacturing Equipment



Source: Adapted from Khan, Mann, Peterson (2021), p. 30, p.36; Note: CVD: chemical vapor deposition

Endnotes

1 I use the broader concept GVC in this paper. Supply chains is a narrower concept, included within GVCs, that focuses only on the cost and time of delivery of products that meet specification.

2 Autor, D.H., Dorn, D., & Hanson, G.H. (2016). The China shock: Learning from labor-market adjustment to large changes in trade. Annual review of economics, 8, 205-240; and Autor, D.H., Dorn, D., & Hanson, G.H. (2021). On the Persistence of the China Shock (No. w29401). National Bureau of Economic Research.

3 Thun, E., Taglioni, D., Sturgeon, T. & Dallas, M.P. (2022) “Massive Modularity: Understanding Industry Organization in the Digital Age — The Case of Mobile Phone Handsets. Policy Research working paper; no. WPS 10164 Washington, D.C.: World Bank Group.

4 Gereffi, G. (2020). “What does the COVID-19 pandemic teach us about global value chains? The case of medical supplies.” Journal of International Business Policy 3, no. 3, 287-301; and Dallas, M.P., Horner R, & Li, L. (2021) “The mutual constraints of states and global value chains during COVID-19: The case of personal protective equipment.” World Development 139, 1-13.

5 Gereffi, G., Humphrey, J., & Sturgeon, T. (2005). The governance of global value chains. Review of international political economy, 12(1), 78-104.

6 Fabless means they lack manufacturing facilities.