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GREEN TECHNOLOGY, NATIONAL SECURITY, AND RAW MATERIALS: ECONOMIC SECURITY AND CRITICAL RARE EARTH METALS

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Introduction

In his 2022 State of the Union address, President Biden outlined what looked like an industrial policy approach to economic policy. He announced huge investments in semiconductor manufacturing, urged Congress to increase spending in research and development, and explained that the approach is necessary to increase international American competitiveness, particularly with China. When he said that the state would "use taxpayers' dollars to rebuild America… [and] do it by buying American" he was greeted with a bipartisan chant of "USA, USA."[1] This was but the latest sign of a swing in the United States towards overt government interventionism.

Deeper intervention in the market is not solely a United States phenomenon. In recent years other large economies, such as Japan, South Korea, and the European Union have also turned towards more direct intervention in their economies. And in China, where market intervention is not unusual, sectors that were more liberalized and market-oriented have been brought under more state control.

Many of these changes have taken place using the language of security. Japan, for example, recently passed a large "economic security" bill, which firmly frames state intervention using securitized language. Despite this framing, not all of the supply chain elements deemed 'critical' in Japan or the United States are related to military readiness or even non-traditional security concerns like public health or the food supply. Also central are technological competition and supremacy in the context of rivalry with China, as well as more traditional economic concerns about a failure to compete internationally.

This paper compares the Japanese and United States approach to supply chain security, interrogating one specific case of potential vulnerability. While the broader focus of my research

[1] Joseph Biden, '2022 State of the Union Address', *The White House*, 2022 <https://www.whitehouse.gov/state-of-the-union-2022/> [accessed 9 March 2022].

asks why some sectors are more securitized than others, this paper dives deeply into one key supply chain—rare earth elements and permanent magnets—that has downstream uses across many technologies. I analyze vulnerability and potential interventionism along this supply chain to interrogate broader issues of securitization and resilience in the global economy. The globalized production processes means that economic intervention policies could potentially target any point along a supply chain, not only mining or manufacturing, but also research and development, logistics and infrastructure, or even the end purchase of a product. Uncovering which parts of the supply chain states choose to target with public policy, and whether those match with supply chain vulnerabilities, helps us evaluate the efficacy of policies as well as make recommendations for the future.

The rare earth element supply chain, and the downstream permanent magnets, are a good supply chain for an initial case study to examine broader trends at this intersection of industrial policy and national security. Rare earth elements,[2] in particular, have been overtly securitized around the world since China allegedly used implemented an export ban to Japan in the midst of a 2010 territorial dispute.[3] Despite the securitization around the world, there is still remarkable variation across national responses, as well as which the focus of government policy within the supply chain. Moreover, there has not been a fundamental shift in the regional dynamics of the rare earth or permanent magnet supply chain except to further concentrate the market in China. Despite years of policy discussion in the United States, and some policy action in Japan, these

[2] For accessible background on rare earth elements see P. Henderson and others, 'Rare Earth Elements. A Briefing Note by the Geological Society of London', in *Geological Society of London*, 2011, pp. 1–13.

[3] Linus Hagström, ''Power Shift'in East Asia? A Critical Reappraisal of Narratives on the Diaoyu/Senkaku Islands Incident in 2010', *The Chinese Journal of International Politics*, 5.3 (2012), 267–97; Julie Michelle Klinger, *Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes* (Cornell University Press, 2018).

materials and technologies are again the focus of new supply chain resiliency efforts[4] and industrial policy.[5]

The paper proceeds as follows. After a discussion of securitization and industrial policy, I define how to conceptualize and measure potential points of supply chain vulnerability. I then address the policies implemented by the United States, Japan, and China to address vulnerabilities, particularly through the lens of economic security. I then do a close examination of the rare earth and permanent magnet industry to analyze how the securitization of industry aligns with actual points of supply chain vulnerability. I conclude with an assessment possible policy responses for supply chain security and policy recommendations.

Security, Criticality, and Raw Materials

Under conditions of economic securitization, some industries are become the targets of industrial policy and securitized speech and others do not. At the same time, some industries are more vulnerable to supply chain chokepoints or even the mechanics of weaponized interdependence.[6] There are (at least) two motivations for states to pursue intervention in supply chains beyond pure rent-seeking.[7] The first is to build capacity in a product or sector for national prosperity and economic growth. Historical examples include export-oriented industrial policy in the East Asian developmental state model or import substitution industrialization.[8] While a sense

[4] White House, 'Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth', *White House 100 Day Supply Chain Review Report*, 2021 <https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf> [accessed 15 September 2021].
[5] Mireya Solis, 'The Big Squeeze: Japanese Supply Chains and Great Power Competition', *Joint U.S.-Korea Academic Studies*, 2021.
[6] Henry Farrell and Abraham L. Newman, 'Weaponized Interdependence: How Global Economic Networks Shape State Coercion', *International Security*, 44.1 (2019), 42–79.
[7] Interventionism also has a rich history of corruption and rent-seeking. Looking at how private companies mobilize for protection under the umbrella of 'economic security' is a place for further research.
[8] Chalmers Johnson, *MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925-1975* (Stanford University Press, 1982); Alice Amsden, *Asia's Next Giant: South Korea and Late Industrialization* (Columbia

of national security threat may be necessary (though not sufficient) for the success of a developmental state the goal is national competitiveness and prosperity.[9]

The second motivation is to build capacity in products or sectors that are vital to national security. This approach is one many states have taken with agriculture, steel, or the production of military equipment. In the Cold War, the United States and allies introduced multilateral export control regimes to protect critical technology and prevent the proliferation of weapons of mass destruction.[10] The descendants of these regimes (for example the Wassenaar Agreement and COCAM) still exist today. Japan, for example, used the Wassenaar protocols to potentially restrict sales of semiconductor materials to South Korea in a recent trade dispute.[11]

These two goals—national wealth and national security—are not mutually exclusive. It can be difficult, however, to differentiate between materials or technologies that have serious dual military/civilian use and need to be supported or restricted to protect national security and those that are primarily intended for industrial policy. New economic security policies exist in this limbo, perhaps nowhere more than at the upstream stages of the supply chain before extreme product or technological differentiation. Raw materials and their manufacture into chemicals, batteries, magnets, or chips are needed for most modern technologies, and could all potentially by 'securitized'.

University Press, 1989); Gregory Noble, *Collective Action in East Asia: How Ruling Parties Shape Industrial Policy* (Cornell University Press, 1998); Douglas A. Irwin, 'The Rise and Fall of Import Substitution', *World Development*, 139 (2021), 105306.

[9] Richard Stubbs, 'What Ever Happened to the East Asian Developmental State? The Unfolding Debate', *The Pacific Review*, 22.1 (2009), 1–22; Tianbiao Zhu, 'Developmental States and Threat Perceptions in Northeast Asia', *Conflict, Security & Development*, 2.01 (2002), 5–29.

[10] Jamil Jaffer, 'Strengthening the Wassenaar Export Control Regime', *Chi. J. Int'l L.*, 3 (2002), 519; Ron Smith and Bernard Udis, 'New Challenges to Arms Export Control: Whither Wassenaar?', *The Nonproliferation Review*, 8.2 (2001), 81–92.

[11] Kristin Vekasi, 'Trade Wars at the Intersection of Memory and Industrial Policy in Japan and South Korea', in *Research Handbook on Trade Wars* (Edward Elgar, 2022), pp. 381–97.

Minerals, in particular, lie at a complicated intersection of national security and economic prosperity concerns, as well as being fundamental for green technology. For a transition to net zero, it will be necessary to have a much more abundant supply of minerals to make electric vehicles, solar cells, wind turbine motors, and energy storage technologies. These materials are also crucial for most of the technologies that make contemporary life possible such as computers or cell phones and advanced medical equipment. In addition to these daily uses and near-future uses they are crucial for numerous defense applications.[12]

Conceptualizing and Measuring Supply Chain Chokepoints

Raw material chokepoints can arise from geography, technological expertise in materials processing, or economic, political, or social barriers to resource exploitation. While a chokepoint can arise from all of these barriers simultaneously, as I will show geography is often the least constraining factor indicating that questions of chokepoints and material constraints are largely macroeconomic or policy-driven. Downstream applications are subject to a similar logic, without the element of geography.

This paper measures chokepoints in rare earth elements and permanent magnets in multiple ways: geography, production, firms, trade, and technological expertise. I then assess the policy implications for economic security in Japan and the United States. The degree of vulnerability from a potential chokepoint depends on where it arises, and whether it is compounded by chokepoints from multiple sources. For example, an existing trade chokepoint does not make a country particularly vulnerable if global production is already diversified. A

[12] Valerie B. Grasso, 'Rare Earth Elements in National Defense: Background, Oversight Issues, and Options for Congress', *Congressional Research Service*, 2013 <https://sgp.fas.org/crs/natsec/R41744.pdf>; White House, 'Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth'.

production chokepoint makes a country less vulnerable if the industry is diversified at the firm level. A technological chokepoint, compounded by a lack of diversification at other levels, indicates an inability for a country to pivot quickly to domestic production or alternative suppliers. The different possible chokepoints are described below, and then summarized in Figure 1.

Geographic chokepoint

A geographic chokepoint is when a resource is only available in very limited and constrained geographic areas. True geographic chokepoints are very rare, but they may be created by technology, infrastructure, or transportation. For example, mineral deposits could exist in geographically diverse areas but the world lacks either technology to exploit the resource or it is inaccessible. A true geographic chokepoint would be very difficult to overcome with industrial policy. It may be possible to diversify political risk by nurturing alliances, securing trade or investment deals, and by encouraging foreign direct investment where the resources are located. In the 19th century the great powers overcame raw material chokepoints through military expansion and colonialism.

Production chokepoint

A production chokepoint exists when a high concentration of production occurs in one country or geographic area. Production chokepoints can come into existence because of a strong comparative advantage of domestic firms or because economic factors such as labor costs attract foreign firms to a market creating geographic concentration. Concentration of overall production in a specific location does not necessarily mean a monopolistic environment, particularly if the market is diversified at the firm level. Geographic concentration of production is far more common than geographic concentration, and can be caused by the aforementioned issues of transportation or infrastructure issues.

Firm concentration

A firm-level production chokepoint exists when a single company holds a large share of global production, more so when that firm's production is also geographically concentrated. When both firm and production are highly concentrated the possibility for economic coercion or supply chain issues for more benign reasons are much higher. The intersection of high levels of production and firm concentration is also higher than geographic concentration, particularly in industries that require high levels of technical expertise and an accumulation of intellectual property. For example, Japan's METI has identified numerous industries with substantial global markets where Japan holds over 60 percent of global market share.[13] Japan has focused on nurturing these industries in its "aggregate niche" strategy, and some of them are also dominated by just a small number of elite firms.[14]

Trade concentration

A trade chokepoint exists when a one country relies heavily on a single country or region for imports of a specific product. This measure says little about production or firm concentration although they can be correlated. Trade can present particular vulnerabilities as trade barriers such

[13] Ministry of Economy, Trade, and Industry, '世界の中での我が国製造業の立ち位置と各国の取組', in *2019 年版ものづくり白書* (Tokyo, Japan: Japanese Ministry of Economy Trade and Industry, 2019), pp. 22–48 <https://www.meti.go.jp/press/2019/06/20190611002/20190611002_07.pdf> [accessed 21 March 2022].
[14] Ulrike Schaede, *The Business Reinvention of Japan: How to Make Sense of the New Japan and Why It Matters* (Stanford University Press, 2020).

as formal sanctions, export controls or quotas are more easily planned and implemented by the state compared to control over production and company-level activity. This dynamic is particularly true for largely private-sector economies.

Technological expertise

Technological expertise is the know-how to make a product or complete a manufacturing process. Sometimes greater technological expertise in an area means that a single firm or country will hold a monopoly on the process, at least until others catch up, and sometimes it just means that they can do the process more efficiently, cleanly, or at a higher level of precision than anyone else. Unlike the previous four measures, which can be measured more directly, technology is measured with the country of origin of patent holders. Other possibilities include scientific publications, number of PhD students in a field, or spending on research and development across the public and private sector in specific fields. Patent applications have more cross-border comparability and similar data availability. Further studies should explore other measurement strategies.

A technology-driven chokepoint is one that is easily securitized, particularly if there are direct defense or dual-use applications. Some elements of the economic security legislation in Japan have focused on defending technology chokepoints, as have executive actions in the United States such as those taken against Chinese companies Huawei and ZTE. More than these uses of economic coercion (whether offensive or defensive), however, technology chokepoints are difficult, expensive, and time-consuming to overcome. They also require the planning and implementation of policies that may not fruition for years or decades introducing time inconsistency problems for political elites who are not insulated from public backlash against costly government programs. They are also more difficult for political elites to explain to the public compared to the other types of potential chokepoints, particularly as the same elites may not understand the technologies themselves.

Table 1 includes a summary of each of these five potential chokepoints, a brief definition, the data source for measurement, and a brief summary of the measurement strategy. A model based solely on stated goals of risk mitigation would predict that as risk increases across any or all of these measures, countries will be more likely to securitize a point in the supply chain as the potential points of vulnerability are higher. However, that model presumes transparency of information and a conceptual grasp of raw material supply chains that may not be held by policymakers and political elites.

Comparative Approaches to Economic Security

Covid-19 disruptions laid bare the vulnerability of globalized and fragmented supply chains, but the vulnerabilities in most cases predated the pandemic.[15] As with many crises, the pandemic provided the political impetus for new or bolder policy initiatives, even as many of them had been introduced prior to the pandemic. Concurrent with these market challenges, the increasingly heated geopolitical climate between the United States and China is turning up the pressure on multinational companies around the world to find strategies to diversify—or even decouple—from the rival economy. Production and industry is no longer considered simply the purview of the market, even in liberal capitalist democracies.

[15] Geoffrey Gertz, 'The Coronavirus Will Reveal Hidden Vulnerabilities in Complex Global Supply Chains', *Brookings*, 2020 <https://www.brookings.edu/blog/future-development/2020/03/05/the-coronavirus-will-reveal-hidden-vulnerabilities-in-complex-global-supply-chains/> [accessed 15 September 2021]; Tom Linton and Bindiya Vakil, 'Coronavirus Is Proving We Need More Resilient Supply Chains', *Harvard Business Review*, 5 March 2020 <https://hbr.org/2020/03/coronavirus-is-proving-that-we-need-more-resilient-supply-chains> [accessed 15 September 2021].

United States

In an apparent turn from laissez-faire the United States Department of Commerce, for example, states in their strategic plan that "economic security is national security. America is safer when important technology and essential products are produced domestically."[16] There is growing discomfort in the United States with reliance on overseas manufacturing, particularly although not limited to China. U.S. policy was evident in the Obama era "pivot" or "rebalance" to Asia,[17] the trade war with China that began in the Trump era,[18] and now the Biden era supply chain security approach.[19] Biden's approach, which builds on the policies of previous administrations, seeks to secure domestic production for elements of supply chains deemed 'critical' and also to pursue economic competitiveness through cooperation with allies. Much of the policy debate in Washington D.C. has been over the degree of government intervention, and how to approach "reshoring" (bringing production to the United States) versus "allyshoring" (encouraging U.S. companies to shift production to allied or friendly countries).

In the United States many minerals (including rare earths) have been given this status, deemed "critical" along with other industries that are central in national security.[20] The United

[16] United States Department of Commerce, 'Strengthen U.S. Economic and National Security', *U.S. Department of Commerce*, 2018 <https://www.commerce.gov/about/strategic-plan/strengthen-us-economic-and-national-security> [accessed 15 March 2022].

[17] H. Mejier and Hugo Meijer, *Origins and Evolution of the US Rebalance toward Asia: Diplomatic, Military, and Economic Dimensions* (Springer, 2015).

[18] Chad P. Bown, 'The US–China Trade War and Phase One Agreement', *Journal of Policy Modeling*, 43.4 (2021), 805–43; Samantha Vortherms and Jiakun Jack Zhang, 'Political Risk and Firm Exit: Evidence from the US-China Trade War', *Available at SSRN 3916186*, 2021; Ka Zeng, '"Exit" vs."Voice": Global Sourcing, Multinational Production, and the China Trade Lobby', *Business and Politics*, 23.2 (2021), 282–308.

[19] White House, 'The Biden-Harris Plan to Revitalize American Manufacturing and Secure Critical Supply Chains in 2022', *The White House*, 2022 <https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/24/the-biden-harris-plan-to-revitalize-american-manufacturing-and-secure-critical-supply-chains-in-2022/> [accessed 15 March 2022].

[20] US Department of Defense, 'Strategic and Critical Materials 2013 Report on Stockpile Requirements', *Office of the Under Secretary of Defense, US Department of Defense (189 Pp.)*, 2013; Department of Defense, 'Securing Defense-Critical Supply Chains', 2022, 78.

States policy research and reports has been largely conducted by the Department of Defense, even as the bulk of demand for minerals is driven by non-military functions. For example, although permanent magnets are used in Tomahawk cruise missiles and Predator drones, the permanent magnet market is largely taken first by automobile motors, and then wind turbines and consumer electronics. In the Biden Administration supply chain security initiative, the Department of Defense took lead on critical minerals, although the Department of Energy has also played a key role in funding some research efforts and new industrial initiatives.[21]

Japan

In Japan, the official language has been less overtly securitized compared to the United States, although it is still clearly related to international competition and rivalry.[22] In recent years, "economic security" (経済安全保障 or 経済安保) has become a buzzword in Japan, capped by the introduction and passage of the Economic Security Legislation in 2022.[23] The Prime Minister's office also created a new cabinet-level economic security position following the October 2021 lower house election. Kishida appointed Kobayashi Takayuki, a former vice-minister for defense, the first Economic Security Minister. The goal of Kobayashi's new position is to help promote 'critical industries' such as semiconductors with in cooperation with Taiwan, minerals, and personal protective gear.[24]

[21] Department of Energy, 'DOE Launches $140 Million Program to Develop America's First-of-a-Kind Critical Minerals Refinery', *Energy.Gov*, 2022 <https://www.energy.gov/articles/doe-launches-140-million-program-develop-americas-first-kind-critical-minerals-refinery> [accessed 24 May 2022].
[22] Akira Igata and Brad Glosserman, 'Japan's New Economic Statecraft', *The Washington Quarterly*, 44.3 (2021), 25–42 <https://doi.org/10.1080/0163660X.2021.1970334>.
[23] Igata and Glosserman.
[24] Tomoyuki Tachikawa, 'Japan's Pick for New Economic Security Post Raises Eyebrows in China | The Japan Times', 2021 <https://www.japantimes.co.jp/news/2021/10/25/business/economy-business/china-japan-economic-security/> [accessed 21 December 2021].

The economic security bill has four pillars: secret patents, supply chain security, private-public partnerships in research & development, and enhancing the security of core infrastructure.

Patent secrecy applies largely to potential nuclear or weapons technology. Investment screening mechanisms that resemble the U.S. CFIUS system was initially a goal of the legislation, although this provision did not make it into the proposed legislation. Instead, Japan has introduced new procedures to protect patents in sensitive technology by keeping them secret and then financially compensating the companies that hold the patent for their losses and penalizing them if they fail to comply. The goal of the secret patents is to keep sensitive and crucial technologies from rivals, particularly China. However, there are clear costs for private sector firms that cannot publish their intellectual property.[25]

Core infrastructure is largely concerned with cyber security issues. These concerns are reflected in how the Public Security Intelligence Agency (PSIA, located in the Ministry of Justice) has approached the economic security. The Ministry of Justice compiled a list of key events in for "economic security" which provide key insight into what the state views as security matters, and potentially what it does not. Unlike other policy documents that do not directly identify China, the PSIA clearly frames it in the context of US-China technology competition.[26] Approximately a 26 percent of economic security events are related to cyber-security, and 13 percent for supply chain security.

Two of the pillars are particularly relevant for the raw mineral discussion: supply chain security and private-public partnerships. As a resource-poor country, Japan has also long had state-led approaches to acquiring the raw materials needed for Japanese industry. Although it is

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[25] Keidanren, '経団連：経済安全保障推進法案の早期成立を求める (2022-03-14)', *一般社団法人 日本経済団体連合会 / Keidanren*, 2022 <https://www.keidanren.or.jp/policy/2022/025.html> [accessed 6 May 2022].
[26] Public Security Intelligence Agency, '経済安全保障特集ページ | 公安調査庁', 2021 <https://www.moj.go.jp/psia/keizaianpo.top.html> [accessed 24 March 2022].

not yet clear which industries will be deemed ‘critical’, past industries that have received state support for supply chain resilience likely provide a guide. As I describe in more detail below, past industrial policy has focused on minerals including rare earths, pharmaceuticals, and personal protective equipment. The legislation could also clear a path for more international collaboration on sensitive research in emerging technologies with the United States.

China

Economic security in China is related to China’s comprehensive domestic political economy approach, particularly its dual circulation strategy (国内国际双循环). At the name implies, dual circulation calls for simultaneously expanding international and domestic economic circulation. Internationally that means continuing to increase exports and domestically to increase demand and production for domestic consumption. “Dual circulation is a strategy to fortify China’s economic resilience in the face of global economic undulations…Beijing sees the framework as a way to guard against economic exposures to the external economy.”[27] Dual circulation is closely related to other broad political economy goals, including Made in China 2025 and Standards in China 2035, both of which emphasize indigenous development of innovation and current and emerging technologies.[28]

[27] Andrew Polk and Jude Blanchette, ‘Dual Circulation and China’s New Hedged Integration Strategy’, 2020 <https://www.csis.org/analysis/dual-circulation-and-chinas-new-hedged-integration-strategy> [accessed 9 February 2022].

[28] Elizabeth Economy, *The Third Revolution: Xi Jinping and the New Chinese State* (Oxford University Press, 2018); Alexander Koty, ‘The China Standards 2035 Plan: Is It a Follow-Up to Made in China 2025 ?’, 2020 <https://www.china-briefing.com/news/what-is-china-standards-2035-plan-how-will-it-impact-emerging-technologies-what-is-link-made-in-china-2025-goals/> [accessed 31 May 2022].

While this strategy was first announced after a Politburo meeting in May 2020,[29] it is reminiscent of past political economy approaches. Michael Pettis points out that a reorientation towards domestic demand was first emphasized by Premier Wen Jiabao in 2007.[30] He argues elsewhere that this task was difficult in 2007, and remained difficult in 2020 because Chinese global competitiveness relies on keeping wages low.[31] Analysts at CSIS pointed out that dual circulation bears similarity to the 2015 supply-side structural reform.[32] More recent trends in Chinese policymaking, particularly after the Sixth Plenum in 2021 potentially address some of these challenges that Pettis and others have indicated in balanced internal markets and external competitiveness. While still not completely defined, the Common Prosperity approach could help balance some of these concerns while also addressing the issue of social and economic inequality.

Heavily export-dependent economies experience volatility with the broader global economy, something that they cannot control. Shifting one's economy to domestic demand means more predictability and stability. According to the World Bank, trade in merchandise as a percent of GDP hit a high in China of 64 percent in 2007, a number in line with export-reliant European countries like Germany, Denmark, or Sweden. These "small states in world markets" compensate for the external volatility with strong safety nets via the social welfare system.[33] In major economies like the United States and to a lesser extent Japan, on the other hand, trade makes up only 15-25 percent of the total economic output. In 2020, China stood at 32 percent,

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[29] People's Daily, '中共中央政治局常务委员会召开会议 中共中央总书记习近平主持会议--新闻报道-中国共产党新闻网', 2020 <http://cpc.people.com.cn/n1/2020/0515/c64094-31709627.html?mc_cid=28966ada58&mc_eid=902fe70bde> [accessed 9 February 2022].
[30] Michael Pettis, 'The Problems with China's "Dual Circulation" Economic Model', *Financial Times*, 25 August 2020 <https://www.ft.com/content/a9572b58-6e01-42c1-9771-2a36063a0036> [accessed 9 February 2022].
[31] Matthew C. Klein and Michael Pettis, *Trade Wars Are Class Wars* (Yale University Press, 2020).
[32] Polk and Blanchette.
[33] Peter Katzenstein, *Small States in World Markets* (Cornell University Press, 1985).

after a steady decline from the 2007 peak. Shifting to an economy oriented towards domestic production *and* consumption is neither unique to China nor all about self-reliance and insulation from geopolitics and trade wars. But the sectors that are promoted and timing of dual circulation are related to foreign policy.

In China, there is a much more explicit connection between the domestic growth and prosperity of the country and its national security. Recognizing the need for more raw materials than are domestically available, China first had the "going out" policy[34] and more recently economic diplomacy efforts have been wrapped into the Belt and Road Initiative.[35] The Chinese government has also put considerable effort into domestic competencies in raw materials processing, which are described in depth below.

Global Rare Earth Supply Chains

Rare earths are not geologically rare, although their current mining and intermediate production structure give that impression. While approximately 30 percent of global rare earth reserves are located in Chinese territory, China currently controls between 50-60 percent of global rare earth mining, and 80-90 percent of the market in the intermediate processing stage. Figure 1 shows global rare earth mining production from 1994-2020. In the mid-1990s, global production completed its shift from the United States to China. By 2000s, when China was accused of economic coercion with rare earths, they were mining over 90 percent of global supply. China achieved this dominant position in the market through long-term investments in

[34] Elizabeth Economy and Michael Levi, *By All Means Necessary: How China's Resource Quest Is Changing the World* (Oxford University Press, 2014).
[35] Min Ye, *The Belt Road and beyond: State-Mobilized Globalization in China: 1998–2018* (Cambridge University Press, 2020); Axel Dreher and others, *Banking on Beijing: The Aims and Impacts of China's Overseas Development Program* (Cambridge University Press, 2022).

basic research, a mechanism to nurture a public-private pipeline, and the development of deep talent and expertise.

The United States used to be the major global player in rare earths from World War II until the early 1990s. Following World War II, when India restricted rare earth imports to the United States as part of a broader industrial policy strategy, the United States government made large investments in basic research in the rare earth sector, as well as developing a mechanism to support a public-private pipeline of knowledge.[36] The Rare Earth Information Center quarterly newsletter was a particularly effective mechanism for facilitating knowledge transfer from the national Ames Laboratory to private companies using innovations in rare earths in industry. However, as of the 1980s investments from the government had ceased, and basic research in rare earths greatly cooled. By the 1990s, this public-private investment mechanism had disappeared, while China had begun to effectively use very similar policies in order to facilitate the growth of their own domestic sector.

Today, China holds the commanding position in the global rare earth supply chain, from mining to processing to end-uses. The 17 elements in the rare earth group are mostly not rare: some are more abundant than copper, and they can be found across continents. Figure 2 provides a map of existing mines and potential rare earth deposits around the world. Current mining production is limited to a small number of countries: only 15 are listed in the 2022 USGS Mineral Commodity Summaries, with 75 percent coming from China (60 percent) and the United States (15 percent). There are potential mines, however, in at least 75 countries.[37] A true

[36] Joanne Abel Goldman, 'The US Rare Earth Industry: Its Growth and Decline', *Journal of Policy History*, 26.2 (2014), 139–66.
[37] K. Burger Labay and others, 'Global Distribution of Selected Mines, Deposits, and Districts of Critical Minerals', 2017.

geographic chokepoint does not exist in this industry. In short, China's market position was determined by policy, not geography.

The map in Figure 2 is particularly important because supply chain vulnerabilities come from three things, none of them related to the supply of mining sites: 1) a willingness (and legal ability) to bear high environmental externalities; 2) technological expertise in the intermediate or midstream stages of separation and refinement; and 3) market risks introduced by information failure. Supply chain vulnerabilities that create chokepoints are related to these three factors.

Chinese policies have somewhat ameliorated the first risk factor through improving environmental governance, have excelled in the second via industrial policy, and everyone is struggling with the third. Chinese policy has aimed to consolidate domestic industry, control production numbers and eliminate illegal mining, standardize production procedures, and enforce environmental protections and other regulations. There are a number of market and policy tools that China has historically used and continues to use to maintain their dominance in the rare earth industry. These include export controls, production quotas, state investment in basic research, nationalization of the industry, and most recently state consolidation into a vertically integrated mega-firm. Chinese dominance in the rare earth industry is a matter of policy, not geography.[38]

Rare earth mining is highly polluting and bears high environmental and health costs for local communities. After they have been removed from the ground they must be separated, refined into oxides, and then made into metals and alloys before they are ready for industry. The secondary process is also highly environmentally damaging.[39] Although the shift from the United States to China was *initially* enabled by China's lower environmental and regulatory standards

[38] Kristin Vekasi, 'The Geoeconomics of Critical Rare Earth Minerals', *Georgetown Journal of International Affairs*, 22.2 (2021), 271–79.
[39] Klinger.

compared to the U.S., it is not the case that China maintains their lead today for this reason. Over the past decade, China has increased introduced new environmental regulations, enforced existing ones, and innovated some cleaner mining and refining processes.

The process of separation and refinement is the area where China has invested a great deal of intellectual capital and state resources. Today, China's dominance in rare earths is due more to their investment in the separation and refining process than trade or industrial policies. When it comes to rare earths, much like other technologies, investment in basic research and training of the talent of tomorrow is where supply chain vulnerabilities and potential chokepoints arise. The next sections assess Chinese industrial structure and how it has led to the concentration of industry at the firm and intellectual property level.

China's Industrial Structure in the Global System

Figure 3 shows the global landscape of rare earth-related firms as of March 2022. Many of the firms (particularly those in India) have a very low level of business activity, with annual sales at zero, and few or no employees. There are two large companies based in the United States, two very large vertically integrated Chinese companies that include both mining and post-processing and numerous smaller Chinese companies that focus on intermediate stages of the production process. This geographic pattern is perhaps more revealing of vulnerabilities for Japan and the United States than mines. This section explains how Chinese policy has helped produce this outcome.

China nominally tightened rare earth regulations in the early 2000s, but struggled in enforcement because of the proliferation of illegal mines.[40] In 2012, the central Chinese

[40] Charles Kilby, 'China's Rare Earth Trade: Health and the Environment', *The China Quarterly*, 218 (2014), 540–50; Klinger.

government started a process of consolidation sparked by a recognition of many of the negative social and environmental externalities in the industry as well as acknowledgement of increased future global and domestic demand for the minerals.[41] Instead of hundreds of small miners, the consolidation turned the industry into six regional state-owned conglomerates. In December 2021, there was further consolidation of the industry in the creation of the new mega-firm. The new China Rare Earth Group is the result of a merger of three large mining conglomerates and two research institutes. It will control China's heavy and medium rare earths, under the supervision of the State-owned Assets Supervision and Administration Commission of the State Council (the highest administrative level).[42] It will control some 30-40 percent of global supply.[43]

The main goals of the new mega-firm are rooted in the domestic political economy, including market consolidation under state control, matching supply to demand, and an emphasis on vertical integration and higher value-added domestic production. These goals are connected to broader Chinese goals in the Made in China 2025 plan and Xi Jinping's New Era economic policies. The consolidation may also lead to more price stability, although that is not guaranteed. Prices for rare earths have been increasing due to surging demand and constraints on Chinese producers, particularly due to increased enforcement of environmental regulations.[44]

In the future, the northern companies around the Baotou Mine in inner Mongolia will also likely be consolidated so China will have only two huge vertically integrated state-owned

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[41] State Council, *Situation and Policies of China's Rare Earth Industry. , The People's Republic of China. 2012* (Information Office of the State Council, People's Republic of China, 2012).
[42] Xinhua, 'China Rare Earth Group Founded in Jiangxi-Xinhua', 2021 <https://english.news.cn/20211223/d29675f608ef46f3a2d00106eeef2b2c/c.html> [accessed 24 May 2022].
[43] Kristin Vekasi, 'Chinese Rare Earth Consolidation a Cause for Concern', *East Asia Forum*, 2022 <https://www.eastasiaforum.org/2022/03/30/chinese-rare-earth-consolidation-a-cause-for-concern/> [accessed 24 May 2022].
[44] Yeping Yin, 'China's Rare Earth Price Exceeds a Historic High amid Booming Demand and Tight Supplies - Global Times', 2021 <https://www.globaltimes.cn/page/202111/1238808.shtml> [accessed 24 May 2022].

enterprises that control both rare earth mining and post-processing. The southern firm focuses on the heavy rare earth minerals, and the possible northern firm will focus on the light rare earth minerals.

Trade Vulnerabilities and China's Production Quota System

Previously, China used a system of discriminatory domestic versus foreign prices and export controls. In a case brought by the United States, European Union, and Japan, these export controls were found to be against China's accession agreement to the WTO in 2015.[45] The WTO case was sparked by Japan's accusation of Chinese economic coercion, but concerns about high trade dependence on Chinese rare earths undergirded the decision to pursue a dispute.[46] Figure 4 shows Japanese and United States imports of rare earths from 1990-2020. Japan, in particular, had high import reliance on China in the 2000s, which had been somewhat mitigated from 2015. These data cannot differentiate between different rare earth elements because they do not differentiate between different metals or alloys, and so can underestimate the vulnerability a country might face in supply shortages or economic coercion for specific technologies. I address that issue below in the discussion of permanent magnets.

Following the WTO decision, China did drop expert controls, and they were replaced by a system of production quotas that continued to limit supply and typically kept prices low, steady, and gave Chinese producers an advantage over potential foreign competitors. This reality

[45] World Trade Organization, 'DS431: China — Measures Related to the Exportation of Rare Earths, Tungsten and Molybdenum', 2015 <https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm> [accessed 24 September 2021].
[46] Kristin Vekasi, 'Politics, Markets, and Rare Commodities: Responses to Chinese Rare Earth Policy', *Japanese Journal of Political Science*, 20.1 (2019), 2–20; Eugene Gholz and Llewelyn Hughes, 'Market Structure and Economic Sanctions: The 2010 Rare Earth Elements Episode as a Pathway Case of Market Adjustment', *Review of International Political Economy*, 28.3 (2021), 611–34.

is reflected in trade data, as well as the degree to which non-Chinese mining companies have struggled to remain solvent, also addressed in more detail below.

Production quotas for the regional conglomerates are set centrally by the Ministry of Commerce, and enforced by the local governments. In recent years, production quotas have failed to meet demand and are starting to stress China's domestic rare earths sector.[47] Although an environmentally responsible and self-sufficient rare earth industry is a stated goal in China's recent five-year plans, domestic demand for rare earths has already outstripped domestic supply.

The 2016 "Rare Earth Industry Development Plan" published by the Ministry of Industry & Information Technology (MIIT) in conjunction with the 13th five-year plan, described many of these policies with specified targets for increased profitability and improvements in the high value-added segments of the industry, meeting higher environmental standards, and decreased production and smelting reflecting the goal of industry consolidation. One goal in the plan was to "improve mechanisms to keep the prices of superior minerals stable through limiting production." The 13th five-year plan, in particular, focused on the shift in China's political economy to higher value-added products with increased environmental sustainability. Goals included strengthening "geological environmental governance and ecological restoration in regions of intensive mineral resource mining" and "green mining."[48]

By the time the 14th five-year plan was announced in 2021, many, though not all, of the previous goals had been met or were in process. China had moved up the value-added chain, as evidenced by their large research and development investments and expertise in the intermediate

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[47] Sun Yu and Tom Mitchell, 'State Interference Threatens China's Control of Rare Earth Production', *Financial Times*, 29 October 2020.
[48] 13th Five-Year Plan, 'The 13th Five-Year Plan for Economic and Social Development of the People's Republic Of China (2016–2020)', *Compilation and Translation Bureau, Central Committee of the Communist Party of China*, 2016 <https://en.ndrc.gov.cn/policies/202105/P020210527785800103339.pdf> [accessed 29 September 2021].

stages of production. As of this writing, no detailed regulations of rare earths under the 14th five-year plan yet exist. Overall, however, the plan calls to "promote breakthroughs in advanced metals and inorganic non-metal materials such as high-end rare earth[s]…[to] accelerate the breakthrough in key technologies". The plan is heavily focused on the newer industrial policy in China to shift towards higher value-added production, green technologies, and an economy more driven by domestic production *and* demand.[49] While rare earths are not the only mineral targeted in the plan, these minerals are central to these broader goals. Many of the objectives—electric vehicles, space technology, new materials, computing and more—will require a reliable source of rare earths for either Chinese producers or foreign producers based in China.

China imports rare earths, particularly those needed for permanent magnets. They also import unprocessed concentrate from the United States, which is then refined within China's vertically integrated industry. As a U.S. Department of Energy report notes, most rare earth imports into the United States are in finished products. Even as U.S. mining production has increased in recent years (see Figure 1), China's command of the midstream is unrivaled.

In recent years, China has also started to rely on rare earth mining in regions of Myanmar that border China. The imports from Myanmar come from poorly regulated mines in that country, and also potentially from Chinese ores that are illegally mined and laundered across the border.[50] China's increased efficacy in enforcing environmental regulation, the consolidation of the industry, and the production quotas have restricted supply and made mining and processing in China more expensive. There is also increased demand for rare earths for permanent magnets

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[49] 14th Five-Year Plan, *第十四个五年规划和 2035 年远景目标纲要[China's 14th Five-Year Plan and the Long-Range Objectives Through the Year 2035 (Draft)]* (National Development and Reform Commission, 4 March 2021) <https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202103/P020210323538797779059.pdf> [accessed 29 September 2021].
[50] Tom Daly, 'China Becomes World's Biggest Importer of Rare Earths: Analysts', *Reuters*, 13 March 2019, section Commodities <https://www.reuters.com/article/us-china-rareearths-idUSKBN1QU1RO> [accessed 24 May 2022].

and catalysts, particularly driven by the fast growth of China's electric vehicle market. Even China faces supply chain vulnerabilities. For example, when Covid-19 policies temporarily closed the China-Myanmar border, the price of rare earths started to rise dramatically. These price pressures were relieved to some extent when the border reopened and may be further ameliorated by the merger of the large mega-firm.

Rare earths and permanent magnets

Demand for rare earths, particularly heavy rare earths that can be used in permanent magnets, is increasing and projected to increase more dramatically in the coming decades.[51] As Figure 5 shows, demand for rare earths, particularly neodymium, but also dysprosium, praseodymium, and samarium, are expected to increase dramatically in the coming years largely due to green technologies, particularly in the automotive industry where neodymium-iron-boron (NIB) permanent magnets are used for motors (the technology and mineral needs are similar for wind turbines). Neodymium is in MRI machines and lasers, and NIB magnets are found in computers, cell phones, and other electronics, in addition to the aforementioned wind turbines and motors. End uses span the health sector, green energy sector, defense, and everyday consumer products. NIB magnets are ubiquitous.

By 2025, one estimate predicts a total demand for major rare earth permanent magnet applications of 94,500 metric tons (see Figure 5). In 2020, global rare earth production was 240,000 metric tons, but this includes all 17 elements, not just the key ones. In conversation, industry insiders have indicated that in recent years, the world has used around 3,000 more tons

[51] Adamas Intelligence, 'Rare Earth Elements: Market Issues and Outlook', *Adamas Intelligence*, 2020 <https://www.adamasintel.com/unfathomable-rare-earth-demand-growth/> [accessed 24 May 2022]; Kirsten Hund and others, 'Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition', *World Bank*, 2020.

of neodymium per year than is produced although given the lack of transparency the precise numbers are difficult to pin down.

China's investment in rare earth research and development and the extent of their expertise relative to other countries is evident in the permanent magnet industry and the allocation of patents, one indication of overall investment in research activity. Figure 6 shows patents for permanent magnets overall, neodymium-praseodymium permanent magnets, and samarium-cobalt permanent magnets from 2001-2020. While in 2021 China received 48 percent of patents granted in permanent magnets overall, 99 percent of neodymium magnet patents and 86 percent of samarium-cobalt magnet patents were granted to China. While not necessarily an indication of mastery or command of the most cutting-edge technology, patent allocation does indicate expertise, training, and dedication of resources towards an industry. While I do not present the data here, patents in the rare earth industry overall show this same national trend.[52]

The geographic distribution of permanent magnet companies reflects how many of the major permanent magnet companies are in China, but there is also a much more diversified global market compared to upstream rare earth processing. Figure 7 shows the global distribution of permanent magnet companies. Of the top ten companies by sales, seven are in China, Chinese-based companies control 70 percent of global sales, and the United States is a distant second with 14 percent. With respect to investment in high-tech development and production capacity in the midstream, both Japan and the United States have a high degree of dependence on China. Although there is geographic concentration in China, there is not a similar concentration in a single companies like rare earth mining. The largest company is a branch of the large Chinese technology company Innuovo, and it holds 7.7 percent: far from a monopolist market share.

[52] Vekasi, 'The Geoeconomics of Critical Rare Earth Minerals'.

These data also show the vertical integration of the Chinese industry along the supply chain. There are eight companies that are specifically integrated with other rare earth companies, and they are all Chinese.[53] These companies are a reflection of how the Chinese industry is vertically integrated, from raw materials to component. On the non-Chinese side, Magnaquench is a subsidiary permanent magnet company with six branches in the United States. Magnaquench has Canadian parent company Neo Performance Materials, a rare earth mining company that is working towards Chinese-style vertical integration as well as geographic diversification with mining capacity in Russia and post-processing in Estonia.

Japanese domestic production is minimal, although there are 11 Japanese firms (branches of Hitachi) around the world. Japan has unsurprisingly outsourced much of their permanent magnet production to Southeast Asia: those subsidiaries are Japanese. Shin-Etsu Magnetics has a large plant in the Philippines, and Hitachi Metals a large plant in Indonesia.

Assessing Vulnerability

Relying on a single geographic source for any key material inherently introduces vulnerability in a supply chain, even without concerns about rivalrous politics. There has been increased weaponization of trade and supply chains around the world over the past decade, including the alleged case of China with rare earth elements.[54] However, more than the intentionality suggested by potential economic coercion, geographically concentrated raw mineral supply chains increase vulnerability because there is simply an inability to nimbly

[53] The companies are JL Mag Rare-Earth, Baotou Steel Rare Earth Magnetic Materials, Ganzhou DMEFC Rare Earths, Shengyilun Rare Earth Materials Application Academy, Yancheng Tonghui Rare Earth, Ganzhou Chengzheng Rare Earth New Material, Wuxi Rare Earth Permanent Magnet, and Ningbo Dongqianhu Tourism Holiday Resort Rare State Magnetism Materials.

[54] Daniel W Drezner, Henry Farrell, and Abraham L Newman, *The Uses and Abuses of Weaponized Interdependence* (Washington, DC: Brookings Institution Press, 2021).

respond to any crisis or a demand shock. The near certainty of increased future demand in this sector will exacerbate this vulnerability. The types of vulnerability in the rare earth and permanent magnet supply chain reveal where vulnerabilities lie.

Under the status quo, actual geographic chokepoints do not exist at the mining stage. However, there are potential vulnerabilities in production at the mining and post-mining separation and refinement stages. Vulnerabilities in mining can be overcome with support for the companies, and Japan has to some extent accomplished this style of supply chain resilience policy as I describe below. The intermediate or midstream vulnerabilities shown in firm concentration and patent data are where points of potential vulnerability are more stark.

With the industry status quo, potential vulnerabilities include supply side shortages due to booming global demand, export restrictions from China, or the weaponization of the industry. Supply-side shortages due to an undiversified market and booming demand limiting China's export potential and leading to increased costs or even potential shortages for both rare earth elements and downstream products, including permanent magnets are almost certain to occur. Given the ubiquity of these ingredients, these supply shortages would have downstream effects for consumer electronics, medical equipment, and green technology such as electric vehicles and wind turbines. Chinese export restrictions or other trade barriers of rare earth elements and downstream products in an aggravated U.S.-China or Japan-China trade conflict could also cause shortages, causing price increases and shortages in key segments of the supply chain similar to the first scenario. Restriction of key raw materials in the event of a territorial dispute or more severe kinetic conflict that could affect U.S. or Japanese military readiness. This scenario is the least likely. The next section provides a short overview of Japan's relatively successful approach to these vulnerabilities.

Japan's Approach to Rare Earth Vulnerability

After China allegedly restricted rare earth exports to Japan amidst a 2010 territorial dispute, Japan mobilized the private and public sector to build a more resilient supply chain. Japan's historical toolkit of industrial policy and public-private partnerships informed Japan's approach to ameliorate its over-reliance on Chinese rare earths, and Japan has been modestly more successful than other countries. Diversification activities included new economic partnership agreements, joint ventures, mining exploration, and rare earth processing plants throughout Asia, the Americas, and Australia. The Japanese government promoted diversification by improving relations with countries with domestic rare earth reserves through strategies such as diplomatic agreements, overseas development aid projects, and providing opportunities for firms to find overseas partners through economic tours or trade fairs. They also provided direct subsidies and business support through partnerships with a state-owned enterprise.[55]

The Japanese Ministry of Foreign Affairs pursued partnerships and new agreements in countries with rare earth deposits, but not the capacity, sufficient infrastructure, or domestic demand to safely mine and process. Japan pursued economic diplomacy with the United States, Australia, Mongolia, India, Vietnam, and Kazakhstan, including efforts to secure strategic resources through overseas development aid and diplomacy. Not all of these efforts were successful. For example, efforts to start new mining in Mongolia and Kazakhstan largely failed.

Japan also used industrial policy. The Ministry of Economy, Trade and Industry (METI), and the state-owned enterprise Japan Oil, Gas, and Metals Corporation (JOGMEC) developed

[55] For a much more detailed examination of Japan's response see the following: Vekasi, 'Politics, Markets, and Rare Commodities: Responses to Chinese Rare Earth Policy'; Gholz and Hughes.

policies to promote more robust domestic capacity and diversify internationally. METI introduced subsidy competitions for the private sector for international diversification, developing technological alternatives, and the development of new recycling procedures. METI ran these policies in 2009, 2011, 2016, and 2021 (the 2021 call was a broader policy including PPE and other critical sectors in response to the pandemic).[56]

The recipients of the METI money are largely small or medium-sized enterprises, but the real movers in the sector of critical minerals are large-scale enterprises, the trading companies that help secure their materials, and a state-owned enterprise that provides financial backing to these large companies. As a relatively resource-poor country, Japan established two state organizations in the 1960s to ensure a supply of oil and minerals. In 2004, these organizations were combined into the Japan Oil, Gas, and Metals Corporation (JOGMEC), which is under the jurisdiction of METI. While mineral extraction is a key goal, JOGMEC assists along the supply chain. Their goals are to promote early-stage exploration and advanced-stage metal mining, helping develop recycling technologies and metal alternatives. JOGMEC also has a stockpiling program for rare earths. After private companies put in requests for assistance, JOGMEC helps initiate rare earth projects around the world, including in Canada, the United States, South Africa, Australia, Kazakhstan, Vietnam, and Brazil. These are done in partnership with Japanese general trading companies, which are larger companies that (among other roles) solve supply chain problem issues within the Japanese economy for other private firms. For example, JOGMEC and Sojitz are financing the Lynas Rare Earth Project in Australia, which is a key source of non-Chinese rare earths for Japan. With Toyota Tsusho they are helping guarantee a

[56] Solis.

lithium project in Argentina.[57] While JOGMEC provides financing assistance for these projects, they are initiated by the general trading companies.

Japanese rare earth-related investments in Malaysia where Lynas processes the sediment from their mine in Australia are an example of diversification along the supply chain. The early days of this effort were fraught, and Japanese financing, including from JOGMEC and Sojitz, were needed to rescue Lynas from bankruptcy. The rescue enabled a non-Chinese supply of rare earths for Japanese producers, particularly of neodymium and praseodymium used in electric car batteries.

The public-private nexus and use of industrial policy has been key for Japan's efforts in securing a diverse and resilient supply chain. By late 2017, Japan was importing approximately 30 percent of its rare earths from Asian countries other than China, a trend that has continued through 2021. Many of these come from Malaysia, showing the success of JOGMEC's policies.

Vulnerabilities, however, still remain. Following the onset of the Covid-19 pandemic and severe supply chain disruption in China, Japan initiated new but similarly designed industrial policy to encourage diversification from China, either through reshoring or moving into a different overseas market. Looking at the permanent magnet market, Hitachi's large presence in Southeast Asia is one indicator of how these diversification efforts might play out. Through the METI process, at least three companies have received grants to develop rare earth-related companies in Vietnam and Malaysia.[58] Japan is also pursuing cooperation with the United States and other allies (Canada, the European Union, and Australia) to maintain and develop expertise

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[57] JOGMEC, 'JOGMEC Integrated Report 2020', 2020 <http://www.jogmec.go.jp/content/300373866.pdf> [accessed 12 October 2021].

[58] Solis; JETRO, '第一回公募（設備導入補助型（一般枠・特別枠））における採択事業者について | 海外サプライチェーン多元化等支援事業のサービス', ジェトロ, 2020 <https://www.jetro.go.jp/services/supplychain/kekka-1.html> [accessed 12 October 2021].

in the rare earth sector. They hold regular meetings to share research and strategies on critical minerals. Japan and the United States also pledged to jointly develop resiliency in critical minerals during a high-level summit in April 2021. Developing resiliency in critical mineral supply chains is also an element of the Indo-Pacific Economic Framework in which Japan is participating.[59]

Domestic and international interventions

For the United States and Japan to continue their efforts to build a resilient critical mineral supply chain, there are a number of possible government interventions, all with attendant political and economic risks. I focus on possible incentives for the private sector that encourage diversification and deepening expertise along the supply chain rather than restricting access to Chinese markets through tariffs or non-tariff barriers. Given the lack of diversification along the rare earth supply chain at the intermediate and midstream, neither the United States nor Japan have the capacity to maintain a rare earth industry outside of China and meet the supply needed for technological or economic goals. Although cooperation with China does clash with the political

Diversifying at the Mining Stage

[59] ‘Fact Sheet: U.S.-Japan Competitiveness and Resilience (CoRe) Partnership’, *The White House*, 2021 <https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/16/fact-sheet-u-s-japan-competitiveness-and-resilience-core-partnership/> [accessed 15 September 2021]; ‘FACT SHEET: In Asia, President Biden and a Dozen Indo-Pacific Partners Launch the Indo-Pacific Economic Framework for Prosperity’, *The White House*, 2022 <https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/23/fact-sheet-in-asia-president-biden-and-a-dozen-indo-pacific-partners-launch-the-indo-pacific-economic-framework-for-prosperity/> [accessed 24 May 2022].

Diversification at the mining stage, either by further increasing U.S. mining or in third countries, is one possibility to reduce reliance on China and to respond to future increased demand. This strategy is somewhat high risk. To mitigate initial risks, possible policy interventions are 1) guaranteed minimum purchasing from new mines, 2) public-private partnerships similar to the Japanese model where state financing eased initial risks and prices shocks, or 3) loan guarantees, subsidies, or tax breaks for new risky ventures.

Opening new mines is not a short or simple process. In incentivizing new domestic mining, there needs to be a commitment to carry on throughout short-term price shocks, particularly for metals like cerium and lanthanum that are likely to experience more price volatility. If metals from successful mines are introduced, the market can be flooded with new supply, prices bottom out, and the mine will likely be unsustainable in the short term without external support or a deep-pocketed parent company. The large conglomerate companies in China are well-financed, have a soft landing pad untethered to hard market concerns, and can survive lower prices and turbulence in the market. Australian, U.S., and Canadian companies do not have that luxury, and often do not survive past the initial mining stages, particularly because the large mining companies (e.g. Australia's Rio Tinto) have stayed out of the rare earth market.

This phenomenon was particularly evident after the 2010–2011 rare earth price and demand crunch when the prices for some elements went up more than 75 times their original prices. The very high price point of specific elements made it temporarily profitable for new mines to open around the world. However, because the prices quickly crashed back to original levels, all of these new mining ventures quickly faded into insolvency. In one study of new entrants to the market, analyst James Kennedy found that of 400 publicly listed rare earth start-ups around the world from 2012-2019, only five of them had successfully achieved commercial production, and those who had were still dependent on Chinese financing and midstream processing.[60] The former American company Molycorp's experience with the California Mountain Pass Mine is instructive. The United States tried to diversify using its domestic reserves. The Mountain Pass Mine had closed in 2002 due to environmental concerns as well as unprofitability. When prices began to rise, and incidentally at the urging of U.S. policymakers, Molycorp reopened the mine in 2012 only to declare bankruptcy in 2015 when prices collapsed to early 2010 levels.

These issues are exacerbated by information failure. The lack of a global spot price challenges new entrants to the market. It can be difficult to attract financing without reliable and transparent price information that would allow companies to predict return on investment or make reasonable forecasts of insolvency risk.

Diversification at the mining stage *is* important, particularly because of future anticipated demand. For any of these interventions, however, policymakers must be prepared for failure in many of the projects and willing to provide financial support for firms to survive price fluctuations or other unexpected challenges. To achieve diversification at the mining stage, policymakers must take a long-term view.

Diversifying in the Midstream

Midstream diversification—particularly including separation, processing, refinement, but also intermediate products like magnets—requires an additional set of tools and investments. Similar environmental externalities from mining exist at the midstream. It also requires more technical expertise, which takes more time and intellectual capital to develop than a new mine.

[60] James Kennedy, 'China Solidifies Dominance in Rare Earth Processing', *National Defense Magazine*, 2019.

Similar funding mechanisms may be necessary for midstream processing, and have been introduced by the previous administrations, as well as the Biden administration. The Department of Energy's new initiative for extracting rare earths from coal waste and ash is one example of how building midstream resilience might proceed.[61]

To pursue similar innovations, the United States could expand funding for basic rare earth research and prioritize public-private collaboration that will move the results of basic research into the private sector. For example, in the U.S. context the Department of Energy or National Science Foundation can fund university- or national lab-based projects, prioritizing those that have secured joint funding from a private firm so discoveries can be tested and scaled in a commercial environment. The United States already has regular conferences with rare earth experts from Australia, Canada, Japan, and the European Union. The structure of funding could also encourage international collaboration with selected countries to develop a more robust sector outside China, and not just in the United States.

Conclusions and Policy Recommendations

The Japanese and United States governments can help ameliorate supply chain vulnerabilities in rare earths by diversifying along the supply chain. While a focus on the mining stage is tempting, attention to the midstream is likely to yield greater results. The midstream is currently more vulnerable and long-term thinking and innovation in this area can reap higher dividends for national strength and security. The countries should invest in basic research, increase funding and opportunities for national labs, and facilitate knowledge via public-private knowledge transfer. These efforts can be done in conjunction with allies that share similar

[61] Department of Energy.

concerns, including the Quad and the European Union, and can build on existing programs. Some of these efforts are ongoing, but should be increased.

The new Japanese Economic Security legislation could help facilitate cooperation between Japan and the United States on rare earth-related research and development, as could multilateral participation in the Indo-Pacific Economic Framework, or supply chain resiliency initiatives promoted by the Quad. Securitization of the industry in this case could push private sector companies to cooperate more internationally than they would have otherwise.

The United States government should also emulate Japan's model of public-private funding for new mining and separation facilities that help overcome initial political and environmental risks in the rare earth sector. Even with public funding, it is likely that private companies will need to lean on Chinese expertise to develop a resilient business model. The United States should recognize China's technical leadership in this sector and not prohibit private-sector cooperation with Chinese commercial entities in order to be eligible for opportunities.

The necessity of cooperation with China in this sector reveals one of the paradoxes of securitization of an industry. Securitization has enabled deeper state intervention that has helped Japanese companies diversify internationally and financed foreign firms to a surprising extent. In the United States, it has focused attention on an opaque but crucial industry before an actual supply crunch arrived like the semiconductor industry. But at the same time, real success in building a diversified and resilient industry will require cooperation with the country that sparked the initial securitization: China. Threading this needle of state intervention to compete with rivalrous competition will require deft political leadership, but could lead to new frontiers in green technology and national security alike.

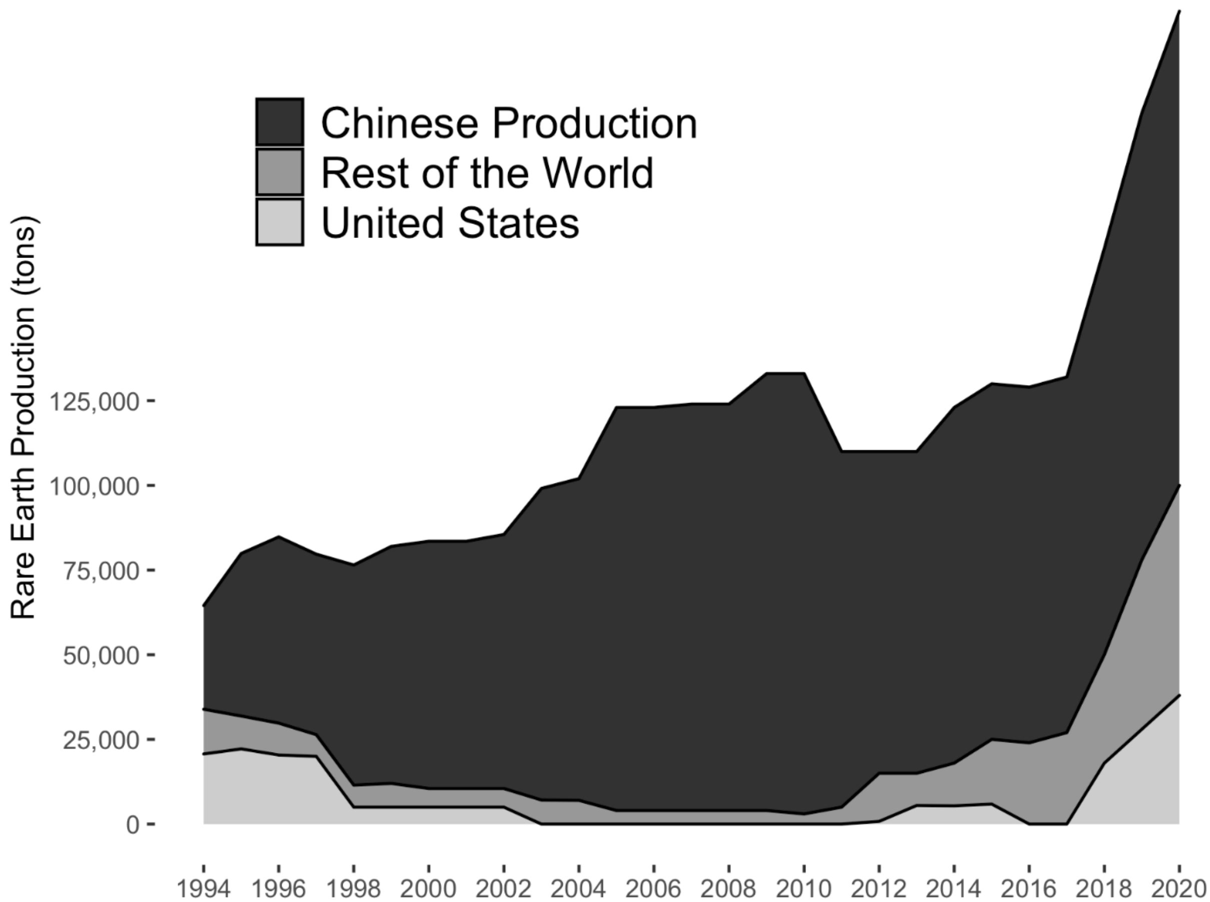
FIGURES

Figure 1 Potential Vulnerabilities and Measurement Strategies

Type of potential chokepoint	**What it measures**	**Data sources and measurement strategy**
Geographic	Where minerals exist under the ground, regardless of current mining or production status	USGS Study [62]; maps of exploitable minerals, HHI by country
Production	How many minerals are mined and processed by country	USGS Mineral Commodity Summaries; maps of mined and refined minerals[63]
Firm	Where companies are mining and processing raw materials around the world, and the size of those companies	Mergent Database; maps of sales, subsidiary status, and country of ownership
Trade concentration	How trade dependent countries are for resources, and the extent to which they import and export raw and refined minerals	UN Comtrade; primary trade partners for Japan and the United States[64]
Technological expertise	The extent to which filed patents related to a mineral are geographically concentrated, and the direction of national trends	Google patent database; percentage of cumulative patents for previous 10 years by country[65]

[62] Labay and others.
[63] USGS, *Mineral Commodity Summaries* (Washington, DC: United States Geological Survey, 2021).
[64] UN Comtrade, 'UN Comtrade International Trade Statistics Database' <https://comtrade.un.org/>.
[65] Google, 'Google Patents' <https://patents.google.com/> [accessed 11 May 2022].

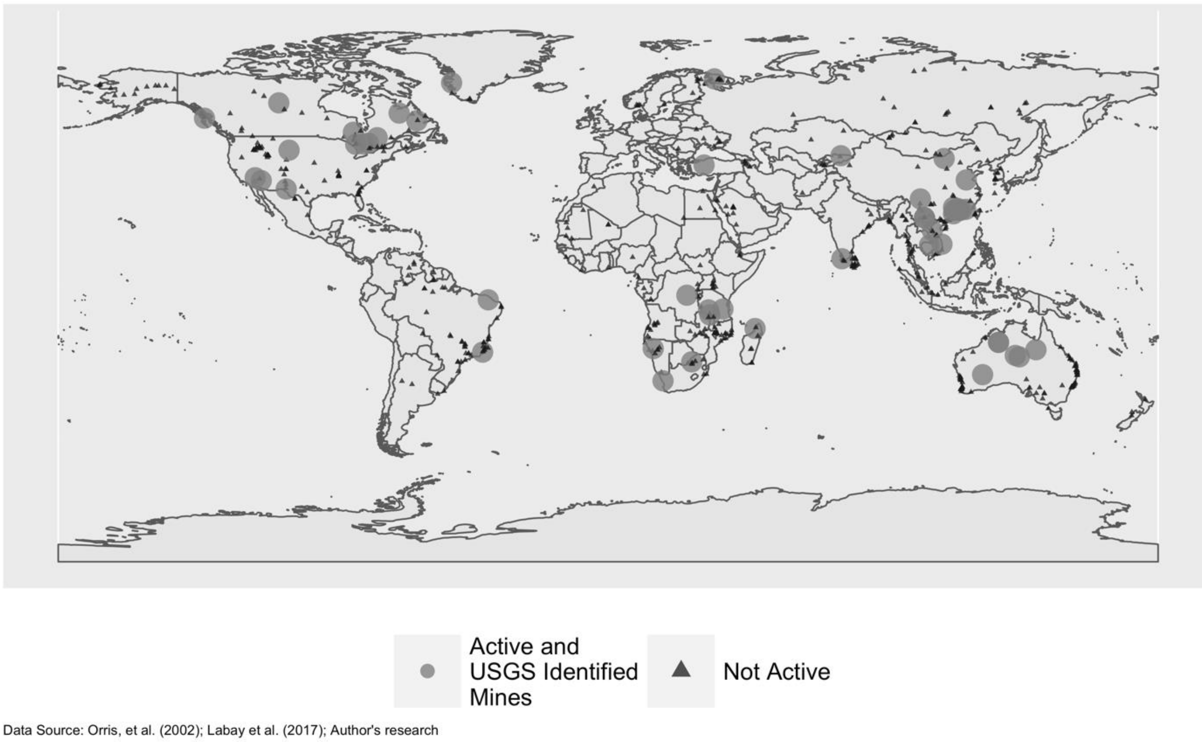
Figure 2 Global Rare Earth Production, 1994-2020



Data are from the US Geological Survey Annual Mineral Commodity Summaries and the author's calculations.[66]

[66] USGS.

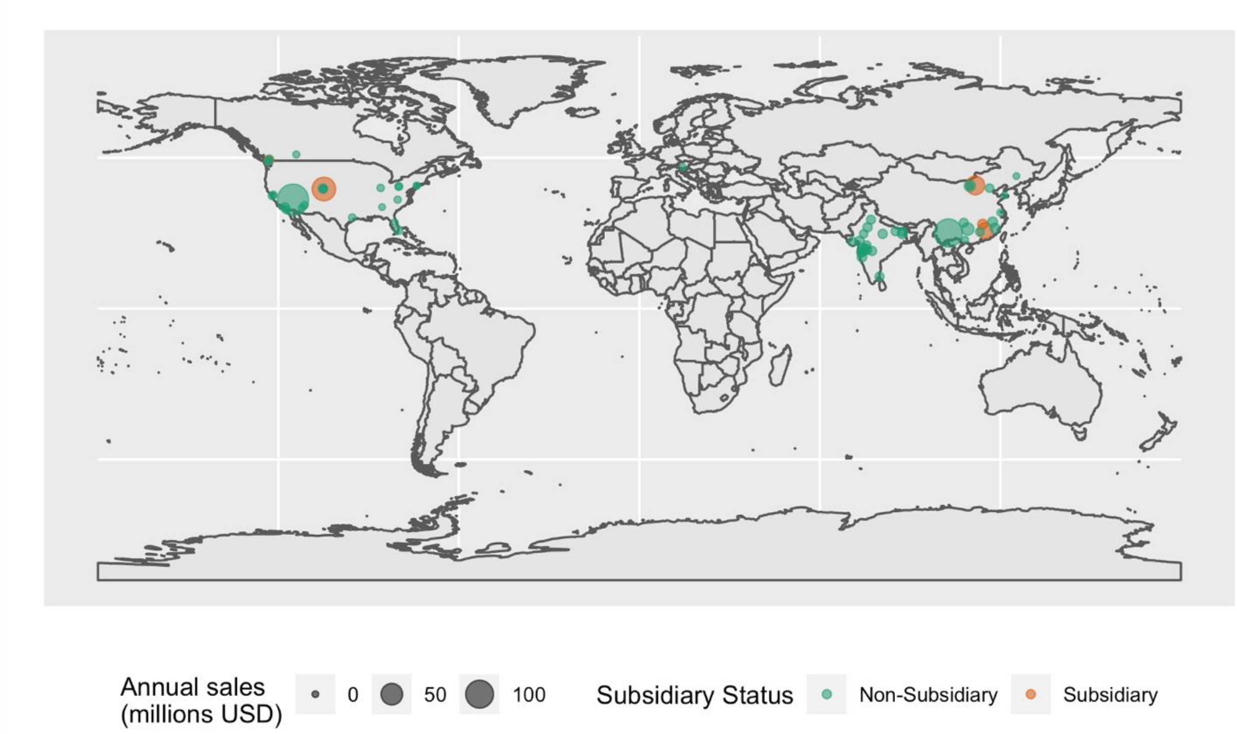
Figure 3 Global Rare Earth Mining Sites and Deposits



This map shows existing rare earth mines in addition to sites identified by the US Geological Survey as highly potential mining sites. Data comes from a USGS study by Labay et al. complemented by the author's own research.[67] The primary takeaway from this figure is that rare earths are not geologically rare.

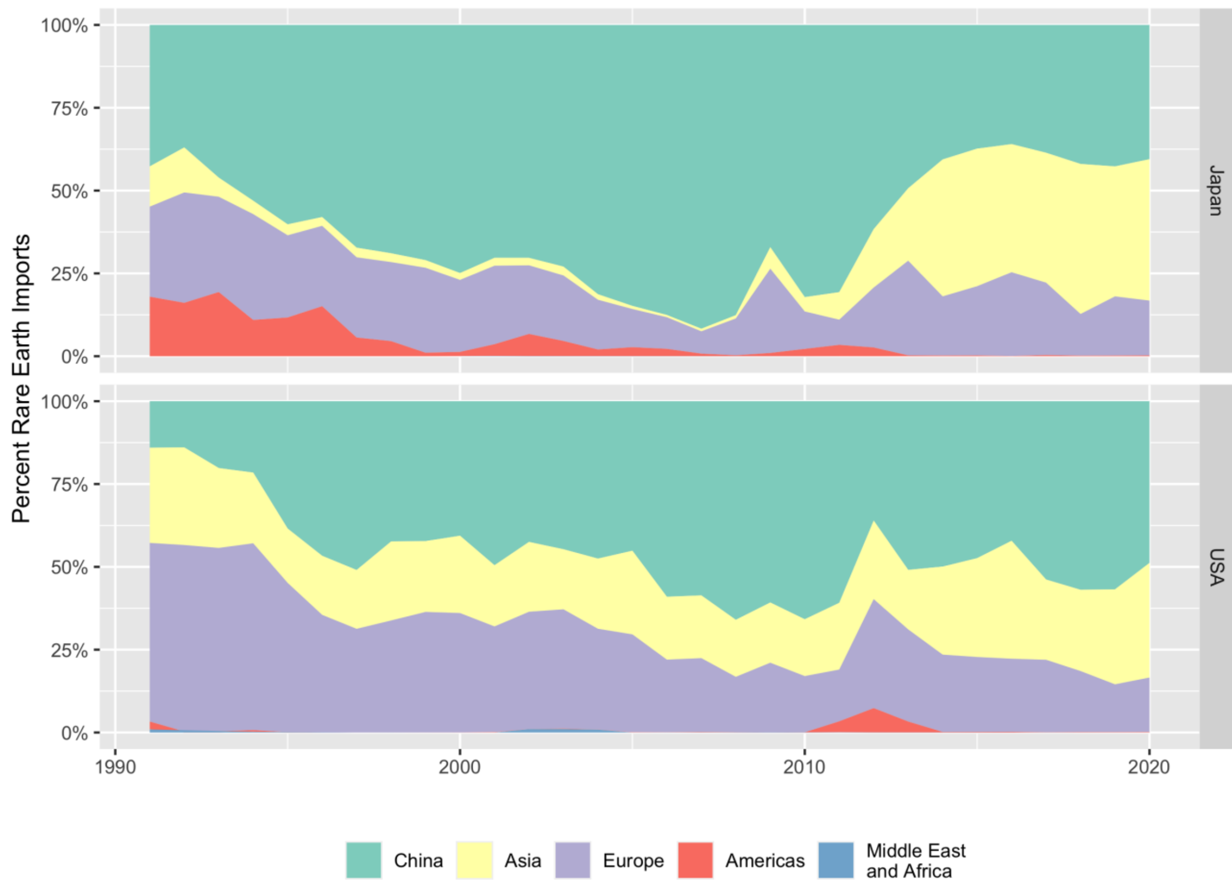
[67] Labay and others.

Figure 4 Global Rare Earth-Related Firms



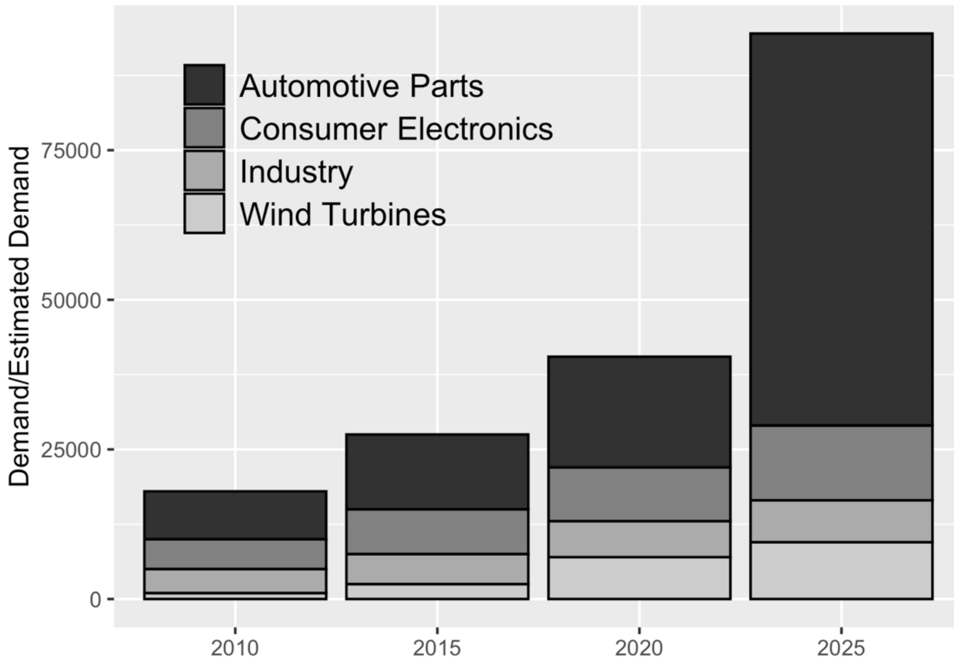
Data source: Mergent database. Note that many of these firms have annual sales of zero, indicating a low level of business activity.

Figure 5 Rare Earth Imports, 1990-2020



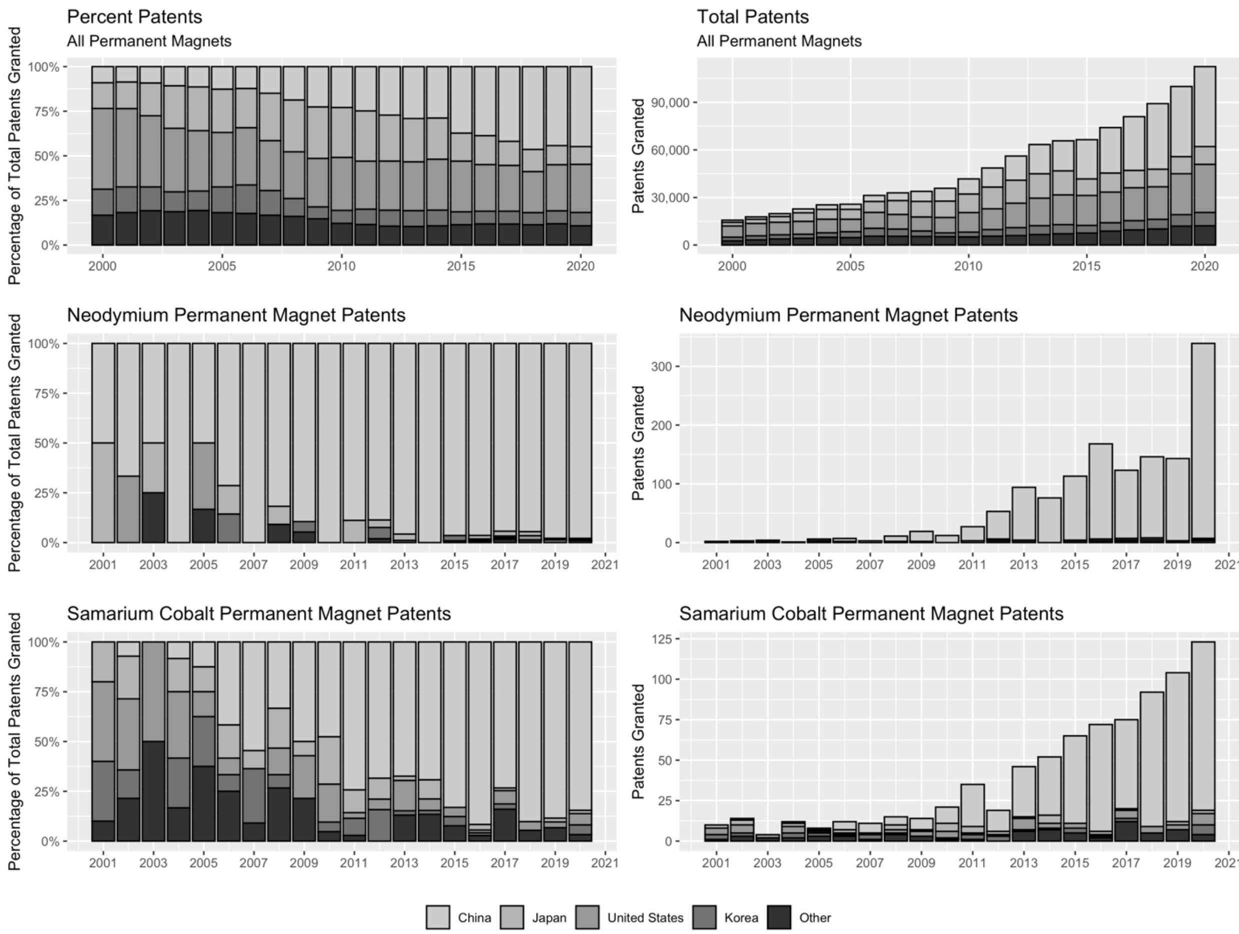
Data source: UN Comtrade. Rare earth imports include three trade categories: “Compounds, inorganic or organic (excluding cerium), of rare-earth metals, of yttrium, scandium or of mixtures of these metals”, “Compounds, mixes of rare-earths, yttrium, scandium nes”, and “Earth-metals, rare; scandium and yttrium, whether or not intermixed or interalloyed”. Unfortunately trade data does not differentiate at the level of the element.

Figure 6 Current and Projected Demand for Permanent Magnets



Data were compiled from Statista by the author. Estimates come from a 2016 Quest Rare Minerals report. Similar estimates can be found in industry reports from Adamas Intelligence and the World Bank's Smart Mining report.

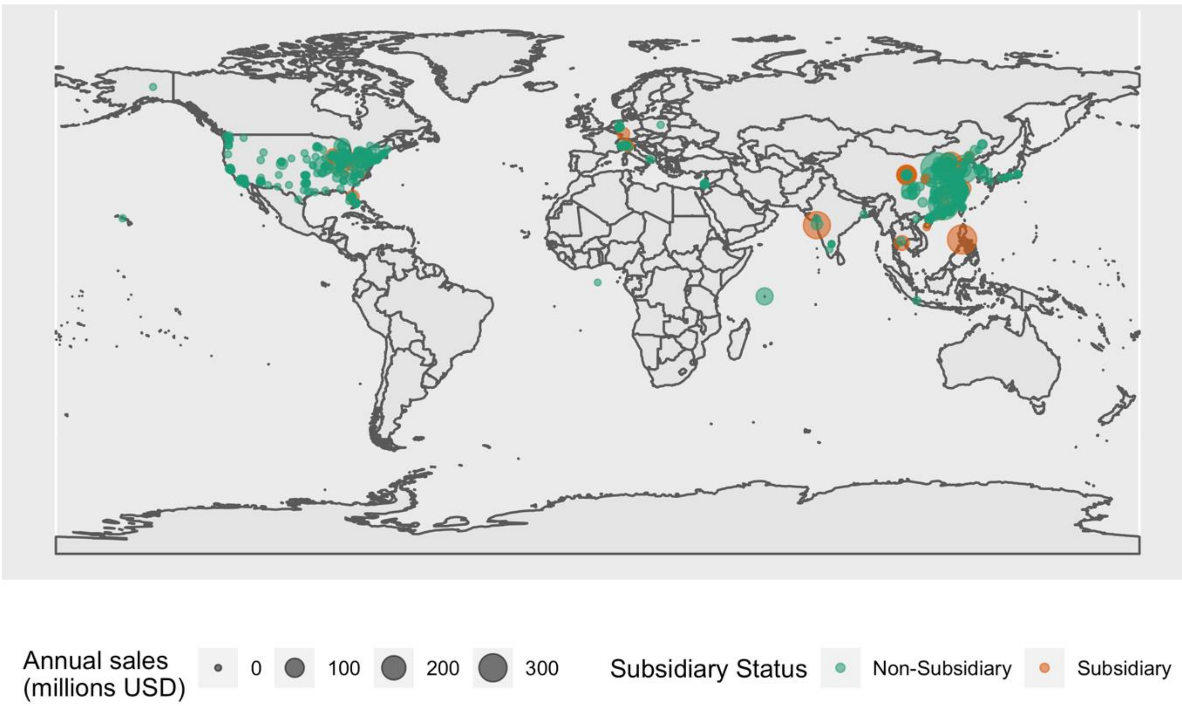
Figure 7 Global Patent Grants in Permanent Magnets, 2001-2020



Data for this figure comes from the Google Patent database, which includes published patents from offices in 105 countries, although the vast bulk of patents come from 15 countries.[68] The top five patent grant offices (the United States, Japan, China, Germany, and the European Patent Office) account for approximately 80% of total patents and the top three alone (the United States, Japan, and China) account for almost 70% of all patents granted. Over the past two decades, China's patent applications and grants have been steadily increasing across many sectors. In the cumulative data as of May 2022, China accounted for 38% of patent grants and 21% of patent applications.

[68] Google.

Figure 8 Global Permanent Magnet Companies



Data source: Mergent database; analysis by author.

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