National Defence Défense nationale

Canadian Forces College

Collège des Forces Canadiennes

American Defence Supply Chain Vulnerabilities

Major Alexandre Wakeham

JCSP 48

Exercise Solo Flight

Disclaimer

Opinions expressed remain those of the author and do not represent Department of National Defence or Canadian Forces policy. This paper may not be used without written permission.

PCEMI 48

Exercice Solo Flight

Avertissement

Les opinons exprimées n'engagent que leurs auteurs et ne reflètent aucunement des politiques du Ministère de la Défense nationale ou des Forces canadiennes. Ce papier ne peut être reproduit sans autorisation écrite.

Canada

CANADIAN FORCES COLLEGE – COLLÈGE DES FORCES CANADIENNES

JCSP 48 – PCEMI 48
2021 – 2022

Exercise Solo Flight – Exercice Solo Flight

American Defence Supply Chain Vulnerabilities

Major Alexandre Wakeham

BUILDING RESILIENCY: AN ASSESSMENT OF AMERICAN DEFENSE SUPPLY CHAIN VULNERABILITIES

The beginning of the 21st century has been characterized by rapid advances in science, technology, ease of mobility, and communications. Combined, these factors have changed human behaviours and reshaped our global environment. Though the exact definition of globalization is heavily debated, it is undeniable that these factors have played a significant role in compressing the relative size of our world in geographical space and time. This compression of space and time has enabled greater global interconnection of people, corporations, economics, and politics at a speed which we have not before seen.

The International Money Fund (IMF) describes globalization as: “The process through which an increasingly free flow of ideas, people, goods, services, and capital leads to the integration of economies and societies”[1]. Globalization, combined with the notion of compression, interconnectedness, integration, and geopolitical factors, such as American unipolarity, contributed to the mass proliferation of capitalism and the free-market economy. Fundamentally, capitalism relies on competition, innovation, and “rewards more efficient production processes, new products conferring superior consumer utility, and better methods of business organization”.[2] As such, these converging conditions and factors have given rise to the development of: “Work-flow

---

[1] Horst Köhler, speech, “Working for a Better Globalization”, (Managing Director, International Monetary Fund, Washington, DC, 28 January 2002), https://www.imf.org/external/np/exr/ib/2002/031502.htm
[2] F. M. Scherer, "The Dynamics of Capitalism," (*The Oxford Handbook of Capitalism*: Oxford University Press, 2012), 32. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/files/mrcbg_fwp_2010-01_Scherer_dynamics.pdf

software, […] the advent of out-sourcing, the rise of off-shoring, the development of supply chaining, and the rise of third-party dedicated internal logistics operations”[3]. Combined, these developments contribute to today’s integrated global value chains (GVC) or supply chains.

GVC (or supply chains) are characterised by firms or countries who purchase inputs or materials from one firm or country, refine those inputs via processing, then sell those inputs to another country or firm who further refines the products, adding value along the way.[4] These exchange processes repeat exponentially until a product has reached its final desired state. GVCs can be extremely complex and non-linear, and also encompass functions such as Research and Development (R&D), Design, Manufacturing or Refinement, Marketing, Packaging, Distribution and Services[5]. Although the free market has determined that GVCs maximize revenues and efficiencies, recent historical developments have demonstrated their inherent vulnerabilities and fragility.

For instance, the COVID-19 pandemic shocked global supply chains with shrinking inventories, material shortages[6] and record supply delays due to national border

---

[3] Philip McCann, "Globalization and Economic Geography: The World is Curved, Not Flat." *Cambridge Journal of Regions, Economy and Society* 1, no. 3 (2008): 351. https://web-p-ebscohost-com.cfc.idm.oclc.org/ehost/pdfviewer/pdfviewer?vid=0&sid=86e0df91-2a3b-4234-9829-6ca6b37dc405%40redis

[4] Nataliya V Smorodinskaya, Daniel D. Katukov, and Viacheslav E. Malygin, "Global Value Chains in the Age of Uncertainty: Advantages, Vulnerabilities, and Ways for Enhancing Resilience." *Baltic Region* 13, no. 3 (2021): 82. https://journals.kantiana.ru/upload/iblock/062/5_78-107.pdf

[5] Gary Gereffi and Karina Fernandez-Stark, *Global Value Chain Analysis: A Primer.* 2nd Ed (Durham: Duke University Global Value Chains Center, 2016), 14. https://www.researchgate.net/profile/Gary-Gereffi/publication/305719326_Global_Value_Chain_Analysis_A_Primer_2nd_Edition/links/579b6f0708ae80bf6ea3408f/Global-Value-Chain-Analysis-A-Primer-2nd-Edition.pdf?origin=publication_detail

[6] Susan Helper and Evan Soltas, “Why the pandemic has disrupted Supply Chains.” *The White House, Council of Economic Advisers* (blog), 17 June 2021. https://www.whitehouse.gov/cea/written-materials/2021/06/17/why-the-pandemic-has-disrupted-supply-chains/

lockdowns[7]. The ripple effects severely impacted commodities such as pharmaceuticals, personal protective equipment, food, semiconductors, automobiles, lumber and many other complex supply chain goods. As well, on 23 March 2021, the Ever Given, a 1,400 foot-long container ship ran aground in the Suez Canal, blocking the maritime trade route for 6 days[8]. The incident backlogged 450 ships and disrupted international supply chains, impacting $9.6bn of trade per day.[9] These events, combined with unpredictable natural disasters, as well as the disruptive threats that are emerging from renewed geopolitical uncertainties (great power competition), lead us to the following research question: To what extent are American supply chain dependencies a threat to its national security and how do these dependencies impact their defense sector?

This paper argues that America's overreliance on complex international supply chains has created vulnerabilities within its defense sector which significantly threaten their national security; and, if left unchecked, will negatively impact American prosperity. To achieve this, this paper will briefly describe the characteristics required to guarantee supply chain resiliency. To this end, the paper is broken into three supply chain vulnerability themes which present challenges to the American defense sector. The first theme addresses the concept of sole sourcing and leverages the example of Rare Earth Elements. We seek to demonstrate that overreliance on a singular nation for resources

---

[7] Knut Alicke and Vera Trautwein, "How COVID-19 is Reshaping Supply Chains." *McKinsey Insights* (Nov 23, 2021): 1. https://www.proquest.com/magazines/how-covid-19-is-reshaping-supply-chains/docview/2638055490/se-2?accountid=9867

[8] Matthew Schwartz, "Suez Canal Traffic Backlog Finally Cleared Following The Ever Given Saga National Public Radio," *National Public Radio*, 3 April 2021. https://www.npr.org/2021/04/03/984111501/suez-canal-traffic-backlog-finally-cleared-following-the-ever-given-saga

[9] Mary-Ann Russon, "The Cost of the Suez Canal Blockage," *British Broadcasting Corporation*. 29 March 2021. https://www.bbc.com/news/business-56559073

creates single points of failure which compromise supply chain resiliency. The second theme explores the complex interconnected supply chains that are required for semiconductor production. This section breaks down the complexities of specialized geographic production and addresses the inherent fragility of extended supply chains and America's defense sector. The last theme explores the outsourcing of domestic manufacturing. This section advocates for a strong domestic manufacturing sector as a mechanism to shore up GVC resiliency. We highlight the secondary effects associated with outsourcing, the impacts on supply chain innovation and the American defense sector. As the themes and analysis are presented, it is important to keep in mind the resurgence of a great power competition.

A Framework for Supply Chain Resiliency

Within the globalized architecture of free trade and the expansive proliferations of networked GVC, it is important to frame the characteristics of supply chain resiliency. In essence, the notion of resilient supply chains is nested within the principal of sustainability given uncertainty. As such, resilient supply chains imply that they are flexible when faced with uncertainty and can maintain production when disrupted or challenged by events. In this respect, supply chain resiliency focuses on the flexibility of a supply chain to absorb shocks from events and adapt quickly with minimal impacts or disruptions.[10] Moreover, supply chain resiliency is also entrenched in the concept of reliability, therefore, resilient supply chains have reliable suppliers, manufactures, trade

---

[10] Nataliya V Smorodinskaya, Daniel D. Katukov, and Viacheslav E. Malygin, "Global Value Chains in the Age of Uncertainty: Advantages, Vulnerabilities, and Ways for Enhancing Resilience." *Baltic Region* 13, no. 3 (2021): 93. https://journals.kantiana.ru/upload/iblock/062/5_78-107.pdf

routes, products, and are timely. Thus, resiliency implies that there is capacity and ability to mitigate unpredicted events.

Sole Sourcing and Rare Earth Elements

Strategic and critical minerals are essential to every developed nation's economic prosperity and defense industry. Within this domain are a group of minerals denoted as Rare Earth Elements (REE). There are 17 REE and although its name might suggest they are rare, they are abundant within the earth's crust.[11] REEs have many technological applications and are incorporated in many common place items such as: Computers, hard drives, headphones, electric vehicle batteries, flat panel screens and many medical devices. Moreover, their application within the defense sector is of equal importance, given that REEs are required to produce: Jet engine propulsions systems, missile and anti missile defense guidance systems, secure communication systems, satellite components, lasers, sonar, night vision and hardened alloys for armored vehicles.[12] Given the long list of sensitive defense materials that require REE, as well as their application in cutting edge defense technologies such as Tomahawk Missiles and F35 Fighters, it is certain that resilient American supply chains must have multisource unfettered access to REE.

To better understand the risks involved with REE supply chains, it is important to map the supply chain process. First, REE must be extracted from the ground as a raw material via mining processes. Once the minerals are extracted, they are crushed and separated for further processing. Following this, the minerals undergo a beneficiation

---

[11] Congressional Research Service, *Rare Earth Elements: The Global Supply Chain,* (Washington, DC: U.S. Government Printing Office, Dec 2013), 2. https://crsreports.congress.gov/product/pdf/R/R41347

[12] Lee Simmons, "Rare-Earth Market", *Foreign Policy*, 12 July 2016. https://foreignpolicy.com/2016/07/12/decoder-rare-earth-market-tech-defense-clean-energy-china-trade/

process which allows for mineral concentration[13]. Once sufficient concentrations of the minerals are achieved, they are purified and purged of impurities to create semi-final working forms of the elements[14]. These semi-final forms are refined in downstream production for applicable products. In the case of the United States, the supply chain vulnerability and dependency is the sole sourced access to the minerals, the refinement process chains and the low costs of the semi-final forms.

Between 1960 and 1980, the United States was once a prolific producer of REE, however, as of 2012, domestic REE mining and production has almost ceased to exist[15]. Moreover, a 2012 United States Geological survey assessed that China's REE mining and processing accounted for 86 percent of the world's total production[16]. Today, the United States has only one REE mine in operation with no capability to refine the minerals into a semi-final form[17]. Accordingly, this leaves America in a vulnerable position, with the majority of access to RREs hinging on the balance of political relations in a time of uncertainty. In essence, China has a sole source monopoly in REE production, exposing America to significant supply risks and a single point of failure[18]. Within this context, there are numerous examples which demonstrate the fragility of this sole source.

---

[13] The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth,* (Washington, DC: Government Printing Office, June 2021), 155. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf
[14] Ibid.
[15] Congressional Research Service, *An Overview of Rare Earth Elements and Related Issues for Congress,* (Washington, DC: U.S. Government Printing Office, November 2020), 3. https://crsreports.congress.gov/product/pdf/R/R46618
[16] Congressional Research Service, *Rare Earth Elements: The Global Supply Chain,* (Washington, DC: U.S. Government Printing Office, Dec 2013), 9. https://crsreports.congress.gov/product/pdf/R/R41347
[17] Ernest Scheyder, "Exclusive U.S. Bill Would Block Defense Contractors from Using Chinese Rare Earths," *Thomas Reuteurs*. 12 Jan 2022. https://www.reuters.com/business/energy/exclusive-us-bill-would-block-defense-contractors-using-chinese-rare-earths-2022-01-14/
[18] Congressional Research Service, *China's Mineral Industry and U.S. Access to Strategic and Critical Minerals: Issues for Congress*, (Washington, DC: U.S. Government Printing Office, March 2015), 10. https://crsreports.congress.gov/product/pdf/R/R43864

First, it is important to recognize that from 2009 to 2013, the Communist Party of China (CPC) implemented sharp export restriction quotas on REE, cutting export restriction from 50,000 metric tonnes (mt) to 30,000 mt[19]. These export restrictions created massive volatility in prices, which surged REE import prices from $6,969 per mt to $170,760 and negatively impacted materials and markets throughout the supply chain.[20] In 2015, a verdict by the World Trade Organization (WTO) established that Chinese export quotas and export taxes were in contravention of regulations and contributed to price manipulation in foreign markets. As such, China would have to abolish export taxes and quotas; however, in response to this verdict, China would re-order the REE industry from within its borders with new policies. In 2016, the mining, extraction, and refinement of REE became controlled by six state run companies and implemented production quotas[21]. This consolidation of state-owned supervision over REE exemplifies the CPC's priority to retain control over REE globalized markets, enable REE tracking and remain a dominant source in their production.

Moreover, in 2010, a dispute between Japan and China erupted over the interception of a Chinese fishing boat near the Island of Senkaku[22]. The island is subject to a territorial dispute between Japan and China. The Chinese fishing boat rammed two Japanese coast guard vessels after being ordered to leave the coastal waters. These

---

[19] Congressional Research Service, *Rare Earth Elements: The Global Supply Chain,* (Washington, DC: U.S. Government Printing Office, Dec 2013), 12. https://crsreports.congress.gov/product/pdf/R/R41347
[20] Congressional Research Service, *Trade Dispute with China and Rare Earth Elements,* (Washington, DC: U.S. Government Printing Office, June 2019), 2. https://sgp.fas.org/crs/row/IF11259.pdf
[21] Shen Yuzhou, Moomy Ruthann and Roderick G. Eggert, "China's Public Policies Toward Rare Earths, 1975–2018," *Mineral Economics* 33, no. 1-2 (07, 2020): 142. https://www.proquest.com/scholarly-journals/china-s-public-policies-toward-rare-earths-1975/docview/2425988103/se-2.
[22] "Boat collision sparks Japan-China Diplomatic row". *British Broadcasting Corporation*. 8 September 2010. https://www.bbc.com/news/world-asia-pacific-11225522

actions resulted in the arrest of the Chinese ship's captain and detainment of the crew. In a retaliatory action, China halted all REE exports to Japan demanding that the ship's crew be released. China would later assert that this was simply in line with quota reductions that had been already established, however, from a supply chain resiliency perspective this is extremely alarming. These actions demonstrate the degree to which China will invoke economic statecraft to leverage strategic and political ends[23]. This sincerely questions America's overreliance on China as its sole sourced position for REE mining, refining, and processing. To that, it is clear that Beijing is demonstrating its ability to manipulate these markets for their gains.

From a strategic perspective, the CPC's dominance in REE production and manufacturing can be employed as a coercive tool and mechanism of compliance given their sole source production. Furthermore, China's monopolization of the REE industry remains in their strategic interest as an economic powerhouse given that China's domestic use of REE continues to rise. Of the 155,000 tons of REE that was produced in 2016, China consumed 67 percent of these resources. This may suggest that Beijing is increasingly focused on its own material interests and less on the value of exports over time.[24] With these factors at play, it is undeniable that America must diversify its access to alternate sources of REE, beyond China's sole source. Likewise, America's REE reserves are estimated at 13 million metric tons, making it the 3rd largest reserve on the

---

[23] Sophia Kalantzakos, *China and the Geopolitics of Rare Earths*, (New York: Oxford University Press, 2018. Oxford Scholarship Online, 2017), 2. https://oxford-universitypressscholarship-om.cfc.idm.oclc.org/view/10.1093/oso/9780190670931.001.0001/oso-9780190670931-chapter-1

[24] Lee Simmons, "Rare-Earth Market", *Foreign Policy*. 12 July 2016. https://foreignpolicy.com/2016/07/12/decoder-rare-earth-market-tech-defense-clean-energy-china-trade/

planet[25]. Thus, there is a case to be made for increased domestic mining and production as a supply chain resiliency strategy. As such, alternative sources and refinement capacities can offset American dependencies on China. In doing so, the REE supply chains become more resistant to the volatility of geopolitical events in East Asia or the manufactured manipulations from within Beijing. From a national security perspective, diversification also ensures that America is not left at the mercy of Chinese production and policies within the context of a renewed great power competition. America must be cautious of Chinese economic statecraft and diversify supply chain sources to ensure resiliency and unfettered access to REE.

Complex Interconnected and Specialized Semiconductor Supply Chain.

The semiconductor industry is equally as important to American national security and is one which is primordial to the success the United States economy and defense industry. Semiconductors are found in virtually every piece of electronics and are the 4th most traded product globally, with trade amounting to $1.7 trillion[26] for a total of 640 billion manufactured microchips a year[27]. They enable all sectors of the economy and are critical to healthcare, automotive, finance, transportation, energy, telecommunications, utilities, and consumer products. Moreover, from a defense perspective, semiconductors enable every modern military system and platform including the F35 Joint Fighter, USS Zumwalt stealth destroyers, missile systems, computers and electronic communication

---

[25] Congressional Research Service, *Rare Earth Elements: The Global Supply Chain,* (Washington, DC: U.S. Government Printing Office, Dec 2013), 9. https://crsreports.congress.gov/product/pdf/R/R41347
[26] Antonio Varas, *et al, Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*. (Boston, MA: Boston Consulting Group, 2021), 36. https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf
[27] Mitch Leslie, "Pandemic Scrambles the Semiconductor Supply Chain." *Engineering (Beijing, China)* 9, (2022;2021;): 1. https://www.sciencedirect.com/science/article/pii/S2095809921005804

and navigation systems[28]. Given their extensive use and integration into all electronics, any supply chain disruptions have widespread impacts across the globe. Most recently, the COVID-19 pandemic has demonstrated the scarcity of semiconductor chips as they relate to the automotive sector, whereby shortages have created significant price increases and low inventories[29].

Semiconductor supply chains are extremely complex and rely on many highly specialized transformation processes which are spread across the global geography[30]. The intensive and complex specialization of the transformation of silicone into semiconductors (or microchips) speaks to how the regionally specialized manufacturing approach emerged. "The global structure of the semiconductor supply chain, with geographic specialization across layers, means that companies interact and collaborate across borders, in relationships of mutual dependency."[31] In their completed form, a semiconductor (or microchip) consists of thousands of highly miniaturized components which require between 400 and 1400 manufacturing steps depending on the complexity of the chip. As such, the lead time for semiconductor chip construction across the supply chain from initiation to product integration can take up to 100 days[32]. From start to finish,

---

[28] The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth,* (Washington, DC: Government Printing Office, June 2021), 24. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

[29] Susan Helper and Evan Soltas, "Why the pandemic has disrupted Supply Chains." *The White House, Council of Economic Advisers* (blog), 17 June 2021. https://www.whitehouse.gov/cea/written-materials/2021/06/17/why-the-pandemic-has-disrupted-supply-chains/

[30] Antonio Varas, *et al, Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*. (Boston, MA: Boston Consulting Group, 2021), 27. https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

[31] Ibid., 37

[32] The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth*, (Washington, DC: Government Printing Office, June 2021), 27. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

a semiconductor can cross up to 70 international borders with a total cumulative transit time of 2 weeks.[33] To demonstrate the complexities involved with semiconductor GVC, we will examine the throughput of a semiconductor that is found in any modern electronic handheld device. Although the process is simplified, it demonstrates the globalized nature of production and emphasizes the vulnerabilities associated with visibility in extended supply chains, challenging supply chain resiliency.

There are 6 major regions that primarily contribute to the semiconductor GVCs: The US, South Korea, Japan, China, Taiwan and Europe. Specific to these regions are the breakdown of essential segments that include: Design, fabrication, assembly, testing and packaging (ATP), materials, manufacturing equipment and commercialization [34]. The design phase unfolds in the United States and/or Europe and is focused on the intellectual property and development of a semiconductor chip for commercial or defense use. This phase relies on highly sophisticated R&D and advanced software to successfully design a chip. Additionally, the manufacturing equipment that is required to produce semiconductors is extremely specialized and precise, capable of working in miniature scales within nanometers at the sub-atomic level.[35] Firms in the US, Europe and Japan are the largest producers of these specialized tools that are required to manufacture

---

[33] Ibid., 27.
[34] Antonio Varas, *et al, Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*. (Boston, MA: Boston Consulting Group, 2021), 27. https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

[35] The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth*, (Washington, DC: Government Printing Office, June 2021), 34. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

semiconductors. As an example, a single extreme ultraviolet lithography tool for semiconductor wafer production can cost approximately $150 million[36].

For materials, silicone is the primary resource for semiconductor production; it must have a high concentration in silica with little contaminants.[37] For this example, the silicone extraction takes place in the United States (although high quality silica comes from other regions such as Japan). Once extracted, it is then milled and refined into high grade silicone. The silicone is then shipped to Japan where it is melted and crystalized into a single layer crystal. Single layer crystals are shipped to South Korea where they are sliced into wafers and polished. Wafer production requires a high level of specialized equipment and 90% of the wafer production occurs within 5 companies which are located in Southeast Asia[38]. The wafers are then shipped to foundries in Taiwan where they are imprinted with circuit patterns and interconnected before being shipped to Malaysia. "Taiwan alone accounts for 73 percent of the global foundry businesses"[39] making it one of the most highly dense and specialized geographic regions within the GVC for semiconductor production.

In Malaysia, the chips are sorted depending on specifications, they are then tested and packaged. Once packed, they are shipped to China where they are incorporated into electronic circuit boards and placed into devices or products. These products are then shipped back to the United States or other markets for consumer consumption, retail, and

---

[36] Ibid., 35.
[37] Douglas Heaven, "The Humble mineral that transformed the world", *Made on Earth Series, British Broadcasting Corporation,* https://www.bbc.com/future/bespoke/made-on-earth/how-the-chip-changed-everything/
[38] Congressional Research Service, *Semiconductors: U.S. Industry, Global Competition, and Federal Policy*. (Washington, DC: U.S. Government Printing Office, Oct 2020), 10. https://crsreports.congress.gov/product/pdf/R/R46581
[39] Ibid., 17.

commercialization. Each segment of the semiconductor GVC is complex and relies on a highly skilled and knowledgeable work force. Depending on the complexity of the semiconductor and its final application, it can take as many as 300 different inputs to complete a single wafer[40]. Moreover, the highly specialized foundries that are required for circuit printing present a significant capital expenditure which creates barriers to entry. Estimates assess that a foundry can cost from $7 billion to $20 billion depending on the exact nature and type of semiconductor that it constructs. [41] Futhermore, continuous advances in technology require consistent investments to enable state of the art manufacturing that is in line with new developments vis-à-vis R&D cycles. This is the case with the most advanced semiconductors which are fabricated at high density ranges below 10 nanometers, whereby 100 percent of these chips are made in foundries in Taiwan and South Korea[42].

Not withstanding all the highly specialized regional inputs that are required for semiconductor manufacturing, the high level of transit required to enable trade also presents itself as a vulnerability within the GVC. The multiple transportation nodes required to enable the entire production of a semiconductor can be compromised by various global, environmental, and geopolitical events. Supernatural events, such as fires,

---

[40] Antonio Varas, *et al, Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*. (Boston, MA: Boston Consulting Group, 2021), 22 https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

[41] Congressional Research Service, *Semiconductors: U.S. Industry, Global Competition, and Federal Policy*, (Washington, DC: U.S. Government Printing Office, Oct 2020). 14. https://crsreports.congress.gov/product/pdf/R/R46581

[42] Antonio Varas, *et al, Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*. (Boston, MA: Boston Consulting Group, 2021), 42. https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

floods, earthquakes, and other natural disasters can create resounding production delays, supply shortages, loss of manufacturing facilities and knowledge (personnel) which can shock the entire supply chain. For instance, in 2011, the earthquake off the coast of Japan and subsequent tsunami significantly impacted Japan's semiconductor fabrication plants. At the time, Japan accounted for 23% of global chip manufacturing and the extensive damages and power outages left numerous factories closed or idle[43]. Moreover, the tsunami damaged critical infrastructure such as roads and rail lines which were essential to the export of semiconductors. [44]

More recently, in 2021, Taiwan experienced its worst drought in over 56 years. This led to the government imposing restrictions on water consumption, which affected semiconductor manufacturing. The Taiwan Semiconductor Manufacturing Company (TSMC), a leading producer in advanced wafer technologies, requires over 156,000 metric tons of fresh water a day for foundry operations[45]. Any reduction in water capacity restricts operations and strains semiconductor production capacities. As these examples demonstrate, there is no shortage of hazardous events which can impact the interconnected GVCs for semiconductor production. The effect of these unforeseen events ravage the global economy, creating semiconductor shortages across the multiple economic sectors which rely on their timely production.

---

[43] Pengfei Zhang, "Japan Earthquake-when the Big One Hit [Associate Editor's View]." *IEEE Solid State Circuits Magazine* 3, no. 2 (2011): 5. https://ieeexplore-ieee-org.cfc.idm.oclc.org/document/6051583
[44] K. Pletcher, and John P. Rafferty, "Japan earthquake and tsunami of 2011." *Encyclopedia Britannica*, Last Accessed 3 May 2022. https://www.britannica.com/event/Japan-earthquake-and-tsunami-of-2011/Aftermath-of-the-disaster
[45] "Taiwan's Worst Drought in Decades Deepens Chip Shortage Jitters", Agence France-Press, 20 April 2021. https://www.industryweek.com/supply-chain/article/21161812/taiwans-worst-drought-in-decades-deepens-chip-shortage-jitters

The highly specialized and geographically clustered nature of production for semiconductors coupled with large, interconnected processes makes this GVC extremely vulnerable to disruption.[46] Additionally, their expansive reliance on specialized equipment, labour skills, foundry capacities and high capital cost barrier to entry create multiple points of failure when applying concepts of resiliency. Since semiconductors are small and light, they are easily shipped across the globe, making them also prone to shipping disruptions. Likewise, the fact that semiconductors are highly traded prior to their final application means that they are increasingly susceptible to cyber attack and trade dispute[47]. Overall, specialization within the semiconductor industry has facilitated efficiencies, however, it has created significant vulnerabilities which are not easily reconciled. Simply put, the high degree of specialization across multiple production nodes has exposed the semiconductor industry to high degrees of disruption and domino effects. With the majority of the production of semiconductors outsourced, America is left at the mercy of too many uncertainties. It is clear that America must establish some capability of high-density domestic foundry production autonomy if it is to insulate itself from further shock events likely to disrupt semiconductor GVCs. Lastly, an assessment of the United States military's reliance on semiconductors gives further weight to this suggestion, especially as we explore cyber and counterfeiting vulnerabilities.

[46] Andrew Herod, "What does the 2011 Japanese Tsunami Tell Us about the Nature of the Global Economy?" *Social & Cultural Geography* 12, no. 8 (2011): 832 https://www-tandfonline-com.cfc.idm.oclc.org/doi/full/10.1080/14649365.2011.629301

[47] Susan Lund *et al,* "Risk, Resilience, and Rebalancing in Global Value Chains" *McKinsey Global Institute*, (Aug 2020): 67.

Counterfeit Semiconductors and Circuits

Within the semiconductor GVC, reliability is associated with each companies' ability to produce high grade products and inputs, on schedule, and with little defects. GVCs with high degrees of trade and complexities are more vulnerable to interference and undermine the establishment of resiliency. To be resilient, semiconductor supply chains require a high degree of reliability with low failure rates[48]. To build this reliability, resilient supply chains must demonstrate a high degree of transparency, allowing their functioning to remain predictable. This ensures that both the components and the steps within the GVC are accounted for, from source materials, to the specialized production processes.

The enormity of material inputs, steps and complexities required to fabricate semiconductor chips contributes to supply chain visibility challenges[49]. Since most of the manufacturing activities are outsourced to specific geographic regions, minimal controls and oversight across the entire production cycle are feasible. Surveillance of items such as raw materials and wafers is not infallible, and materials can be stolen, modified, and reintroduced at numerous points in the supply chain.[50] Thus, poor supply chain visibility coupled with complex semiconductor manufacturing processes exposes the United States military to vulnerabilities such as: Cyber attack, counterfeiting materials and malicious

---

[48] Peter Marston, "How to Combat Counterfeit Semiconductors." *Ecn* (May 20, 2015), 1. https://www.proquest.com/trade-journals/how-combat-counterfeit-semiconductors/docview/1688643004/se-2?accountid=9867.

[49] Ujjwal Guin, *et al,* "Counterfeit Integrated Circuits: A Rising Threat in the Global Semiconductor Supply Chain." *Proceedings of the IEEE* 102, no. 8 (2014): 1207. https://ieeexplore-ieee-org.cfc.idm.oclc.org/stamp/stamp.jsp?tp=&arnumber=6856206

[50] Peter Marston, "How to Combat Counterfeit Semiconductors." *Ecn* (May 20, 2015), 1. https://www.proquest.com/trade-journals/how-combat-counterfeit-semiconductors/docview/1688643004/se-2?accountid=9867.

insertions into products[51]. "The consequences of a counterfeit semiconductor can cause costly failures in a wide range of consumer, health, transportation, and military systems".[52] In 2012, the United States Senate Armed Service Committee reported that from 2009 to 2010, there were over 1,800 cases of suspected counterfeit electronic parts contained within the defense supply chains and military systems[53]. Further investigation into these suspected counterfeit semiconductors and microchips determined that approximately 70% of those items originated from China.[54]

Counterfeiting processes are highly reliant on electronic waste and electronic recycling programs. Old semiconductors and chips are disassembled, washed, sanded down, recoated with paint and reserialized. Once refreshed, the semiconductors and circuits are reintroduced back into the market and sold via the internet, or shell companies. As an alarming example of such penetration of recycled materials, counterfeit items were found in critical defense systems such as Terminal High Altitude Area Defense (THAAD) Missile systems and military aircraft such as C-17 Globemasters, C130J transport aircraft and SH-60 anti submarine-warfare helicopters[55]. Such an insertion of a cheap counterfeit semiconductor into a state-of-the-art multi million-dollar platform will undoubtedly and unacceptably compromise a defense system's reliability

---

[51] The White House, *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth*, (Washington, DC: Government Printing Office, June 2021), 75. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf
[52] Congressional Research Service, *Semiconductors: U.S. Industry, Global Competition, and Federal Policy*, (Washington, DC: U.S. Government Printing Office, 26 October 2020), 23. https://crsreports.congress.gov/product/pdf/R/R46581
[53] U.S. Senate Committee on Armed Services, *Inquiry into counterfeit electronic parts in the Department of Defense supply chain*, *Report 122-167*, (Washington, DC: United States Senate), 9. http://www.armed-services.senate.gov/imo/media/doc/Counterfeit-Electronic-Parts.pdf
[54] Ibid.
[55] Ibid., 8.

and functionality. This represents a significant and ever-present risk to American national security. The origin and quality of the materials used in such sensitive equipment can tolerate no such lack of transparency.

Disturbingly, these counterfeit semiconductors are introduced into the defense supply chains without detection, either during initial equipment production cycles or maintenance life cycles. Modern military equipment is supported by thousands of complex systems of electronic components. These systems rely on complex interconnected supply chains and many levels of tiered sub contractors. For instance, a F35 Multi-role fighter will contain more than 3,500 integrated circuits[56] with a supply chain which spans more than 1,900 companies[57]. In the case of the F35, the breadth of sub-contractors represents a serious problem for supply chain visibility, company vetting and the control of semiconductor counterfeiting practices. At any moment during its initial production or maintenance schedule, counterfeit materials can be nearly effortlessly introduced to the unprotected ecosystem of the multi-factor F35 supply chain.

In other scenarios, equipment circuits and semiconductors become obsolete, and must obligatorily be maintained, creating vulnerabilities for equipment counterfeiting or malicious insertion during these scheduled repairs. For example, the F15 Eagle, which entered service in 1975, uses semiconductors and circuits which inevitably and predictably require life-cycle repairs. In many instances, the semiconductors required are no longer in production due to technological advances and low demand. As a result, the United States must source semiconductors from independent distributors and resellers.

---

[56] Ibid., 16.
[57] Lockheed Martin. “The Global F-35 Enterprise”. Last Accessed 3 May 2022. https://www.lockheedmartin.com/en-us/products/f-35/f-35-global-partnership.html

This context creates opportunities for counterfeit hostile or malevolent vendors to introduce their products into the defense supply chain, because the department of defense is limited to a few alternative acquisitions of the required part[58]. Poor supply chain visibility and a lack of domestic production capacity set the perfect conditions for American defense supply chains to be exploited in such a manner.

Together, these examples illustrate the wide scope of interconnected semiconductor supply chains and the many points of vulnerabilities that are susceptible to counterfeiting. Counterfeit chips and semiconductors can be integrated during the final assembly of a product, during the ATP process, or even during repairs over the course of an item's lifecycle[59]. In extreme cases, the R&D and schematics that are created for semiconductor printing can be altered by malicious employees working at outsourced foundries[60]. Across the entire supply chain of electronics, it is estimated that counterfeit semiconductors (and microchips) account for over $100billion in lost revenue. Moreover, the U.S. military estimates that "up to 15 percent of all spare and replacement parts for its weapons, vehicles and other equipment are counterfeit"[61] These figures, in conjunction with the impact to military systems functionality implores us to recognize the urgent need for greater supply chain resiliency, with one main goal being to limit the numerous

---

[58] Joseph M Russell, "Counterfeit Electronic Parts Controls in the Department of Defense Supply Chain". (Naval Postgraduate School, June 2015), 33. https://apps-dticmi l.cfc.idm.oclc.org/sti/pdfs/ADA632499.pdf
[59] Office of the Under Secretary of Defense, *Task Force On Cyber Supply Chain.* (Washington, DC: U.S. Defense Science Board, Feb 2017), 8. https://www.defensedaily.com/wp-content/uploads/post_attachment/160441.pdf
[60] Ibid.
[61] Larry Greenermeier, "The Pentagon's Seek-and-Destroy Mission for Counterfeit Electronics", *Scientific American,* (28 April 2017). https://www.scientificamerican.com/article/the-pentagon-rsquo-s-seek-and-destroy-mission-for-counterfeit-electronics/#

supply chain disruptions due to high product failure rates resulting in the presence of such counterfeit items.

American military supply chains would quantifiably benefit from tighter screening controls which can safeguard against overseas counterfeit semiconductor propagations. Given the counterfeiting costs to industry, American corporations that supply military hardware would benefit not only financially from tighter sub-contractor scrutiny but also in their sense of confidence in the integrity of the materials used. Such preventative mechanisms as screenings and vetting would decrease supply chain disruptions and enable greater supply chain resiliency by increasing product reliability and production visibility. To build a solid structure of independence, the Department of Defense should explore domestic joint venture manufacturing capabilities with commercial industry partners, thus reducing dependencies on foreign resellers all the while minimizing the undesirable elements of equipment acquisition.

The Requirement for a Robust Manufacturing Sector

Over the past 20 years, China has positioned itself as a global manufacturing super-power and a focal point in the supply chain within the global economy. Chinese state reforms in monetary policy combined with cheap labour, massive foreign investment, and their entrance to the WTO in 2001, greatly enable this positioning[62]. To quantify the extent of China's position as a global manufacturer vis-à-vis the United States, we examine trade deficits, investment in value added manufacturing as well as investment in manufacturing R&D. The United States census bureau revealed that the

---

[62] I. Colotla., *et al, China's Next Leap in Manufacturing.* (Boston: Boston Consulting Group, 2018), 2. https://www.bcg.com/publications/2018/china-next-leap-in-manufacturing

trade imbalance for 2021 equated to $355 Million, that is to say that the United Stated imported approximately three times more goods than it exported to China.[63] As well, "According to U.N. estimates, China displaced the United States as the largest manufacturing nation in 2010. In 2016, China's value added in manufacturing exceeded $3 trillion, compared to $2.2 trillion for the United States."[64] Furthermore, from 2000 to 2010, American manufacturing jobs decreased by 34% for a total of 6.17 million jobs[65]. In many cases, the lack of investment in manufacturing within the United States has led to the erosion of domestic production capabilities and has forced the United States to be reliant on outsourced foreign suppliers.[66] Although manufacturing is merely one function within a GVC, it is an element which also carries significant implications for national security, technological innovation and overall Research and Development (R&D)[67]. As a result, a resilient manufacturing sector in America is one which ultimately "supports economic prosperity, global competitiveness, and arms the military with capabilities to defend the nation."[68] Therefore, the practice of offshoring production leaves America in a rather precarious position.

---

[63] United States Census Bureau, "Foreign Trade: Trade in Goods with China 2021/2022," Last accessed 3 May 2022, https://www.census.gov/foreign-trade/balance/c5700.html
[64] Congressional Research Services, *U.S. Manufacturing in International Perspective*. (Washington, DC: U.S. Government Printing Office, Feb 2018), 2. https://crsreports.congress.gov/product/pdf/R/R42135
[65] Stephen Ezell, and R. Atkinson, *The Case for a National Manufacturing Strategy*. (Washington, DC: Information Technology and Innovation Foundation, 2011), 4. https://itif.org/files/2011-national-manufacturing-strategy.pdf
[66] Office of the Under Secretary of Defense for Acquisition and Sustainment, *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United* States, (Washington, DC: U.S. Government Printing Office, 2018), 25. https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND%20DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF
[67] Ibid., 14.
[68] Ibid., 1.

Technological innovation is the foundation for long-term economic growth. This is because the economies which create new technologies tend to profit most from their innovations[69]. Moreover, history has repeatedly demonstrated that "Technology, more than any other outside force, shapes warfare"[70]. In essence, the relationship which fosters technological innovation and R&D within GVC is heavily reliant on a strong manufacturing sector. Increasingly, R&D sectors within the manufacturing GVCs are co-locating their innovation within the same countries that are producing their manufactured goods. Consequently, as the outsourcing of manufacturing becomes more typical, so has the off shoring of R&D been relocated[71]. "The issue of co-location of R&D and manufacturing is especially important because it means the value-added from both R&D and manufacturing will accrue to the innovating economy."[72] In 2011, the information and technology innovation foundation found that 90% of electronics R&D was occurring in Asia[73]. As well, in 2015, China's manufacturing R&D sector out spent the United

---

[69] Timothy R Heath. and William R. Thompson, "Avoiding U.S.-China Competition is Futile: Why the Best Option is to Manage Strategic Rivalry," *Asia Policy* 13, no. 2 (04, 2018): 105, https://www.proquest.com/scholarly-journals/avoiding-u-s-china-competition-is-futile-why-best/docview/2036387306/se-2?accountid=9867

[70] Alex Roland, *War and Technology*, (Philadelphia: Foreign Policy Research Institute, 2009), 2. https://www.fpri.org/article/2009/02/war-and-technology/

[71] Office of the Under Secretary of Defense for Acquisition and Sustainment, *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United* States, (Washington, DC: U.S. Government Printing Office, 2018), 30. https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND%20DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF

[72] Stephen Ezell, and R. Atkinson, *The Case for a National Manufacturing Strategy*. (Washington, DC: Information Technology and Innovation Foundation, 2011), 14. https://itif.org/files/2011-national-manufacturing-strategy.pdf

[73] Ibid., 2.

States manufacturing sector on R&D by $42 billion for a total of $278 billion[74], marking this as a historical first.

As multinational corporations relocate manufacturing and R&D outside of the United States, the highly skilled individuals that lead innovation are following. A report from the U.S. China Economic Security review established that many United States multinational corporations prefer to conduct R&D in China due to the co-location of consolidated supply chain ecosystems[75]. Thus, mining, manufacturing, R&D and talent within Science, Technology, Engineering, Math (STEM) are becoming geographically localized. This is problematic for America because top researchers and STEM disciplined talents are being drawn away from the United States. Although cheap labour, market access and an extensive manufacturing sector have positioned China as a central manufacturing hub, it is the shifting of R&D and talent within the GVC outside of America which is the real cause for concern.

America must carefully consider its manufacturing sector and understand the broader implications of technological innovation; failing to do so will prevent the retention of economic technological competitive advantage and prosperity. Moreover, continued positioning of manufacturing, R&D and GVCs within the geographical boundaries of China only ensures their competitive advantage against American strategic interests. By 2049, China seeks to position itself as lead innovator and manufacturer in

---

[74] Congressional Research Services, *U.S. Manufacturing in International Perspective*. (Washington, DC: U.S. Government Printing Office, Feb 2018), 14. https://crsreports.congress.gov/product/pdf/R/R42135
[75] U.S.-China Economic Security Review Commission. *Trends in U.S. Multinational Enterprise Activity in China, 2000-2017*. (Washington, DC: U.S. Government Printing Office, July 2020), 20. https://www.uscc.gov/sites/default/files/2020-06/US_Multinational_Enterprise_Activity_in_China.pdf

technology and industry[76]. Thus, a resurgence of investment in manufacturing sectors within America, as well as the creation of domestic supply chain eco-systems can offset the outsourcing of manufacturing and technological advances which are occurring increasingly more often in China. This is extremely important when considering the implications for the defense sector which relies on such innovation leads.

Losses in R&D and intellectual innovation will disadvantage America's ability to maintain technological superiority amongst renewed geopolitical tensions and power competition. America must foster a healthy balance between domestic and overseas manufacturing supply chains in order to retain innovation and talent within its borders. The overextension of outsourced overseas manufacturing will only further erode current capacities while potentially propping up nations that wish to challenge America. Currently, America's manufacturing supply chain remains vulnerable to the overextension of overseas outsourcing with considerable negative impacts to domestic technological advances. Thus, America should carefully reflect on reshoring manufacturing sectors that are entrenched with defense, therefore allowing R&D and the prospect of secure GVCs and technological leadership.

Strategic Diversification, Domestic Capability and Resiliency

In conclusion, supply chain resiliency in the 21st century is not a concept which is easily reconciled, nor implemented given the extreme complexity and moving parts involved. Today's highly interconnected and trade-dependant economies are driven by capitalistic efficiencies which generally run counter to the notion of resiliency,

---

[76] Congressional Research Services, *"Made in China 2025" Industrial Policies: Issues for Congress*, (Washington, DC: U.S. Government Printing Office, Aug 2020), 1. https://crsreports.congress.gov/product/pdf/IF/IF10964.

eliminating duplication and redundancies. As demonstrated, today's supply chain efficiencies remain fragile and susceptible to a plethora of geographic natural phenomenon, unforeseen disasters, and geopolitical uncertainties or manipulations. Assuredly, a future must be created in which resiliency considerations are factored into GVCs as protective measures. Moreover, America's defense sector and national security will remain fragile in future scenarios should such supply chain resiliency considerations be ignored or overlooked. Supply chain resiliency means dependability to the limit that it is possible in the light of omnipresent uncertainty. Given the unpredictability of renewed power competitions, America must contemplate with great gravitas the vulnerabilities which have been presented in this paper.

This paper examined America's sole source dependency on the Chinese REE mining and production capacities. It identified that this strategy, be it intentional or not, places America and its defense sector in a compromising position when considering China's ability to leverage economic statecraft. Moreover, China's state-run empire on REE leaves this sector exposed to further manipulation by Beijing. As such, America should explore domestic capacities within this sector to alleviate this sole sourced point of failure while protecting its defense industries' access to these critical minerals. Following this, the paper examined the expanse of the interconnected semiconductor GVC. It was demonstrated that the large, regionalized specialization required in complex interconnected GVCs are highly susceptible to global shocks. These large GVCs rely heavily on trade, cooperation, and multiple transitory nodes, whereby each manufacturer is dependant on another entity. As a result, these supply chains have significant ripple effects that are not well insulated against disruptive events. Moreover, overspecialization in the semiconductor GVC creates multiple points of failure while also contributing to poor regulatory practices and a lack of transparency. In essence, this overspecialization and lack of transparency places the American defense sector at the mercy of subcontractors and resellers who can easily disrupt supply chains with counterfeit products. To counter this, American should look to subsidize joint ventures within its borders and secure some domestic production capability.

Lastly, the paper examined the importance of a robust manufacturing sector as a strategy to diversify production and reduce dependencies on China's power-house manufacturing sector. This section also addressed the secondary impacts on innovation as manufacturing relocates overseas. It pointed to the erosion of domestic production and innovation as a prerequisite to technological leadership, an integral component of the defense sector. For America and its defense sector, the government must continue to improve their understanding and application of resilient supply chains. Without government legislation or a more collaborative approach between government and industry, America will continue to fall into supply chain dependencies which will compromise its national interests and security. There is a fine balance between the free-market and the inherent supply chain vulnerabilities it creates.

BIBLIOGRAPHY

Alicke, Knut and Vera Trautwein. "How COVID-19 is Reshaping Supply Chains." *McKinsey Insights* (Nov 23, 2021): 1-4. https://www.proquest.com/magazines/how-covid-19-is-reshaping-supply-chains/docview/2638055490/se-2?accountid=9867.

"Boat Collision sparks Japan-China Diplomatic row". *British Broadcasting Corporation*. 8 September 2010. https://www.bbc.com/news/world-asia-pacific-11225522

Colotla, I., Y. Zhou, V. Du, J. Wong, J. Walters, J. Rose, and L. Maecke. *China's Next Leap in Manufacturing.* Boston: Boston Consulting Group, 2018. https://www.bcg.com/publications/2018/china-next-leap-in-manufacturing

Ezell, Stephen, and R. Atkinson. *The Case for a National Manufacturing Strategy*. Washington, DC: Information Technology and Innovation Foundation, 2011. https://itif.org/files/2011-national-manufacturing-strategy.pdf

Gereffi, Gary and Karina Fernandez-Stark. *Global Value Chain Analysis: A Primer.* 2nd Ed. Durham: Duke University Global Value Chains Center, 2016. https://www.researchgate.net/profile/Gary-Gereffi/publication/305719326_Global_Value_Chain_Analysis_A_Primer_2nd_Edition/links/579b6f0708ae80bf6ea3408f/Global-Value-Chain-Analysis-A-Primer-2nd-Edition.pdf?origin=publication_detail

Greenermeier, Larry. "The Pentagon's Seek-and-Destroy Mission for Counterfeit Electronics". *Scientific American,* (28 April 2017) https://www.scientificamerican.com/article/the-pentagon-rsquo-s-seek-and-destroy-mission-for-counterfeit-electronics/#

Guin, Ujjwal, Ke Huang, Daniel DiMase, John M. Carulli, Mohammad Tehranipoor, and Yiorgos Makris. "Counterfeit Integrated Circuits: A Rising Threat in the Global Semiconductor Supply Chain." *Proceedings of the IEEE* 102, no. 8 (2014): 1207-1228. https://ieeexplore-ieee-org.cfc.idm.oclc.org/stamp/stamp.jsp?tp=&arnumber=6856206

Heath, Timothy R. and William R. Thompson. "Avoiding U.S.-China Competition is Futile: Why the Best Option is to Manage Strategic Rivalry." *Asia Policy* 13, no. 2 (04, 2018): 91-119. https://www.proquest.com/scholarly-journals/avoiding-u-s-china-competition-is-futile-why-best/docview/2036387306/se-2?accountid=9867

Helper, Susan and Evan Soltas. "Why the pandemic has disrupted Supply Chains." *The White House, Council of Economic Advisers (blog)*, 17 June 2021, https://www.whitehouse.gov/cea/written-materials/2021/06/17/why-the-pandemic-has-disrupted-supply-chains/

Herod, Andrew. "What does the 2011 Japanese Tsunami Tell Us about the Nature of the Global Economy?" *Social & Cultural Geography* 12, no. 8 (2011): 829-837 https://www-tandfonline-com.cfc.idm.oclc.org/doi/pdf/10.1080/14649365.2011.629301?needAccess=true

Kalantzakos, Sophia. *China and the Geopolitics of Rare Earths*. New York: Oxford University Press, 2018. Oxford Scholarship Online, 2017. https://oxford-universitypressscholarship-om.cfc.idm.oclc.org/view/10.1093/oso/9780190670931.001.0001/oso-9780190670931-chapter-1

Köhler, Horst. Speech. “Working for a Better Globalization”. Managing Director, International Monetary Fund, Washington, DC, 28 January 2002. https://www.imf.org/external/np/exr/ib/2002/031502.htm

Leslie, Mitch. "Pandemic Scrambles the Semiconductor Supply Chain." *Engineering (Beijing, China)* 9, (2022;2021;): 10-12. https://www.sciencedirect.com/science/article/pii/S2095809921005804

Lund, Susan., James Manyika, Jonathan Woetzel, Ed Barriball, Mekala Krishnan, Knut Alicke, Michael Birshan, Katy George, Sven Smit, Daniel Swan, Kyle Hutzler, “Risk, Resilience, and Rebalancing in Global Value Chains” *McKinsey Global Institute*. Aug 2020. https://www.mckinsey.com/~/media/mckinsey/business%20functions/operations/our%20insights/risk%20resilience%20and%20rebalancing%20in%20global%20value%20chains/risk-resilience-and-rebalancing-in-global-value-chains-full-report-vh.pdf?shouldIndex=false

Marston, Peter. "How to Combat Counterfeit Semiconductors." *Ecn* (May 20, 2015). https://www.proquest.com/trade-journals/how-combat-counterfeit-semiconductors/docview/1688643004/se-2?accountid=9867

McCann, Philip. "Globalization and Economic Geography: The World is Curved, Not Flat." *Cambridge Journal of Regions, Economy and Society* 1, no. 3 (2008): 351-370. https://web-p-ebscohost-com.cfc.idm.oclc.org/ehost/pdfviewer/pdfviewer?vid=0&sid=86e0df91-2a3b-4234-9829-6ca6b37dc405%40redis

Pletcher, K. and Rafferty, John P. "Japan earthquake and tsunami of 2011." *Encyclopedia Britannica*, Last Accessed 3 May 2022. https://www.britannica.com/event/Japan-earthquake-and-tsunami-of-2011/Aftermath-of-the-disaster

Roland, Alex. *War and Technology*. Philadelphia: Foreign Policy Research Institute, 2009. https://www.fpri.org/article/2009/02/war-and-technology/

Russell, Joseph M. “Counterfeit Electronic Parts Controls in the Department of Defense Supply Chain”. Joint Applied Project, Naval Postgraduate School, June 2015. https://apps-dtic-mil.cfc.idm.oclc.org/sti/pdfs/ADA632499.pdf

Russon, Mary-Ann. “The Cost of the Suez Canal Blockage.” *British Broadcasting Corporation*. 29 March 2021. https://www.bbc.com/news/business-56559073

Scherer, F. M. "The Dynamics of Capitalism." *The Oxford Handbook of Capitalism*: Oxford University Press, 2012. https://www.hks.harvard.edu/sites/default/files/centers/mrcbg/files/mrcbg_fwp_2010-01_Scherer_dynamics.pdf

Scheyder, Ernest. “Exclusive U.S. Bill Would Block Defense Contractors From Using Chinese Rare Earths.” *Thomas Reuteurs*. 12 January 2022. https://www.reuters.com/business/energy/exclusive-us-bill-would-block-defense-contractors-using-chinese-rare-earths-2022-01-14/

Schwartz, Matthew. “Suez Canal Traffic Backlog Finally Cleared Following The Ever Given Saga National Public Radio.” *National Public Radio*, 3 April 2021. https://www.npr.org/2021/04/03/984111501/suez-canal-traffic-backlog-finally-cleared-following-the-ever-given-saga

Simmons, Lee. “Rare-Earth Market”. *Foreign Policy*. 12 July 2016. https://foreignpolicy.com/2016/07/12/decoder-rare-earth-market-tech-defense-clean-energy-china-trade/

Smorodinskaya, Nataliya V., Daniel D. Katukov, and Viacheslav E. Malygin. "Global Value Chains in the Age of Uncertainty: Advantages, Vulnerabilities, and Ways for Enhancing Resilience." *Baltic Region* 13, no. 3 (2021): 78-107. https://journals.kantiana.ru/upload/iblock/062/5_78-107.pdf

“Taiwan's Worst Drought in Decades Deepens Chip Shortage Jitters” Agence France-Press, 20 April 2021. https://www.industryweek.com/supply-chain/article/21161812/taiwans-worst-drought-in-decades-deepens-chip-shortage-jitters

United States Census Bureau. “Foreign Trade: Trade in Goods with China 2021/2022.” Last accessed 3 May 2022. https://www.census.gov/foreign-trade/balance/c5700.html

United States. Congressional Research Service. *An Overview of Rare Earth Elements and Related Issues for Congress.* Washington, DC: U.S. Government Printing Office, 24 November 2020. https://crsreports.congress.gov/product/pdf/R/R46618

United States. Congressional Research Service. *China's Mineral Industry and U.S. Access to Strategic and Critical Minerals: Issues for Congress*. Washington, DC: U.S. Government Printing Office, March 2015. https://crsreports.congress.gov/product/pdf/R/R43864

United States. Congressional Research Services. *"Made in China 2025" Industrial Policies: Issues for Congress*. Washington, DC: U.S. Government Printing Office, Aug 2020. https://crsreports.congress.gov/product/pdf/IF/IF10964

United States. Congressional Research Service. *Rare Earth Elements: The Global Supply Chain.* Washington, DC: U.S. Government Printing Office, Dec 2013. https://crsreports.congress.gov/product/pdf/R/R41347

United States. Congressional Research Service. *Semiconductors: U.S. Industry, Global Competition, and Federal Policy*. Washington, DC: U.S. Government Printing Office, 26 October 2020. https://crsreports.congress.gov/product/pdf/R/R46581

United States. Congressional Research Services. *U.S. Manufacturing in International Perspective*. Washington, DC: U.S. Government Printing Office, Feb 2018. https://crsreports.congress.gov/product/pdf/R/R42135

United States. Congressional Research Service. *Trade Dispute with China and Rare Earth Elements.* Washington, DC: U.S. Government Printing Office, June 2019. https://sgp.fas.org/crs/row/IF11259.pdf

United States. Office of the Under Secretary of Defense. *Task Force on Cyber Supply Chain.* Washington, DC: U.S. Defense Science Board, Feb 2017. https://www.defensedaily.com/wp-content/uploads/post_attachment/160441.pdf

United States. Office of the Under Secretary of Defense for Acquisition and Sustainment. *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States.* Washington, DC: U.S. Government Printing Office, 2018. https://media.defense.gov/2018/Oct/05/2002048904/-1/-1/1/ASSESSING-AND-STRENGTHENING-THE-MANUFACTURING-AND%20DEFENSE-INDUSTRIAL-BASE-AND-SUPPLY-CHAIN-RESILIENCY.PDF

United States. The White House. *Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth.* Washington, DC: Government Printing Office, June 2021. https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

United States. U.S.-China Economic Security Review Commission. *Trends in U.S. Multinational Enterprise Activity in China, 2000-2017*. Washington, DC: U.S. Government Printing Office, July 2020.

https://www.uscc.gov/sites/default/files/2020-06/US_Multinational_Enterprise_Activity_in_China.pdf

United States. U.S. Senate Committee on Armed Services. Inquiry into counterfeit electronic parts in the Department of Defense supply chain (Report 122-167). Washington, DC: United States Senate. http://www.armed-services.senate.gov/imo/media/doc/Counterfeit-Electronic-Parts.pdf

Varas, Antonio, Raj Varadarajan, Ramiro Palma, Jimmy Goodrich, and Falan Yinug. *Strengthening the Global Semiconductor Supply Chain in an Uncertain Era*. Boston, MA: Boston Consulting Group Boston, 2021. https://www.semiconductors.org/wp-content/uploads/2021/05/BCG-x-SIA-Strengthening-the-Global-Semiconductor-Value-Chain-April-2021_1.pdf

Yuzhou, Shen, Moomy Ruthann, and Roderick G. Eggert. "China's Public Policies Toward Rare Earths, 1975–2018." *Mineral Economics* 33, no. 1-2 (07, 2020): 127-151. https://www.proquest.com/scholarly-journals/china-s-public-policies-toward-rare-earths-1975/docview/2425988103/se-2.

Zhang, Pengfei. "Japan Earthquake-when the Big One Hit [Associate Editor's View]." *IEEE Solid State Circuits Magazine* 3, no. 2 (2011): 5-6. https://ieeexplore-ieee-org.cfc.idm.oclc.org/document/6051583