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Lessons from China's Weaponisation of Critical Minerals: A Case Study of Gallium and Germanium

Amit Kumar
Pranay Kotasthane[*]

Abstract

China's weaponisation of its dominance in the production of gallium and germanium between 2023 and 2025 failed to achieve sustained leverage over the United States. While Beijing's restrictive licensing requirements, and subsequent blanket ban successfully induced significant price volatility — with international retail benchmarks for high-purity variants appreciating by over 200 per cent — export controls did not translate into a contraction of the US' industrial consumption. The assessment reveals that the US' demonstrated remarkable resilience, bolstered by rapid substitutability, supply chain diversification, and even domestic capability building. For gallium, the US successfully pivoted to Japanese, German, and Canadian suppliers, reducing reliance on direct Chinese imports. With respect to Germanium, the US succeeded in insulating itself by relying on diversification, limited domestic production and robust domestic recycling capability.

Keywords: China; Critical Minerals; Gallium; Germanium; Export Controls; Trade Weaponisation; Economic Coercion

JEL Codes: F51; F52; F13; Q37

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[*] Amit Kumar is a Staff Research Analyst with the Geostrategy Programme and Pranay Kotasthane is the Deputy Director at the Takshashila Institution.

1. Introduction

As geopolitical contestation between the world's two largest economies shows no signs of slowing down, export controls have emerged as one of the most preferred tools for competing. In the past three years, both the US and China have resorted to a wide range of export control measures to impose costs on one another and test each other's resilience.

One such battle was fought over access to gallium and germanium. In July 2023, China imposed export restrictions on the sales of these two elements (Ministry of Commerce of the People's Republic of China 2023). It imposed licensing requirements on Chinese exporters and tightened end-user controls in an attempt to specifically target the US. The restrictions came into effect from August 1, 2023 (Ministry of Commerce of the People's Republic of China 2023).

The decision was significant, given China's dominance in the production of gallium and germanium and the US' overwhelming dependence on imports to service its needs. China continues to account for ~99 per cent of the global primary, low-purity gallium (99.99 per cent) production, (U.S. Geological Survey 2025a) and about 60 per cent of global germanium production (U.S. Geological Survey 2025b). This dominance enables Beijing to weaponise the world's dependence.

Gallium is essential to the manufacturing of certain kinds of semiconductors and optoelectronic devices (U.S. Geological Survey 2025a). Germanium, on the other hand, finds application in fibre optics, infrared optics, semiconductor applications, solar cells, and radiation detectors (U.S. Geological Survey 2025b). Given their specialised use cases in critical technologies, Beijing hoped to inflict strategic pain on the US.

Building on its previous restrictions, China, on December 3, 2024, further tightened the export controls and imposed a total ban on the sales of gallium and germanium to the US (Ministry of Commerce of the People's Republic of China 2024). The United States Geological Survey (USGS), in its November 2024 report, estimated that a total ban on exports of gallium and germanium from China could cost the US about $3.4 billion in GDP (U.S. Geological Survey 2024c).

China finally lifted the ban on November 7, 2025, until November 27, 2026 (Ministry of Commerce of the People's Republic of China 2025; "China Suspends" 2025). The licensing requirements, however, continue to remain in place (Ministry of Commerce of the People's Republic of China 2025).

Even as the ban stands withdrawn, the impact of China's restrictions on the US is a useful case study to examine the effectiveness of export restrictions. Two and a half years later, a few questions remain: Did China succeed in inflicting strategic pain on the US? Or did the US manage to weather the impact of export controls?

Answers to these questions can offer insights into China's preparedness and capability to weaponise trade, and the effectiveness of export controls in meaningfully inflicting sustained pain in the long term.

The lessons are relevant from India's standpoint too, given it has been a frequent target of similar restrictive measures by China. Lately, Beijing has blocked or restricted exports of speciality fertilisers, rare earth elements, tunnel boring machines, and semiconductor equipment to India through formal or informal means. Thus, an understanding of how China's attempts at weaponising played out against an adversarial state carries lessons for Indian policymakers as well.

2. Metrics of Policy Success

To evaluate whether China's export restrictions succeeded in imposing a punitive cost on the US, the paper examines how three metrics, namely consumption, substitution, and price, varied for each of the two elements in the US.

The primary objective of China's export restrictions was to create a supply shortage of the two elements, triggering panic among industries dependent on them. Hence, any fluctuation in the US' consumption of gallium and germanium emerges as the most significant metric to assess China's policy success. Consequently, the paper examines the long-term consumption trends of the US for both gallium and germanium. If export control measures succeeded in creating a scarcity of supply, i.e. pulling the US' consumption downwards, relative to previous years, Beijing can claim vindication. Alternatively, if consumption of the two elements fails to show any significant decline, Beijing's actions could be deemed unsuccessful.

However, it is entirely possible that the US found substitutes for gallium and germanium to compensate for the shortfall in their supply. In that case, a mere reading of its domestic consumption of gallium and germanium will be misleading. Hence, the US' substitution efforts – both by source and material – become a necessary metric to examine in case US consumption was subdued. If Beijing's actions manage to drastically reduce consumption without allowing the US's substitution efforts to succeed, it can claim policy success.

The third and final metric the paper assesses is price variation resulting from China's export restrictions. If export controls led to a drastic price hike, thereby increasing the economic cost for the US, China could claim success. However, this economic cost has to be read in conjunction with its impact on alternatives. If the surge in prices was complemented by the emergence of additional players, Beijing cannot claim success.

3. Gallium

According to the USGS, the US net import reliance (imports minus exports) as a percentage of its total consumption is 100 per cent (U.S. Geological Survey 2025a). It means the US depends entirely on imports to service its domestic demand of gallium.

Generally, the US' imports of gallium are primarily a mix of gallium metal and gallium arsenide (GaAs) wafers. Further, GaAs, gallium nitride (GaN), and gallium phosphide wafers together accounted for 83 per cent of the total gallium imports in 2024 (U.S. Geological Survey 2025a). Gallium metal, triethyl gallium, and trimethyl gallium accounted for another 17 per cent (U.S. Geological Survey 2025a).

The following subsections examine how consumption, substitutability and prices were affected in the US as a result of China's restrictions on the export of gallium.

3.1 Consumption

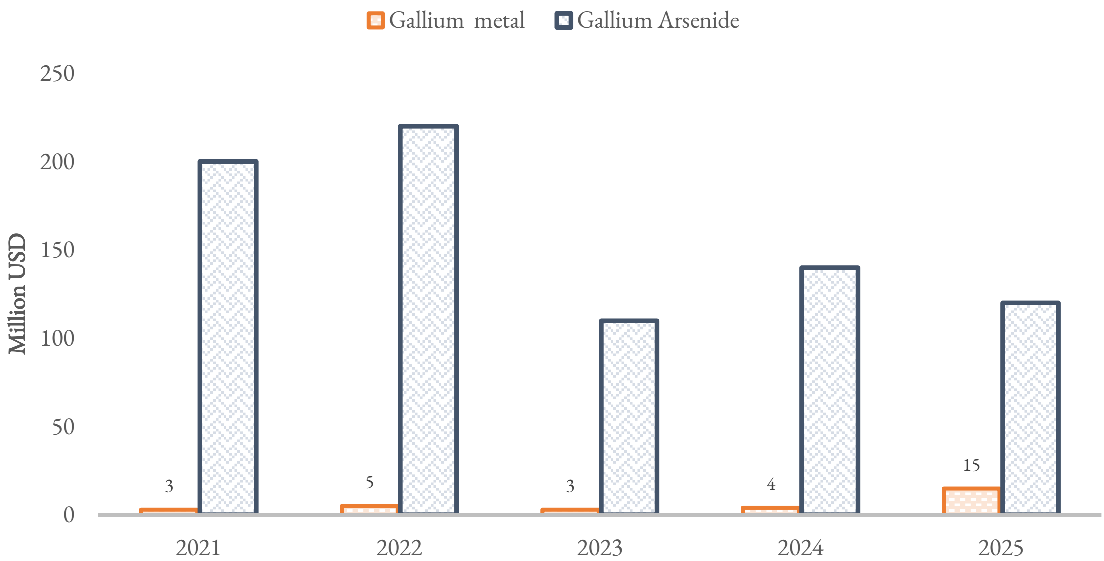
The data on US imports of gallium suggest that China managed to squeeze US imports after the licensing requirements took effect in August 2023.

In 2023, the US imports of gallium metal and GaAs almost halved compared to the previous year, falling to US$ 3 million and US$ 110 million, respectively (U.S. Geological Survey 2024a). While gallium metal imports declined 40 per cent year on year, the corresponding decline for GaAs imports was 50 per cent.

However, in 2024, the US imports recorded a marginal increase (U.S. Geological Survey 2025a). The gallium metal imports rose to US$ 4 million – a 24 per cent increase – while GaAs imports jumped to US$ 140 million – a 33 per cent increase.

The drop in 2023 was expected, as supply remained disrupted throughout most of the second half of the year due to China's sudden introduction of licensing requirements. As Chinese suppliers acquired the necessary licenses by the end of 2023, US imports of gallium metal in 2024 roughly rebounded to pre-licensing levels. However, it is important to note that the corresponding import figures for GaAs failed to rebound to pre-licensing levels.

Figure 1: Gallium Imports by Value

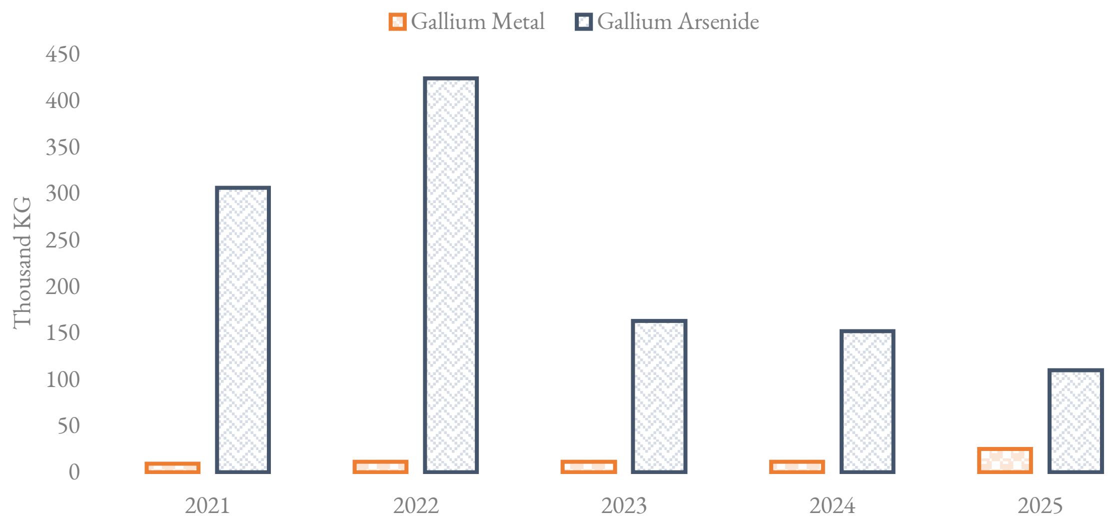


Source: USGS

In December 2024, China imposed a blanket ban on the export of gallium (and germanium) to the US, which it suspended in November 2025 for a one-year period. China's decision was aimed at imposing an even higher cost on US gallium consumption than its prior decision to subject US imports to licensing requirements.

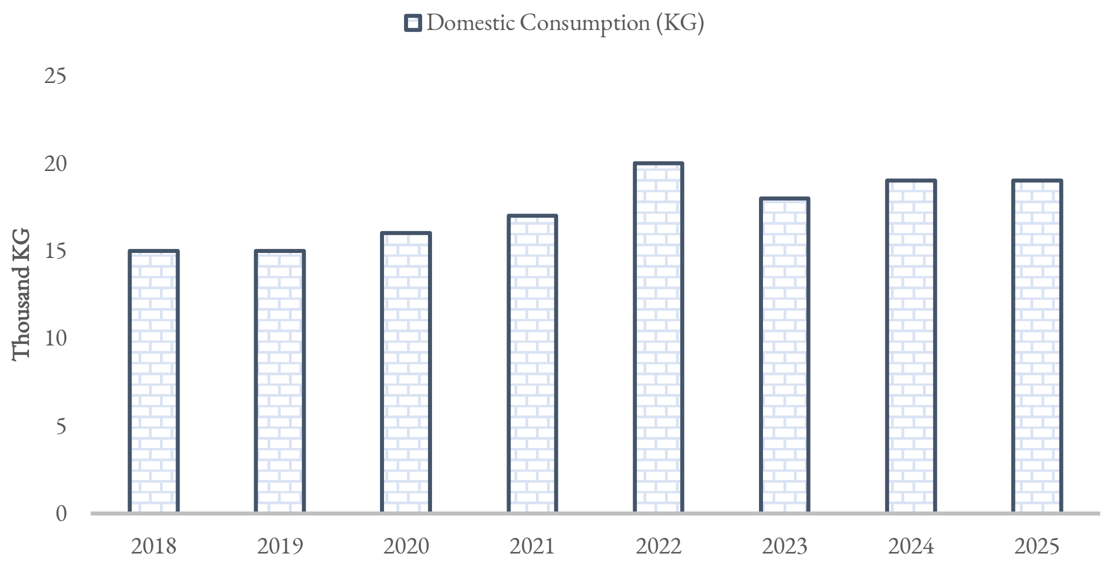
Defying expectations, US imports remained somewhat resilient. In 2025, US imports of GaAs wafers dropped marginally to US$ 120 million, a ~15 per cent year-on-year decline (U.S. Geological Survey 2026a). The decline wasn't as significant despite China's blanket ban. Interestingly, US imports of gallium metal increased nearly fourfold to US$15 million.

Figure 2: Gallium Imports by Volume



Source: USGS

Figure 3: Gallium Consumption by Volume



Source: USGS

Overall, two diverging trends become evident. First, US imports of gallium metal not only remained largely stable in 2023 and 2024, but it also witnessed a near 400 per cent increase in 2025. Second, US imports of GaAs halved in 2023 after the licensing requirement took effect, and hovered around that level in 2024 and 2025, despite the blanket ban taking effect in December 2024.

In volume terms, the decline in gallium arsenide imports was even sharper. From 424,000 kg in 2022, imports fell to 163,000 kg in 2023, and then to 152,000 kg in 2024. In 2025, it declined further to 110,000 kg, indicating a massive hit. On the other hand, imports of gallium metal, by volume, remained largely stable in 2023 and 2024 before registering an increase of over 200 per cent in 2025.

However, during this turbulent period (July 2023-Nov 2025), the US' reported domestic consumption of gallium (inclusive of gallium metal and gallium content in wafers) did not reflect any disruption. Not only did consumption remain stable, but it also saw a marginal year-on-year increase over the years, except in 2023.

Therefore, given that the US' consumption of gallium remained unaffected despite China's recourse to export controls, China can hardly claim any success on this metric.

3.2 Substitution

The US appears to have achieved substantial diversification away from China. In fact, that trend was already underway even before China unveiled the July 2023 restrictions.

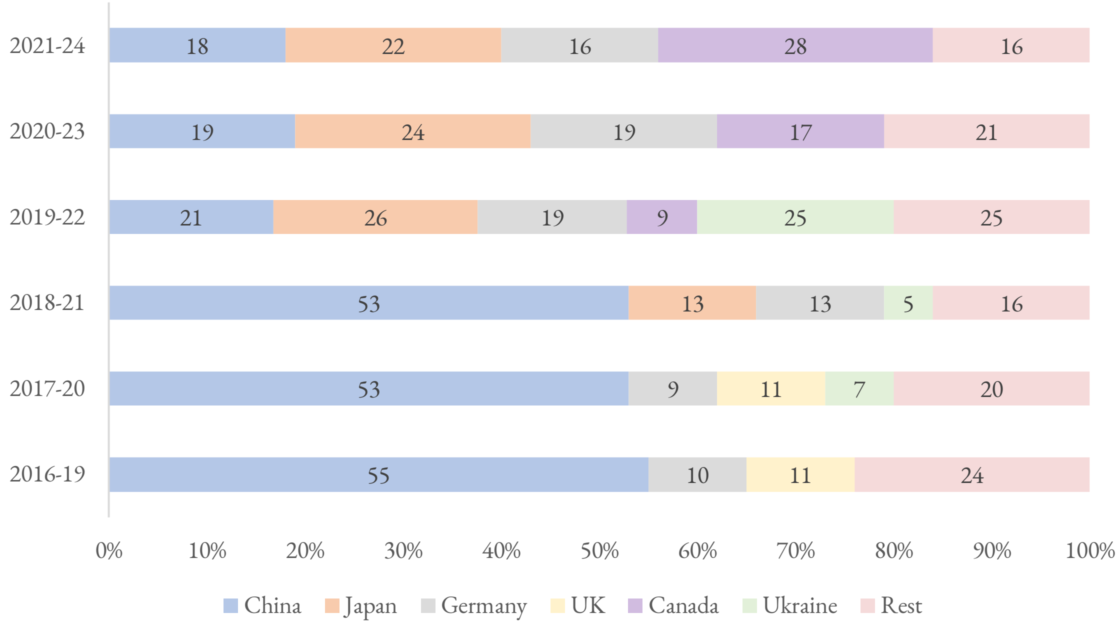
While the US entirely depends on imports to service its domestic gallium consumption, its consumption mix, coupled with China's lack of comparable dominance in processing low-grade gallium into high-purity gallium or wafers, limits its direct dependence on China.

China's current share of US imports of gallium metal has gradually fallen to less than 20 per cent, down from over 50 per cent in 2019 (U.S. Geological Survey 2021a, 2022a, 2023a, 2024a, 2025a, 2026a).

China accounted for 55 per cent of US imports of gallium metal between 2016 and 2019. Its share remained about the same until 2021. However, from 2019 to 2022, it fell sharply to just 21 per cent, suggesting a drastic decline in imports from China in 2022. Between 2021 and 2024, the US dependence on China has further reduced to 18 per cent. Canada, Japan, and Germany have emerged as the US' primary suppliers since 2022.

China's share in the US' imports of GaAs wafers, which in turn make up for an overwhelming majority of its total gallium imports, is even lower. For instance, from January 2021 to July 2023, when the licensing requirements were introduced, China's share in US imports of GaAs averaged a mere 4.8 per cent. Between July 2023 and October 2024, the share dropped below 1 per cent (Hendrix 2024).

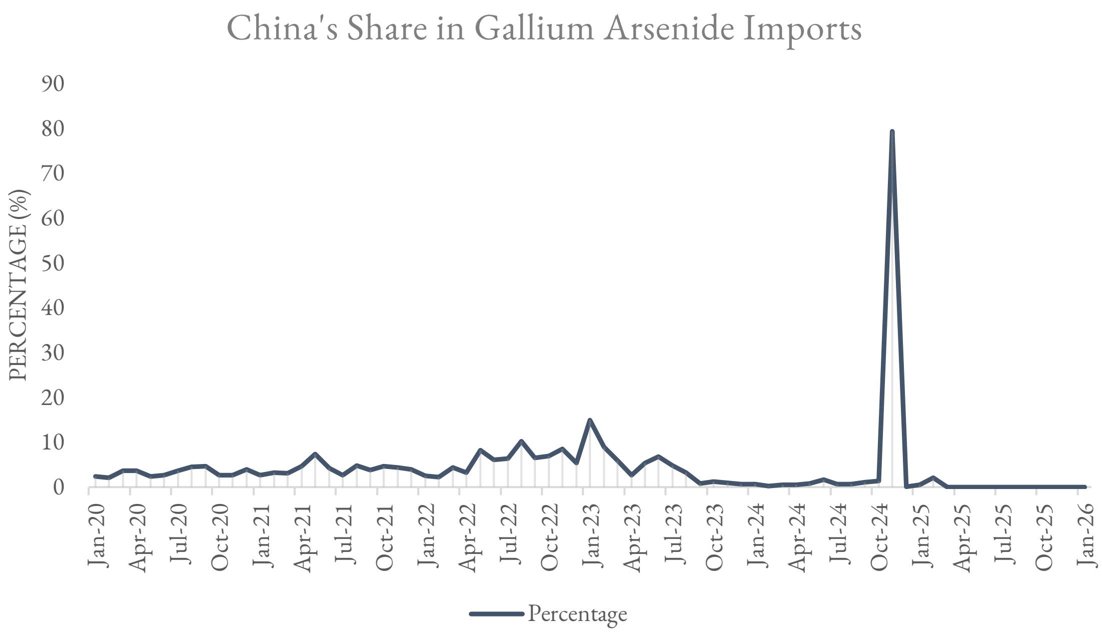
Figure 4: Gallium Metal Imports by Country



Source: USGS

Interestingly, in November 2024, just a month ahead of China's announcement of a blanket ban on the export of gallium to the US, its share soared to over 79 per cent before dropping back to its earlier levels (Hendrix 2024). Eventually, US imports of GaAs from China stopped in April 2025 and have remained so, since then.

Figure 5: China's Share in Gallium Arsenide Imports



Source: USA Trade Census

The data (see Figure 4) show that the US has substantially diversified its gallium imports away from China. But even more notable is that the US managed to sustain its domestic gallium consumption while diversifying away from China. The latest numbers, hence, suggest that the US consumption of gallium remained unaffected by China's export controls, be it licensing or ban.

The US managed to keep its gallium consumption afloat, despite China's export controls and subdued GaAs imports, through two approaches. First, scaling imports of gallium metal almost by 400 per cent. And second, expanding domestic production of GaAs and GaN wafers to offset import shortfalls (U.S. Geological Survey 2026a).

In addition, the US has also found alternatives for GaAs in certain applications, except in the defence and military domain. According to the USGS, liquid crystals made from organic compounds are substituting LEDs in visual displays (U.S. Geological Survey 2025a). Furthermore, silicon-based complementary metal-oxide-semiconductor power amplifiers are competing with GaAs power amplifiers in 3G cellular handsets (U.S. Geological Survey 2025a). Indium phosphide components have also emerged as substitutes for GaAs-based infrared laser diodes in some specific-wavelength applications (U.S. Geological Survey 2025a). Helium-neon lasers are competing with GaAs-based visible laser diodes in applications. GaAs use in solar cells is being replaced by silicon (U.S. Geological Survey 2025a). In heterojunction bipolar transistors, GaAs is being replaced in some applications by silicon germanium. However, in defence-related applications, GaAs- and GaN-based ICs are not easily substitutable owing to their unique properties.

Additionally, there is one facility in New York that recovers high-purity gallium by refining imported low-purity gallium and reprocessing the resulting scrap generated during the manufacture of GaAs wafers (U.S. Geological Survey 2025a). Metallium, an Australian company, is also establishing a recycling plant in the US to recover high-purity gallium from industrial electronic scrap (Recycling Today 2025).

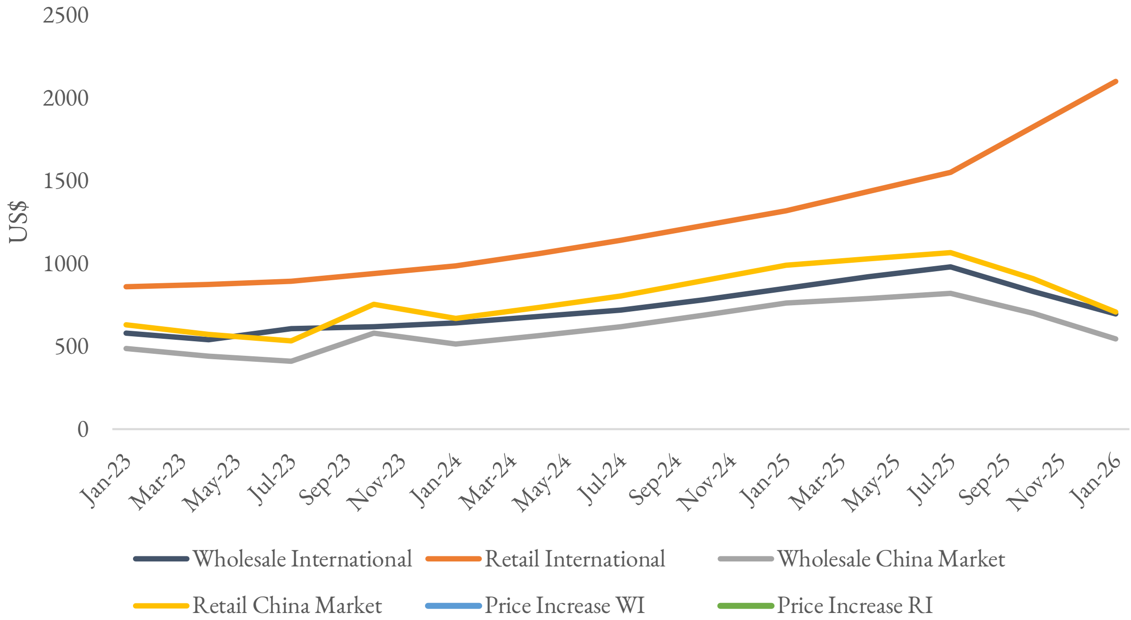
In September, the U.S. Department of Energy announced US$6 million in funding for research and development projects to help establish a domestic supply chain for gallium. This initiative was expected to support technologies to recover gallium from alumina refining or primary zinc smelting, with the goal of restarting domestic primary gallium recovery for the first time in almost 40 years. In November, the U.S. Department of War, under the 'Defense Production Act,' granted a US$ 29.9 million award to a U.S. company to develop a demonstration facility in Louisiana that will recover gallium and scandium from industrial waste (U.S. Geological Survey 2026a).

3.3 Price Volatility

Gallium prices can vary based on grade (high- or low-purity), distribution (wholesale or retail), and market (international, or within China). Data compiled from various sources indicate that average prices for gallium increased substantially after China imposed export controls in July 2023.

International retail prices for high-purity gallium witnessed the maximum appreciation. Wholesale prices in the international market for gallium closely tracked its retail prices in China. Even though China is not a global leader in processing low-purity gallium into high-purity gallium, the fact that it produces ~99 per cent of the global low-purity gallium, allows it to trigger downstream effects on high-purity gallium prices.

Figure 6: High-Purity Gallium Prices



Source: USGS, SMM, Trading Economics, and Strategic Metals Invest

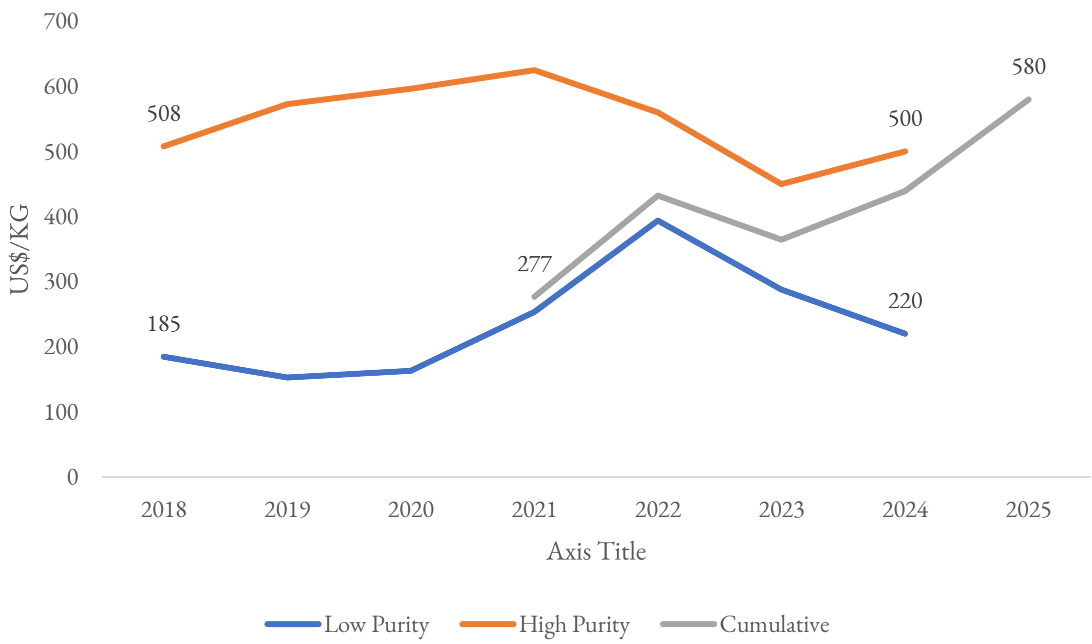
International retail prices for low-purity gallium also rose sharply. Unlike high-purity gallium, international wholesale prices for low-purity gallium traded above the wholesale and retail prices in China after July 2023. Until then, wholesale international prices and retail Chinese prices were largely in sync.

The average annual import prices for gallium reported by the USGS also indicate that they continued to rise substantially. Thus, China's action did succeed in raising costs for the US economy.

Figure 7: Low-Purity Gallium Prices

Source: USGS, SMM, Trading Economics, and Strategic Metals Invest

Figure 8: Average Gallium Price Reported by the US



Source: USGS. Purity wise average import prices for 2025 and cumulative prices before 2021 weren't available.

Yet, while the average import prices increased, the US' consumption of gallium remained largely unaffected, thereby undercutting China's success.

4. Germanium

US dependence on China for germanium isn't as acute. USGS data shows that the US' net reliance on imports as a percentage of estimated consumption is over 50 per cent (U.S. Geological Survey 2025b). However, its dependence on imports as a percentage of total consumption is about 86 per cent (authors' calculations based on U.S. Geological Survey data). The germanium import mix consists of two items, germanium and germanium dioxide. The following subsections examine how three factors—consumption, substitutability, and price—varied for the US in light of Chinese export restrictions.

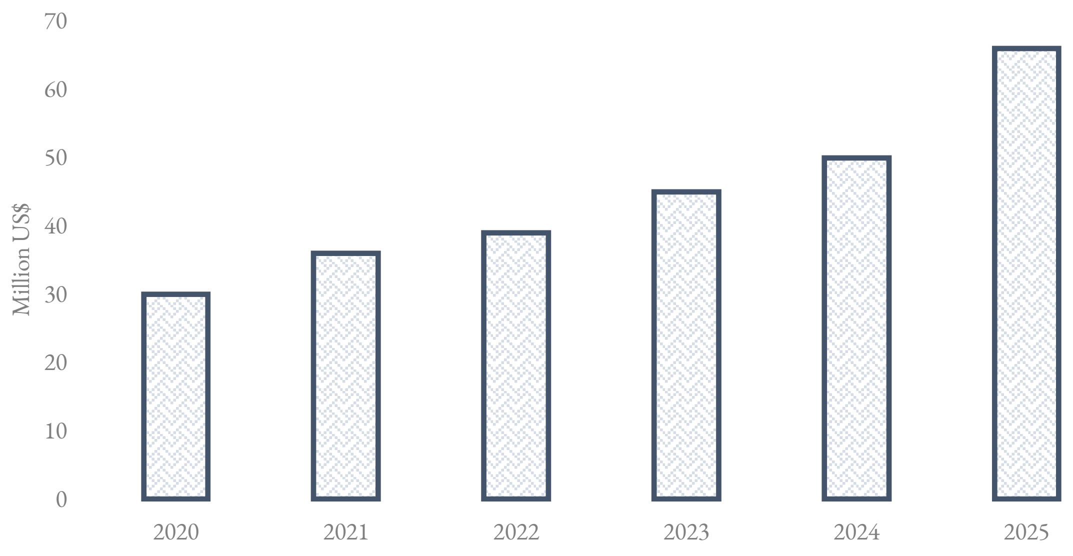
4.1 Consumption

Despite the licensing restrictions that came into effect in July 2023, which affected supplies throughout most of the second half of the year, the US' annual imports of germanium by value showed no impact. In fact, the US' imports by value increased by over 15 per cent in 2023 and then by 11 per cent in 2024 (U.S. Geological Survey 2025b, 2024b).

Interestingly, the spike was even greater in 2025–32 per cent in value terms–even as the second round of restrictions in December 2024 came into effect, which banned the export of germanium to the US (U.S. Geological Survey 2026b).

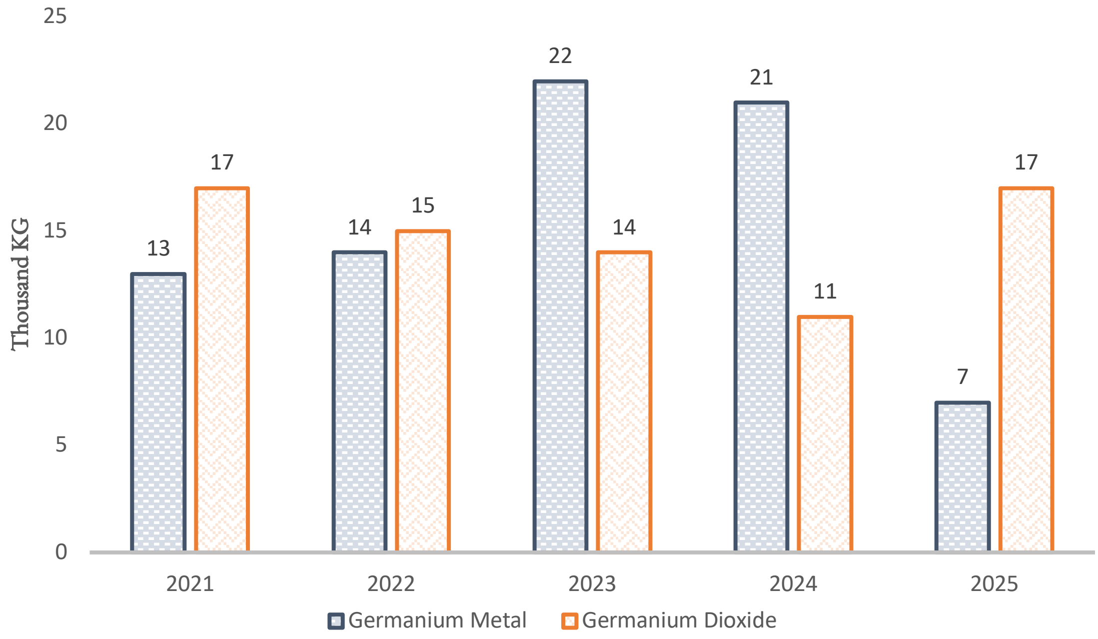
Assessing the US import of germanium by volume sheds more light on these counterintuitive trends. The imports of germanium metal shot up by 57 per cent in 2023 despite the licensing requirements disrupting the global supplies for most of the second half of the year. The imports of germanium dioxide in 2023 remained largely unchanged from 2022 in volume terms, recording a marginal 6.6 per cent decline (U.S. Geological Survey 2024b, 2023b).

Figure 9: Germanium Imports by Value



Source: USGS

Figure 10: Germanium Imports by Volume



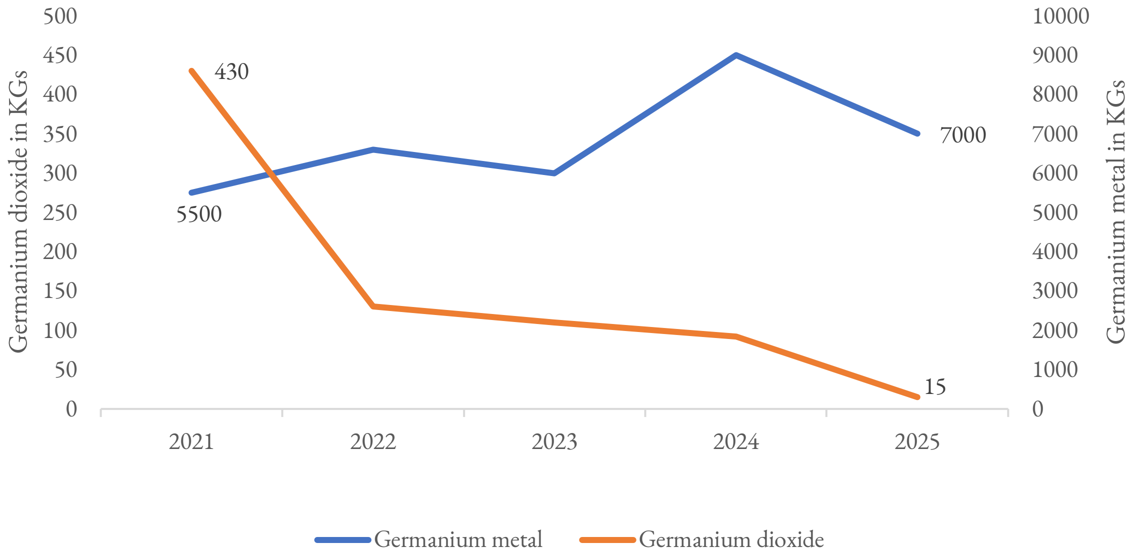
Source: USGS

In 2024, while the licensing requirements remained in place for most of the year, until December 2024, when China announced a blanket ban, US imports of germanium metal remained substantially high, at 21,000 kg, compared to 22,000 kg in 2023 (U.S. Geological Survey 2025b, 2024b). This was a significant jump from the average 13,500 kgs of germanium metal imported by the US in 2021 and 2022. The import of germanium dioxide, on the other hand, saw a 21 per cent year-on-year volume drop in 2024 before sharply rebounding to 17,000 kg in 2025. The import of germanium metal in 2025, however, was only a third of the volume imported in 2024.

Only if the USGS had published annual domestic consumption data for germanium, as it does for gallium, would it have been easier to evaluate the impact of China's export restrictions on the US. However, a lack of domestic consumption data limits the assessment.

Nevertheless, there is a greater likelihood that the US consumption of germanium didn't suffer either despite China's export restrictions. One, germanium dioxide imports by volume in 2025 were the highest since 2021. Second, while imports of germanium metal sharply declined in 2025, it is possible that the decline was due to stockpiling of the metal in the previous two years, as evidenced by the fact that metal imports skyrocketed in 2023 and 2024. Third, the US maintains a national stockpile of germanium, which it must have dipped into to meet its requirement. Fourth, the US has a significant recycling capability to recover germanium from scrap (U.S. Geological Survey 2026b). And finally, the US' exports of germanium metal and dioxide indicate that a significant amount of domestic capacity was consumed locally in 2023 and 2025. The US's exports in 2023 declined as export restrictions came into effect. But as licenses were procured by the end of 2023, allowing for imports from China, the US exports of germanium dioxide increased. However, after China announced a blanket ban in December 2024, the US' export figures dipped sharply again.

Figure 11: Germanium Exports



Source: USGS

Thus, the data from the past five years show that China's export restrictions failed to adversely affect US consumption of germanium. Despite Beijing's attempts to choke the global supply, the US managed to meet its demand.

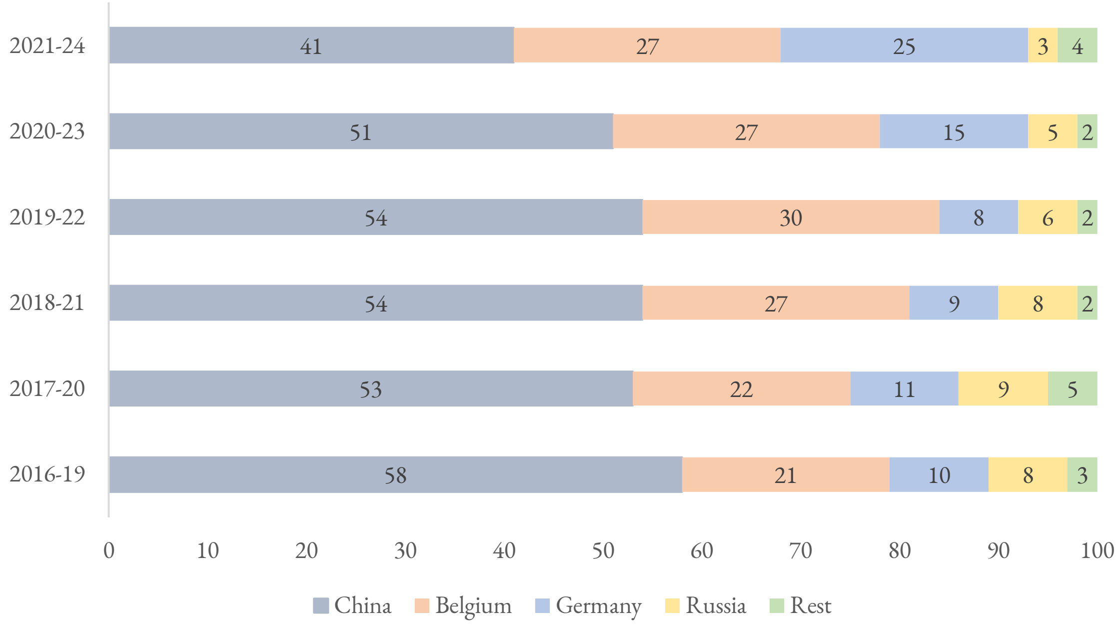
4.2 Substitution

Even though the US is not completely dependent on imports to meet its domestic needs, they are substantial by value. Figure 12 shows US' import dependence by country relating to germanium metal. It reveals that import dependence on China remains significant, even as it may have reduced in recent years (U.S. Geological Survey 2021b, 2022b, 2023b, 2024b, 2025b, 2026b).

However, China does not figure as a significant source of imports for germanium dioxide. In fact, Belgium and Canada alone account for over 93 per cent of the US imports of germanium dioxide.

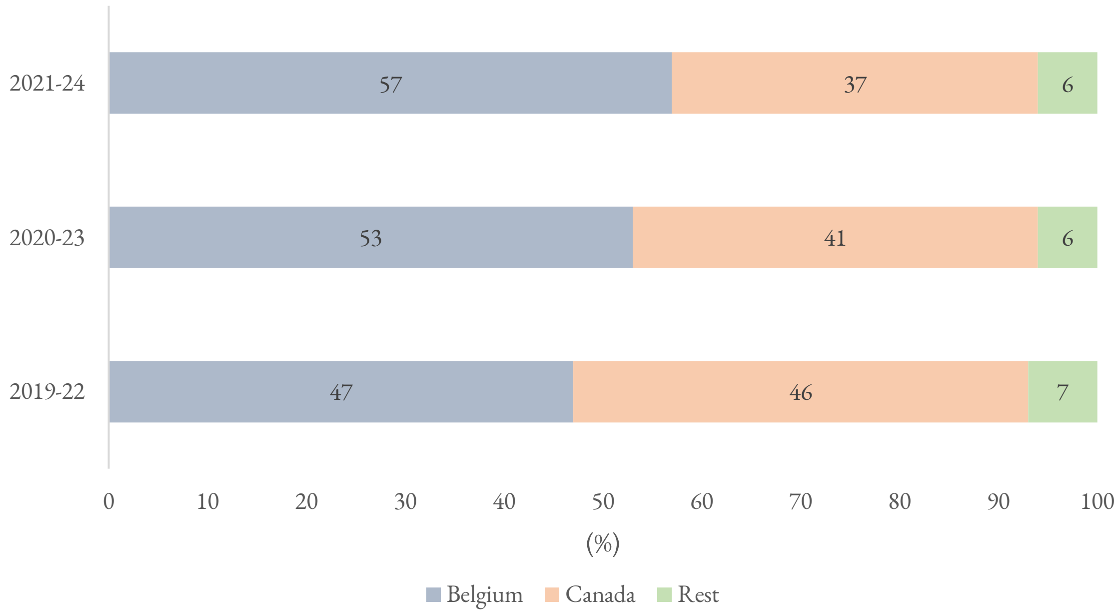
While measuring overall dependence, China makes up for under a quarter of US imports. This perhaps mitigates the impact of Beijing's export restrictions on germanium.

Figure 12: Germanium Metal Imports by Country



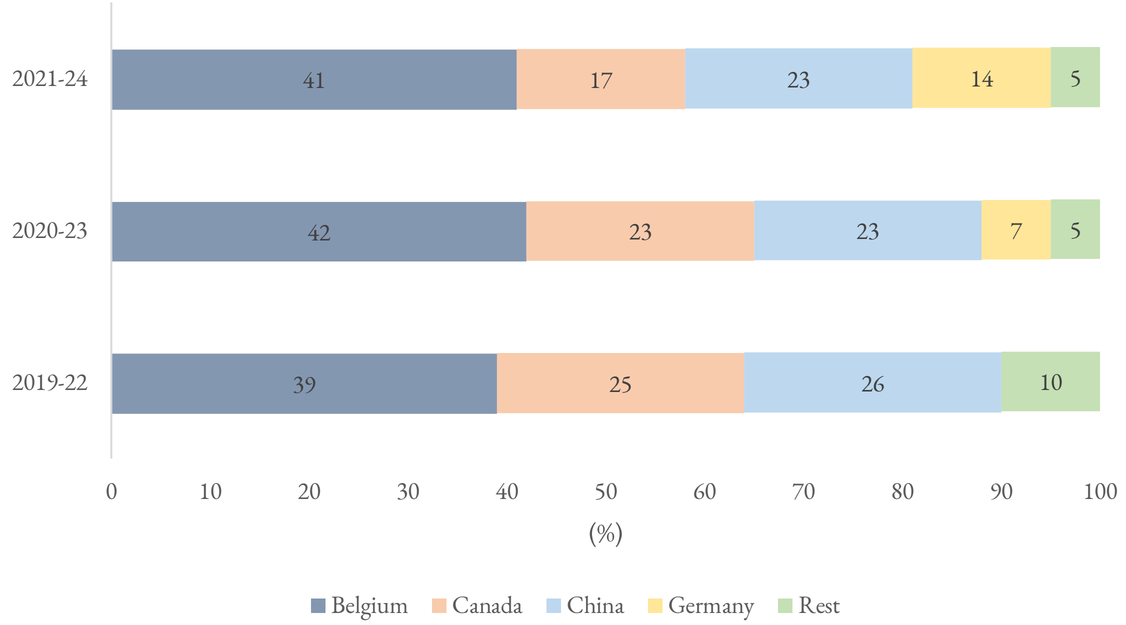
Source: USGS

Figure 13: Germanium Dioxide Imports by Country



Source: USGS

Figure 14: Germanium Dioxide Imports by Country



Source: USGS

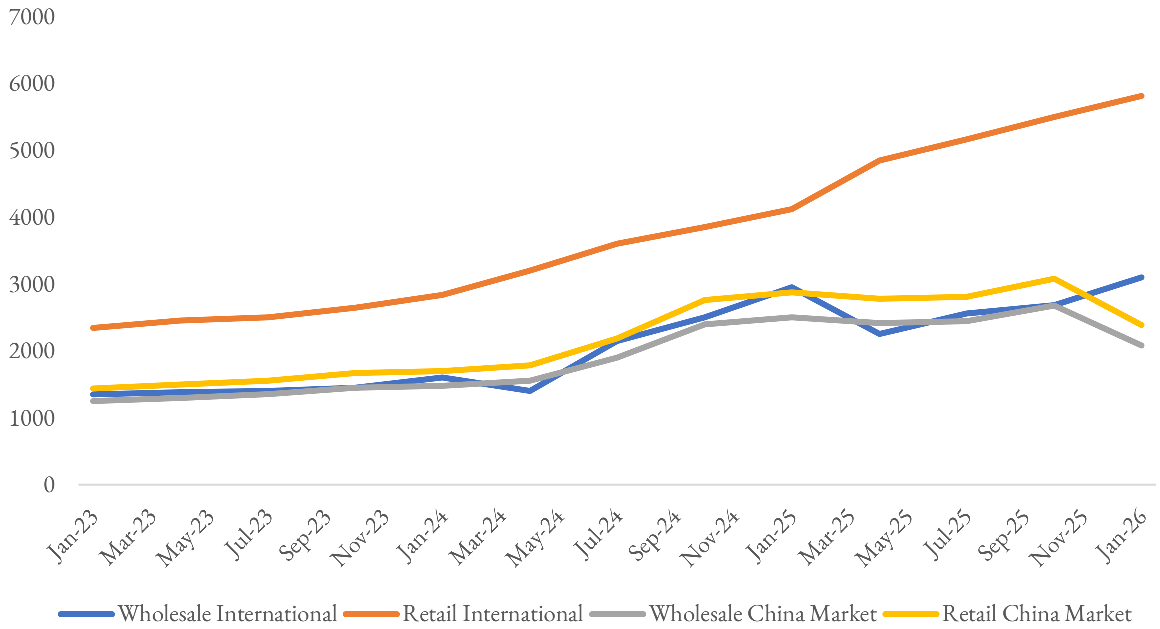
Moreover, the US has a significant domestic capacity. A facility in Alaska mines germanium-rich zinc concentrates that are exported to Canada for further processing. In addition, the US has extensive capacity to recycle germanium from both pre- and post-consumer scrap. For instance, infrared lenses and windows from decommissioned military equipment are routinely recycled to recover germanium. Further, machining scrap from the production of infrared germanium optics and optical fibres is also recycled. Lastly, germanium wafers used as solar cell substrates are reclaimed for reuse.

Substitution of germanium with an alternative material is also possible in certain applications. For instance, silicon or gallium arsenide can substitute germanium in certain electronic applications. Furthermore, some metallic compounds can substitute for germanium in high-frequency electronics and certain light-emitting diode applications. Chalcogenide glass has been used as a substitute for germanium metal in infrared applications. Antimony and titanium are substitutes for use as polymerisation catalysts.

4.3 Price Volatility

China isn't as dominant a player in germanium production, accounting for only 60 per cent of global output. Yet, international retail prices of high-purity germanium have appreciated two-and-a-half times since January 2023. By January 2026, international wholesale prices for high-purity germanium were 2.2 times higher than those in January 2023. The prices in China also appreciated substantially during this period.

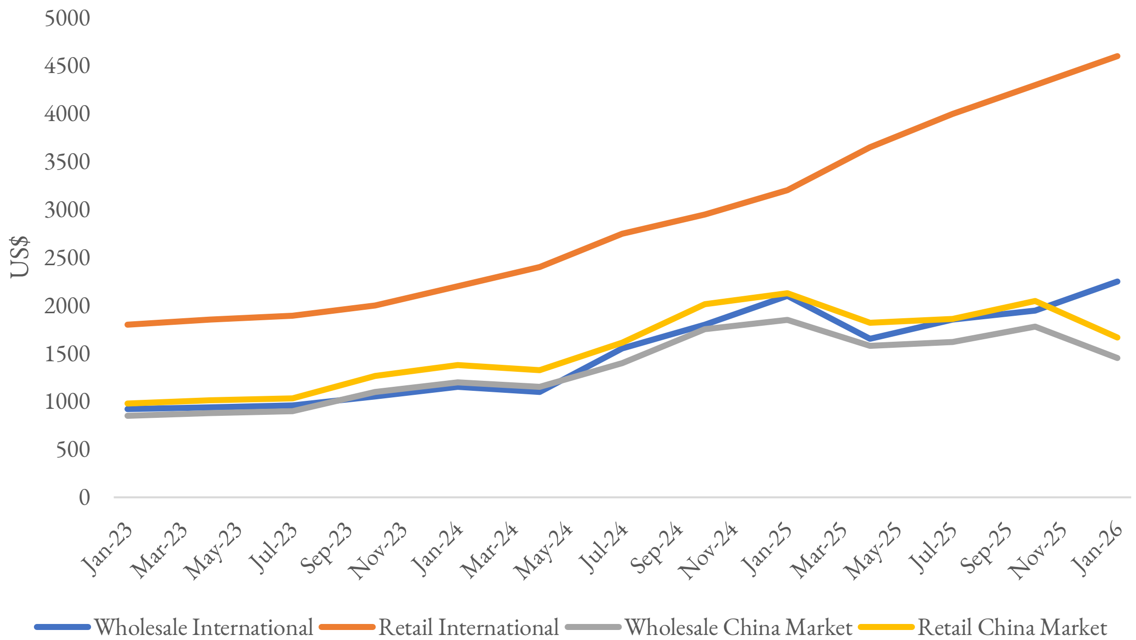
Figure 15: High-Purity Germanium Prices



Source: Earthrarest, SMI,ChemAnalyst, IMARC, SMM, Fastmarkets, Argus, USGS, Mordor, Scrapmonster

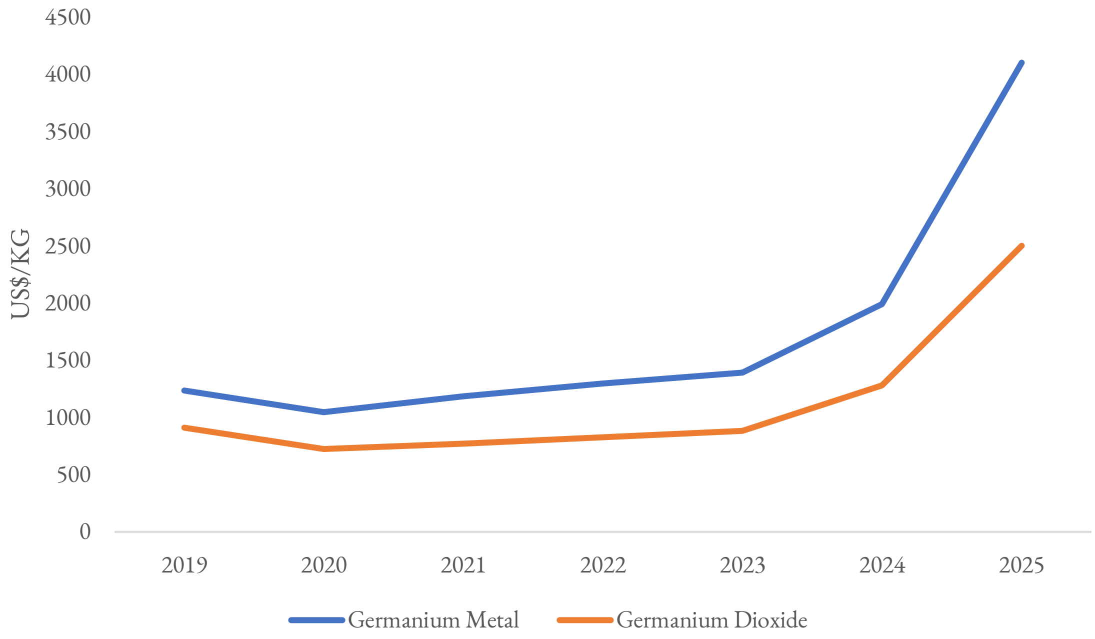
The trend was largely similar for low-purity germanium. International retail prices in January 2026 were at least two-and-a-half times higher than in January 2023. International wholesale prices of low-purity germanium also increased by a factor of 2.4 over the three-year period.

Figure 16: Low-Purity Germanium Prices



Source: Earthrarest, SMI, ChemAnalyst, IMARC, SMM, Fastmarkets, Argus, USGS, Mordor, Scrapmonster

Figure 17: Average Germanium Price Reported by the US



Source: USGS via Argus Media Group

According to USGS, the US has experienced a significant increase in annual average prices of germanium metal and germanium dioxide in 2024. After the total ban took effect in December 2024, the average import price of germanium in the US increased sharply (U.S. Geological Survey 2026b).

The data suggest that in 2024 and 2025, China succeeded in imposing economic costs on the US. Nevertheless, the US consumption of germanium does not seem to have been impacted at all.

5. Conclusion: Lessons for India

Geo-economics, alongside geopolitics, now increasingly defines the US-China rivalry. Semiconductors, rare earths, and critical minerals have emerged as the linchpins of the new battlegrounds where the struggle to gain and restrict access is unfolding.

The overarching trend to have surfaced in this regard is the frequent weaponisation of resources. Consequently, export controls have become increasingly popular as a tool of economic coercion. There's a growing conviction, both in the US and in China, that dependence, if plausible, must be weaponised to protect strategic interests. Each of the two largest economies now operates an expansive, coercive economic toolkit, which they are constantly improving and perfecting to inflict greater damage on the other.

The case study of gallium and germanium is instructive in this regard and offers a few insights. Recourse to export controls will undoubtedly increase economic costs for the target entity—the US, in this case. The average price paid by the US for gallium and germanium during the two-and-a-half-year period that saw China impose export controls and bans rose sharply.

Beyond triggering a price spike, the export measures' effectiveness remained limited. To begin with, the divergence of interests between the government and businesses perhaps also undermined the intended objective. A lack of alignment in their respective interests often gives way to black marketing, smuggling, and rerouting. Further, a single-country ban undermines the effectiveness of export controls by allowing leakage via a third country.

But there is another, much more significant factor that determines the effectiveness of export controls. It concerns whether dependence results from market forces or a significant capability differential. Conversely, a lack of alternatives could be a function of either market or capability gap.

In cases, where the requisite capability is diffused, but the market acts as an inhibitor, a sustained price rise can break the monopolistic dominance. China's predominant position in the production of gallium and germanium is a product of its price competitiveness. Hence, the market can resolve the distortion if prices remain elevated for an extended period.

However, given China's overwhelming dominance in the global production of these two elements, it can also discourage such substitution efforts by flooding the global market with cheap supplies.

Consequently, in such a scenario, state intervention becomes key to mitigating the impact and building resilience. Besides offering subsidies, the options include acquiring equity stakes in potential alternatives, ensuring a minimum price floor for emerging alternatives, and providing preferential market access by mandating domestic content requirements. The US has already experimented with some of these.

For India, the more durable response lies in coordinated action alongside domestic measures that include offtake guarantees, strategic stockpile, research funding for substitutes, and trade agreements that keep alternative routes open. The above case study affirms that such coalitions, working in concert with allied economies, redirect supply chains faster than any single country's production-linked incentive scheme.

However, for the market and the state to work in tandem to break the monopolistic dominance of the coercive state requires one precondition—the differential capability gap between the coercive and dependent country or the rest of the world is not significantly high. If the differential capability is significant, as with advanced photolithography tools, export control can be relatively effective. If not, export restrictions may fail to achieve the desired results. Beijing's dominance in gallium and germanium falls into the latter category. Its sustained weaponisation of resources is likely to trigger greater global diversification in the long run.

The broader takeaway, particularly for India, is one of calibrated urgency. Not every dependence on China warrants the same policy response. Where capability is diffused, as with gallium and germanium, diversification will work. Where the dependence rests on a genuine capability gap, sustained capital infusion (government and private), preferably in partnership with like-minded countries, towards capability and capacity building is needed.

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