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Executive Summary

- Risks in the rare earth sector arise from 1) high environmental externalities, 2) high level of technological expertise needed for separation and refinement, and 3) information failures.
- China has effectively used market intervention, industrial policy, and investment in expertise over the long-term to become the major global player in rare earths.
- Supply chain vulnerabilities arise from the market concentration in China. In coming years, China will be unable to meet their own rising domestic demand nor global needs, particularly for neodymium and other key rare earths needed for permanent magnets.
- The United States government can help ameliorate supply chain vulnerabilities in rare earths by:
  - Investing in basic research, increasing funding for national labs, and facilitating public-private knowledge transfer;
  - Increasing information transparency by developing an international price index, preferably in cooperation with China;
  - Emulating Japan's model of public-private funding for new mining and separation facilities that help overcome initial political and environmental risks.

Global Rare Earth Supply Chains – Developments and Challenges

Rare earths are not geologically rare. While China has approximately 30% of global rare earth reserves, they currently control 50-60% of global rare earth mining, and 80-90% of the market in the intermediate processing stage. Figure 1 in the appendix shows global rare earth mining production. They achieved this dominant position in the market through long-term investments in basic research, a mechanism to nurture a public-private pipeline, and the development of deep talent and expertise. In short, China's market position was determined by policy, not geography.[i]

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.[ii] 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. For reference, Figure 2 in the appendix provides a map of existing mines and potential rare earth deposits around the world. This map is particularly important because supply chain vulnerabilities come from three things, none of them related to the supply of mining sites:

1. Willingness to bear high environmental externalities
2. Technological expertise in separation and refinement
3. Market risks introduced by information failure

Chinese policies have somewhat ameliorated the first factor, have excelled in the second, and the world is struggling with the third. We can evaluate the efficacy of China's policy on the ability to consolidate the 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. As I have written elsewhere, Chinese dominance in the rare earth industry is a matter of policy, not geography.[iii]

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.[iv] Although the shift from the United States to China was *initially* enabled by China's lower environmental and regulatory standards compared to the US, 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 true future dominance lies.

China's Industrial Structure

China nominally tightened regulations in the early 2000s, but struggled because of the proliferation of illegal mines. In 2012, the central Chinese 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.[v] 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).[vi] It will control some 30-40% of global supply.

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. It 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.[vii]

I anticipate in the future that the northern companies around the Baotou Mine in inner Mongolia will also be consolidated so China will have only two huge vertically integrated state-owned 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 (including neodymium).

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. Following that 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 and steady.

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.[viii] 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”.[ix]

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 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.[x] 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 US Department of Energy report notes, most rare earth imports into the United States are in finished products. Even as US 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.[xi] 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 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.[xii] As Figure 3 in the appendix 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 3). 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 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 4 in the appendix shows patents for permanent magnets overall, neodymium-praseodymium permanent magnets, and samarium-cobalt permanent magnets from 2001-2020. While in 2021 China received 48% of patents granted in permanent magnets overall, 99% of neodymium magnet patents and 86% 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.

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. We have seen increased weaponization of trade and supply chains around the world over the past decade, including from China with rare earth elements. 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 respond to any crisis or a demand shock. The near certainty of increased future demand will exacerbate this vulnerability.

With the industry status quo, potential vulnerabilities include the following, listed from most to least likely:

- 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. Given the ubiquity of these ingredients, this move 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 US-China trade conflict, causing price increases and shortages in key segments of the supply chain similar to the above scenario.
- Restriction of key raw materials in the event of a territorial dispute or more severe kinetic conflict that could affect US military readiness in defense of our allies and partners.

Before I address potential tools for the United States government, I will provide a short overview of Japan's relatively successful approach to similar vulnerabilities.

Learning from Japan

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.[xiii]

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 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).

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. They also have 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 lithium project in Argentina.[xiv] 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% 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. Through this process, at least three companies have received grants to develop rare earth-related companies in Vietnam and Malaysia.[xv] Japan is also pursuing cooperation with the United States and other allies (Canada, the European Union, and Australia) to maintain and develop expertise 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.[xvi]

Domestic and international interventions

In this section I assess possible interventions from the United States government, and their attendant 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. At this point, the United States and partners lack the capacity to maintain a rare earth industry outside of China and cooperation with China is in our best interest.

Diversifying at the Mining Stage

Diversification at the mining stage, either by further increasing US 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, for reasons I outline below. 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. **Easing environmental regulations is not recommended** as the political, economic, and social costs from backlash against the project would likely eliminate any gains.

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, US, 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.[xvii] 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 US 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. 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.[xviii]

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, 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.

Policy recommendations

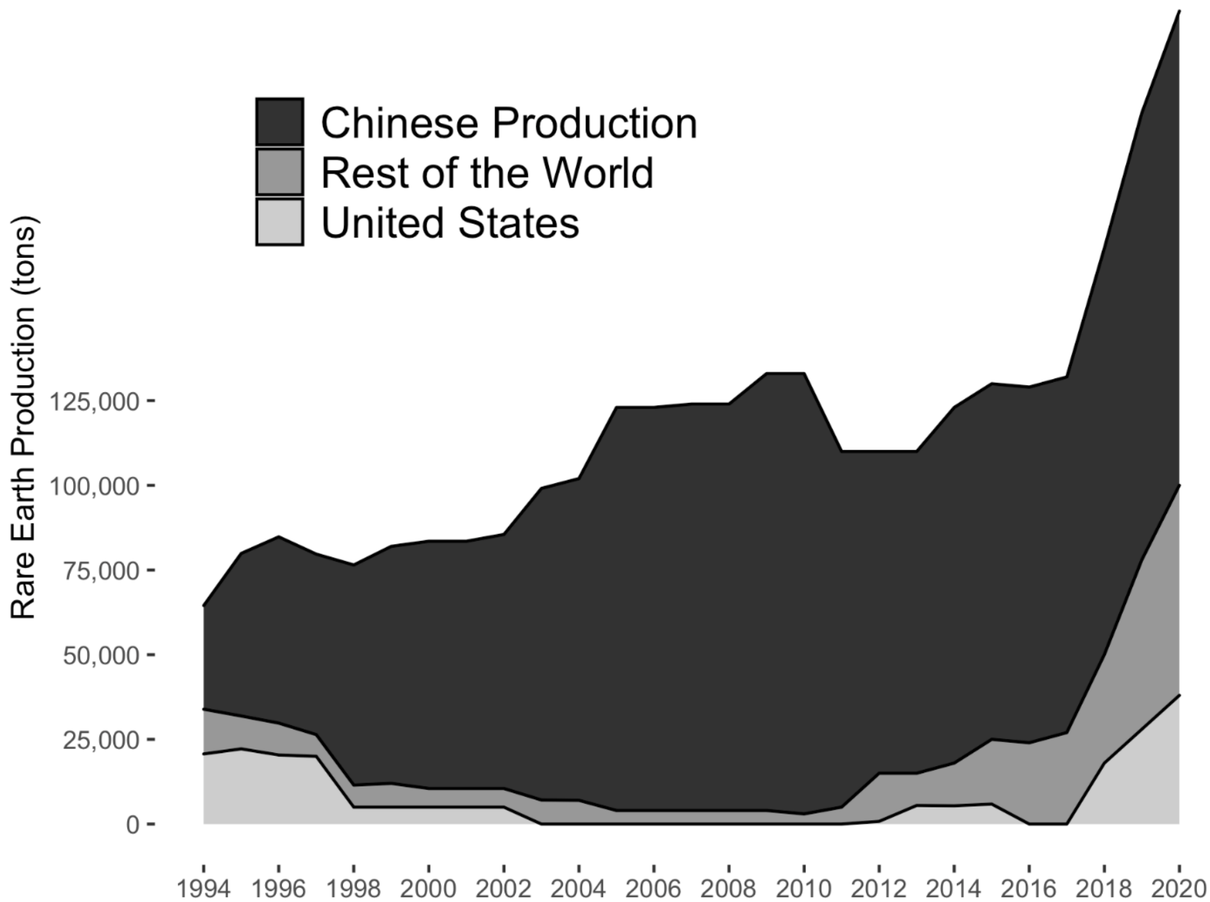
Full supply chain resiliency: The United States government can help ameliorate supply chain vulnerabilities in rare earths by diversifying along the supply chain. While a focus on the mining stage is tempting, attention to the midstream is likely to yield greater results. The midstream is currently more vulnerable and long-term thinking and innovation in this area can reap higher dividends for national strength and security. The United States 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 concerns, including the Quad and the European Union, and can build on existing programs. Some of these efforts are ongoing, but should be increased.

Solving information failures: The United States government should direct the Department of Commerce to increase information transparency in rare earths by developing an international price index, preferably in cooperation with China. While known market prices for all 17 elements would be beneficial, spot prices for neodymium and praseodymium are particularly pressing. This task could also potentially be accomplished through cooperation with international organizations such as the International Monetary Fund. Price transparency would facilitate success for new market entrants.

Public-private cooperation: The United States should 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. In conclusion, The US government should facilitate public-private cooperation in addition to cooperation with Chinese commercial entities.

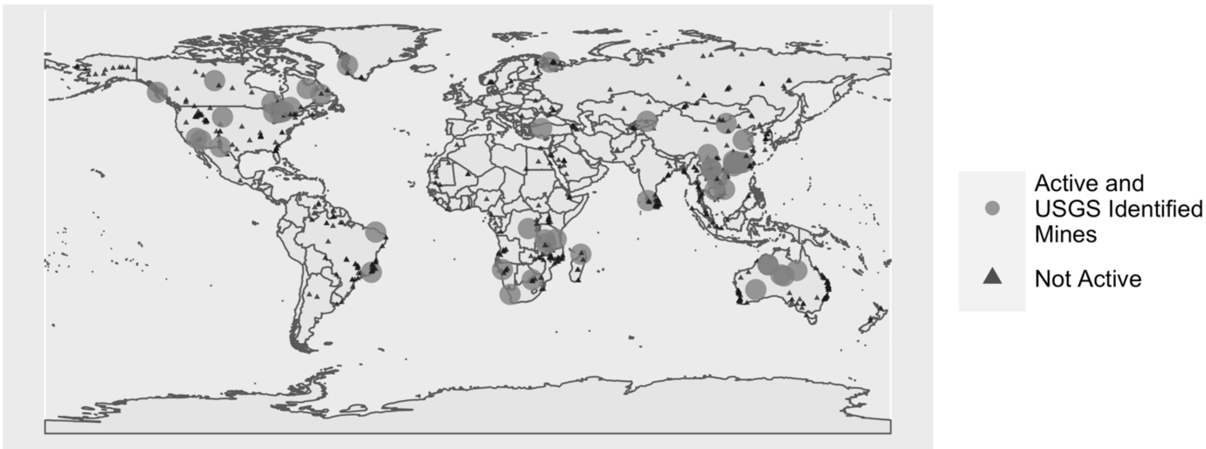
Appendix – Supporting Figures

Figure 1 Global Rare Earth Production, 1994-2020



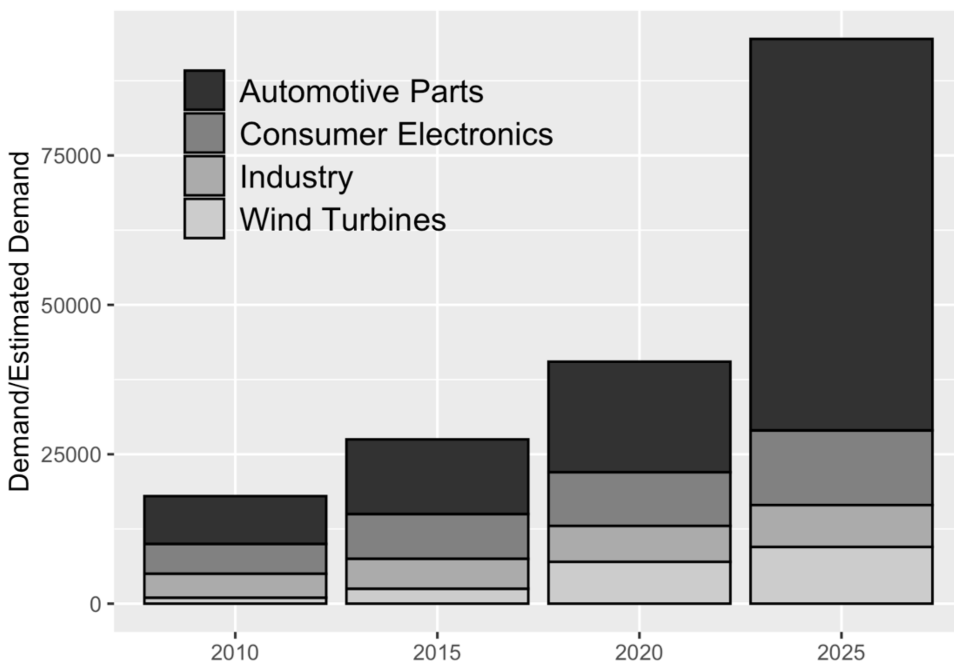
Data are from the US Geological Survey Annual Mineral Commodity Summaries and the author's calculations.[xix]

Figure 2 Global Rare Earth Mining Sites and Deposits



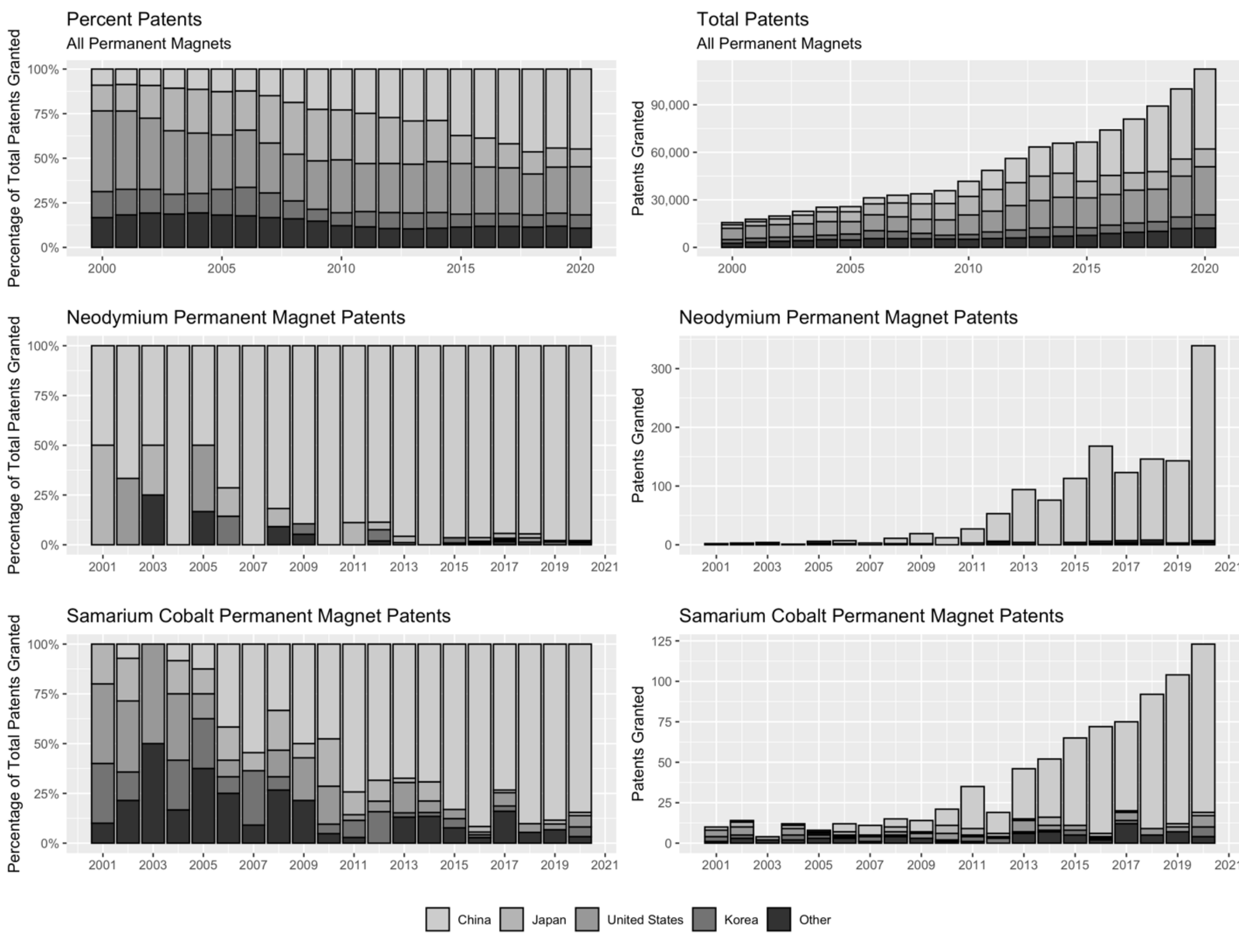
This map shows existing rare earth mines in addition to sites identified by the US Geological Survey as highly potential mining sites. Data comes from a USGS study by Labay et al. complemented by the author's own research.[xx] The primary takeaway from this figure is that rare earths are not geologically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

Figure 3 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 4 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.[xxi] 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.

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[i] P. Henderson et al., "Rare Earth Elements. A Briefing Note by the Geological Society of London," in *Geological Society of London*, 2011, 1–13.

[ii] Joanne Abel Goldman, "The US Rare Earth Industry: Its Growth and Decline," *Journal of Policy History* 26, no. 2 (2014): 139–66.

[iii] Kristin Vekasi, "The Geoeconomics of Critical Rare Earth Minerals," *Georgetown Journal of International Affairs* 22, no. 2 (2021): 271–79.

[iv] Julie Michelle Klinger, *Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes* (Cornell University Press, 2018).

[v] 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).
[vi] Xinhua, "China Rare Earth Group Founded in Jiangxi-Xinhua," December 23, 2021, https://english.news.cn/20211223/d29675f608ef46f3a2d00106eeef2b2c/c.html.
[vii] Yeping Yin, "China's Rare Earth Price Exceeds a Historic High amid Booming Demand and Tight Supplies - Global Times," November 12, 2021, https://www.globaltimes.cn/page/202111/1238808.shtml.
[viii] Sun Yu and Tom Mitchell, "State Interference Threatens China's Control of Rare Earth Production," *Financial Times*, October 29, 2020.
[ix] 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.
[x] 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, March 4, 2021), https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202103/P020210323538797779059.pdf.
[xi] Tom Daly, "China Becomes World's Biggest Importer of Rare Earths: Analysts," *Reuters*, March 13, 2019, sec. Commodities, https://www.reuters.com/article/us-china-rareearths-idUSKBN1QU1RO.
[xii] Adamas Intelligence, "Rare Earth Elements: Market Issues and Outlook," Adamas Intelligence, September 28, 2020, https://www.adamasintel.com/unfathomable-rare-earth-demand-growth/; Kirsten Hund et al., "Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition," *World Bank*, 2020.
[xiii] Kristin Vekasi, "Politics, Markets, and Rare Commodities: Responses to Chinese Rare Earth Policy," *Japanese Journal of Political Science* 20, no. 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, no. 3 (2021): 611–34.
[xiv] JOGMEC, "JOGMEC Integrated Report 2020," 2020, http://www.jogmec.go.jp/content/300373866.pdf.
[xv] Mireya Solis, "The Big Squeeze: Japanese Supply Chains and Great Power Competition," *Joint U.S.-Korea Academic Studies*, 2021; 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, July 17, 2020, https://www.jetro.go.jp/services/supplychain/kekka-1.html.
[xvi] "Fact Sheet: U.S.-Japan Competitiveness and Resilience (CoRe) Partnership," The White House, April 17, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/16/fact-sheet-u-s-japan-competitiveness-and-resilience-core-partnership/; "FACT SHEET: In Asia, President Biden and a Dozen Indo-Pacific Partners Launch the Indo-Pacific Economic Framework for Prosperity," The White House, May 23, 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/.
[xvii] James Kennedy, "China Solidifies Dominance in Rare Earth Processing," *National Defense Magazine*, 2019.
[xviii] Department of Energy, "DOE Launches $140 Million Program to Develop America's First-of-a-Kind Critical Minerals Refinery," Energy.gov, February 14, 2022, https://www.energy.gov/articles/doe-launches-140-million-program-develop-americas-first-kind-critical-minerals-refinery.
[xix] USGS, "Mineral Commodity Summaries" (Washington, DC: United States Geological Survey, 2021).
[xx] K. Burger Labay et al., "Global Distribution of Selected Mines, Deposits, and Districts of Critical Minerals," 2017.
[xxi] Google, "Google Patents," accessed May 11, 2022, https://patents.google.com/.