

A Brief Analysis of the Security Logic of China's Export Controls on Gallium and Germanium

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Abstract: Since August 1, 2023, China has implemented export controls on gallium, germanium, and their compounds. As a major trading country, China is a responsible major power, constantly improves its export control system, and contributes positively towards global security. Although discovered earlier, the production of gallium and germanium is relatively small. International industrial division of labor and market development have promoted the continuous evolution of trade in gallium and germanium. Global resource endowments of gallium and germanium and their trade relations directly impact the security fields. Implementing export controls on gallium and germanium will contribute to safeguarding China's national security and interests. In addition to directly reducing the threat of the United States that uses gallium and germanium products to produce weapons, it will also help maintain the stability of the gallium and germanium supply chain, strengthen China's leading position in the global supply chain of related products and secure the competitive opportunities for Chinese enterprises in related industries to safeguard industrial security. In order to effectively implement controls on gallium and germanium, enhance the resilience of the relevant supply chains, and fulfill its international commitments, China should actively adopt diversified synergistic promoting and safeguarding measures.

Keywords: Export Controls, Gallium, Germanium, National Security

Export controls, unlike export prohibition, rely on licensing and other mechanisms to ensure that exports align with specific policy objectives. On July 3, 2023, the Ministry of Commerce (MOFCOM) and the General Administration of Customs (GAC) of the People's Republic of China issued Notice No. 23 of 2023. This notice imposed export controls on gallium metal (elemental), gallium nitride, gallium oxide, gallium phosphamide, gallium

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arsenide, indium gallium arsenide, gallium selenide, gallium antimonide, as well as germanium metal, zone-fused germanium ingots, phosphorus germanium zinc, epitaxy growth substrates, germanium dioxide, and germanium tetrachloride.¹ Starting on August 1, these items were prohibited from being exported without permission of the administration. This announcement marked a significant adjustment to the import and export license management catalogue for dual-use items and technologies following the implementation of the Export Control Law of the People's Republic of China on December 1, 2020, which garnered significant attention and was poised to have numerous profound global implications. It will impact global weapons production in the military fields and may trigger a domino effect in the global semiconductor industrial chain and supply chain. This could provide a more secure external environment for China's development.²

I. EXPORT CONTROL IS AN IMPORTANT MECHANISM FOR CHINA TO FULFILL ITS RESPONSIBILITY AS A MAJOR POWER IN MAINTAINING GLOBAL SECURITY

The advent of export controls is linked to the evolution of international trade. Multilateral trade agreement, a cornerstone of international economic law, grant WTO members the right to a security exception. This clause permits members to breach their obligations or infringe upon the interests of other members under specific conditions to protect their paramount security interests. Consequently, members can employ economic strategies to achieve political objectives while upholding fundamental national security interests. Nonetheless, the political, diplomatic, military, and security dynamics between international trade participants exert a more immediate and pronounced influence on the enactment of export controls.

1 Bureau of Industrial Security and Import and Export Control, Ministry of Commerce of the People's Republic of China, Announcement of the Ministry of Commerce and the General Administration of Customs on the Implementation of Export Control on Gallium and Germanium Related Items No. 23 of 2023, July 3, 2023, <http://mofcom.gov.cn/article/glml/202307/20230703419666.shtml> (Last Visited on May 5, 2024).

2 Zhipei Chi, The Implementation and Constraints of the US Strategy of Scientific and Technological Containment of China, *Pacific Journal*, Vol. 6, No. 6, 2020, pp. 27–42.

A. Export Control Systems Emerged in Western Countries and Developed Rapidly during Wartime

While export controls between the United States and the United Kingdom have a long history, the former has implemented intermittent export restrictions since its establishment, particularly during periods of war and armed conflict. In the 18th century, Britain banned the export of machines used in wool, silk, cotton, and flax production, while Alexander Hamilton, then US Treasury Secretary, tried to circumvent it.³ The US has employed both quantitative restrictions and export bans to regulate the export of arms and technology, given that the Constitution bars Congress from imposing taxes on exports. The modern era of export controls in the US can be traced back to 1940, when Congress granted the president the authority to oversee military equipment and ammunition. Following the United States' involvement in World War II, this authority was broadened to encompass civilian goods. The President of the United States was granted the power to establish export control policies, considering national security, foreign policy, and economic factors.⁴ After World War II, the United States, along with 17 other members, established the Coordinating Committee on Multilateral Export Control (CoCom) to impose an embargo on the Soviet Union, China, and other socialist nations. Although this export control regime ceased to function in the 1990s, a series of multilateral export control regimes including the Australia Group (AG), Chemical Weapons Convention (CWC), Missile Technology Control Regime (MTCR), Nuclear Suppliers Group (NSG), Wassenaar Arrangement (WA) and Zangger Committee have taken shape and exerted extensive influence worldwide.

B. China Undertakes the Responsibility of a Major Trading Power, and Actively Interacts and Cooperates with Its Trading Partners

As a global power, China has forged close economic and trade ties with a wide spectrum of nations, possessing an escalating influence in both scope and strength. It has emerged as the largest trading partner for over 120 countries

3 David J. Jeremy, British Technology Transmission to the United States, *Business History Review*, Vol. 47, No. 1, 1973, pp. 24–52.

4 Congressional Research Service, The US Export Control System and the Export Control Reform Act of 2018, Updated on June 7, 2021.

and regions. The evolution of China's foreign trade not only furnishes robust support for nations to capitalize on their comparative advantages and cater to domestic market demands but also significantly impacts the interplay among global industrial, supply, and value chains. Furthermore, China is the central node of the global trade network. To effectively undertake the responsibilities inherent to a major power, China not only complies with the resolutions of international organizations like the United Nations (UN), but also orchestrates both internal and external affairs in alignment with international norms and proactively engages in initiatives. In April 2004, the UN Security Council unanimously passed Resolution 1540. This resolution mandated all nations to enhance their domestic oversight and export controls of weapons of mass destruction, along with materials and technologies, to thwart the acquisition of these items by non-state actors. Concurrently, China became a member of the NSG in 2004, revised the Regulations on the Control of Nuclear Export and the Regulations on the Control of the Export of Dual-use Nuclear Items and Related Technologies. Additionally, China has sought membership in the MTCR and to engage in, communicate, discuss and have dialogues with WA on the related issues of export control. While cooperating internationally, China emphasized constructing domestic legal frameworks. Based on references to international practices and its own experience, the Export Control Law came into effect on December 1, 2020. This legislation codifies existing export control measures to ensure national security and interests, meet international obligations such as non-proliferation, and enhance the regulation of export controls. The enforcement of this law fortified the legal foundation of export controls. It has become an important basis for domestically coordinating and optimizing the export control system, facilitating international trade relations, and enhancing the stability of the export control-related legal environment.

C. Due to Geopolitical Conflicts, Countries Are Becoming More Active in Implementing Export Controls to Ensure Security

Within the past several years, there has been a marked increase in global geopolitical conflicts. These encompass terrorism, state disputes, military coups, and armed conflicts, all of which represent non-traditional modes of conflicts that are reshaping the primary forms of confrontation and imposing

greater demands on international trade. While international trade primarily aims to enable all parties to leverage their resource endowments, economic and industrial strengths, exchange needs through equitable transactions, and foster economic development, its adverse effects cannot be overlooked. Although it is undesirable for some countries to abused export control measures through enacting the so-called “competitive strategies” against commodities and technologies with extensive and fundamental applications, such as those in the semiconductors industry, under the guise of national security protection, leaving the international trade detrimental to international security and social development unattended is not beneficial for maintaining the secure, rational and sustainable international economic and trade relations. The international community and governments frequently express concerns and allegations that international trade compromises global peace and security. For instance, pickup trucks can be utilized to transport weapons or enhance weapon mobility also due to their superior passing ability and robust power. Similarly, civilian drones have been employed in military offensives, including reconnaissance and the damaged of explosives. Furthermore, SpaceX satellites offer low-orbit communication relay services where communication infrastructure has been damaged, potentially altering the balance of power in geopolitical conflicts. The pursuit of maximizing interests alone is insufficient to meet the security needs of the international community. The world’s trading powers are both responsible for and capable of assuming a more proactive and significant role in managing import and export trade flows. The development, enhancement, and execution of China’s export control system epitomize its commitment to its responsibilities as a major global power. This is crucial for mitigating the misuse of trading goods and achieving its objective of peaceful progress.

II. THE GLOBAL ENDOWMENT AND TRADE RELATIONSHIP OF GALLIUM AND GERMANIUM RESOURCES AFFECT SECURITY DIRECTLY

As minerals were discovered late and existed as byproducts, the market supply and demand relationship of gallium and germanium cannot be fully reflected in their prices. The influence of production capacity and demand on suppliers

is indirect. The United States, the world's leading importer of gallium and germanium, relies heavily on these for both military and civilian industries, while China is the primary exporter. In recent years, with the deepening of gallium and germanium development and the expansion of its application scope, the development of compound alternative raw materials has been accelerated, creating more favorable conditions for the development of the global semiconductor industry.

A. The Acquisition Method and Usage Characteristics Determine the Limited Scale of Global Gallium and Germanium Production

The market prices of natural resources are closely related to their acquisition costs and uses. Unlike precious metals such as gold and silver, and commonly used metals like iron, aluminum, and copper, gallium and germanium were both discovered late, were both predicted to exist by the scientists before they were found. In 1871, the Russian chemist Dmitri Mendeleev synthesized the periodic table of elements and postulated the existence of an undiscovered “alumina-like element” after zinc and beneath aluminum in the table. Four years later, a French chemist discovered this element from sphalerite and named it gallium, derived from Gallia, the Latin word for Gaul, or ancient France. Mendeleev also posited the existence of a “quasi-silicon element” situated between silicon and tin. In 1886, German chemist Friedrich Winkler extracted this element from silver mines, and named it germanium, derived from Germania, the Latin word for Germany. Gallium and germanium are less readily available than gold and silver, have fewer direct consumer uses and lower economic demands, and are both base metals. They are typically procured as byproducts of other minerals from nature, making their prices historically low and attracting limited international attention. The extraction of gallium and germanium as byproducts has an intrinsic link to their associated ores. This significantly influences the unique market supply and demand dynamics, as well as the price mechanism for these elements. In comparison to global steel production, which was 1.89 billion tons of crude steel in 2022,⁵ gallium and germanium are exceedingly scarce, representing less than one in ten million of this volume. Despite their

⁵ World Steel in Figures 2023, <https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2023/> (Last Visited on August 25, 2023).

minute quantities, these elements are crucial to industrial processes. The supply chain relationships between these metals are determined based on their unique characteristics and applications in production and daily life. A report by the US Congressional Research Service (CRS) indicated that global gallium production increased significantly from 100 tons in 2000 to 320 tons in 2017, with China contributing to approximately 94% of it. Similarly, global germanium production escalated from 71 tons in 2000 to 106 tons in 2017, with China accounting for 57% of it.⁶

B. Gallium and Germanium Have Gained Extensive Attention with the Development of the Semiconductor and Optical Industries

The current practical applications of gallium and germanium are closely related to semiconductors and optics. At the time of their discovery, besides being used as containers due to their strong malleability, metals were also important for conducting electricity. However, gallium and germanium, which have poor electrical conductivity, were not considered useful. The value of gallium and germanium was not discovered until the late 1930s. In 1941, the accelerated advancement of germanium semiconductor components facilitated the substitution of germanium diodes for vacuum tubes in electronic devices. This transition, coupled with the escalating demand for radar technology, significantly increased the consumption of gallium and germanium. Over 80% of gallium is used in the semiconductor industry, where both metals are utilized as compounds.⁷ Gallium arsenide is utilized in high-speed logic chips and preamplifiers for mobile phones, while aluminum gallium arsenide and indium gallium arsenide are light-emitting materials for blue laser diodes.⁸ The conversion of electricity into laser light endows gallium arsenide with the capability to manufacture light-emitting diodes and solar cells. Furthermore, it is a crucial material in semiconductor products essential for defense applications and high-performance computing. Electronic devices that emit light and operate at radio frequencies, fabricated from gallium nitride, are used

6 Congressional Research Service, Critical Minerals and US Public Policy, June 28, 2019, p. 14.

7 Shenghui Zhang et al., List, Application and Global Pattern of Critical Minerals of China, *Conservation and Utilization of Mineral Resources*, No. 5, 2022, p. 148.

8 Brennan M., Gregarious Gallium, *Nature Chemistry*, No. 6, 2014, p. 1108.

in sectors such as wireless infrastructure and satellite technology. Gallium-based power semiconductor components are crucial materials in the fabrication of radar and communication equipment. Copper indium gallium selenide thin films are highly efficient at generating photovoltaic power, while gallium arsenide-based metal-semiconductor field effect transistors are key materials for microwave integrated circuits widely used in phased array radar equipment. Gallium products not only form a crucial foundation in semiconductors but are also extensively applied in the military sector.

Germanium, similar to other elements, has major applications in fields such as optical fibers, infrared technology, solar energy, and semiconductors. Germanium tetrachloride can enhance the long-distance transmission capacity of optical fibers. Furthermore, germanium can often be combined with gallium to have a crucial role. Gallium arsenide lasers necessitate the use of germanium lenses and windows. High-efficiency germanium-based gallium arsenide multijunction solar cells are ideal for space-based systems such as satellites and space stations. These include infrared imaging devices used in remote-controlled unmanned weapons and drones. Germanium's significance as a raw material in the information age was underscored by the invention of the point-contact transistor in 1947. However, this role has evolved with technological advancements. The improvement of silicon refining technology in the 1960s temporarily reduced the industrial demand for germanium, but the new demand for silicon-germanium alloys in microchips has recently begun to increase. Military infrared night vision equipment and optical fiber communication apparatus, constructed from germanium, are pivotal in the production of weapons, including warplanes. The principle of demand determining supply is evident here, with comparative advantage as the catalyst for international trade. The United States, recognized as the world's largest importer of semiconductor products, imports gallium and germanium for both commercial applications and to bolster its expanding global military influence.

Throughout the past few years, the US has continually expanded its support for Taiwan province of China through arms sales. Moreover, it has increased the deployment of military bases in the Philippines and elsewhere, and invited other so-called allies to demonstrate their force under the guise of "freedom of navigation" and joint military exercises. This poses a severe threat

to China's national security. Advanced fighter jets, including the F-35, have increased regional security risks due to their superior capabilities. After China imposed sanctions, Lockheed Martin and other weapons makers said that this would not affect the production of F-35 fighter jets even if China imposed a total embargo on key products including gallium and germanium sold to the United States in the short term. However, after their inventory is depleted, the production of weapons may require dynamic adjustments, which suggests that export controls on key materials could potentially benefit regional security.

C. The International Industrial Division of Labor and the Market Development to Promote the Continued Evolution of Trade in Gallium and Germanium

Gallium and germanium are the primary raw materials within the supply chain, with their trade distribution reflecting an international competitive landscape. According to the United Nations Commodity Trade Statistics Database (UN Comtrade), gallium, germanium, indium, niobium, and vanadium are classified under HS811292. Furthermore, as stated in Announcement No. 23 of the MOFCOM and the GAC in 2023, both gallium and germanium are subject to export control measures. Figure 1 shows that the number of countries importing gallium and germanium globally is exhibiting a fluctuating decreasing trend. On the one hand, as more countries become interested in the uses of gallium and germanium, they attempt to increase imports; on the other hand, due to limited exports and international competition, the number of importing countries is restricted, with a decrease observed for three consecutive years since 2020.

The trade value of gallium and germanium has shown a downward fluctuating trend. Recently, due to surging demand, nations have been increasingly willing to effectively utilize gallium and germanium. The processing and refining of compounds with enhanced added value have also led to changes in the global trade patterns of goods made from gallium and germanium. The data depicted in Figure 2 reveals a gradual decline in the global import value of gallium and germanium. This value gradually decreased from \$1.32 billion in 2011 to \$570 million in 2022, a decrease of 56.8%; during the same period, the export value dropped from \$1.1 billion to \$420 million, a maximum decline of 61.8%. The concurrent decrease in both imports

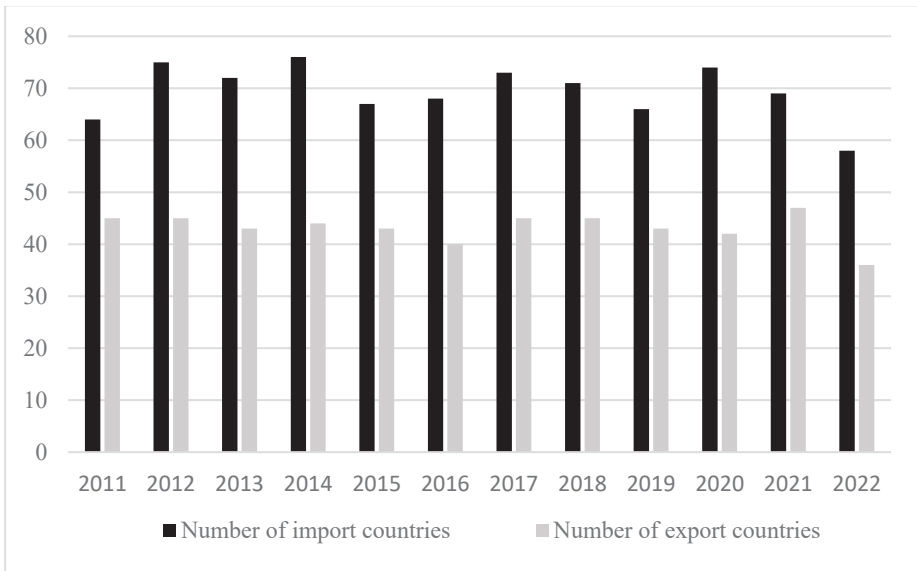


Figure 1: Number of Countries Importing and Exporting Gallium and Germanium from 2011 to 2022

Source: Prepared by the authors based on UN Comtrade data.

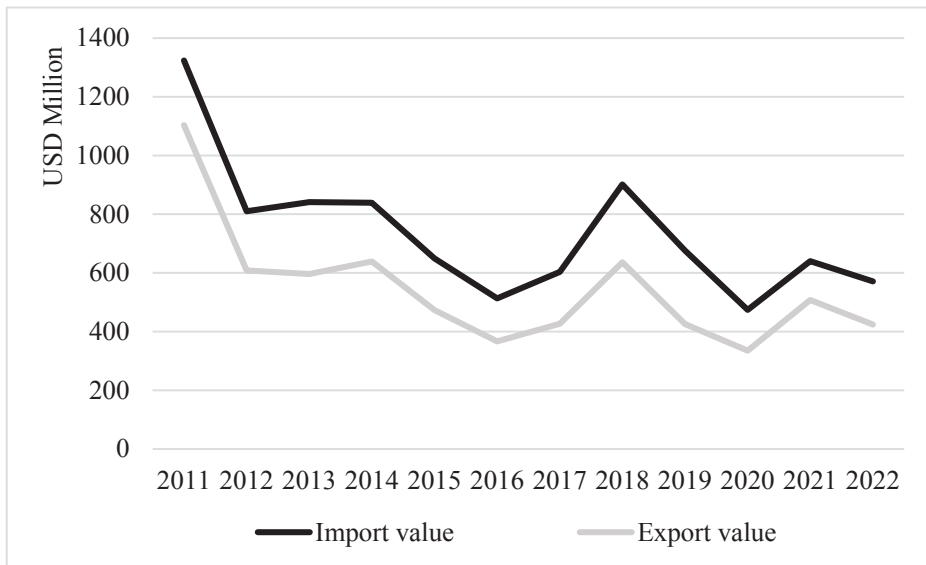


Figure 2: Global Import and Export Value of Gallium and Germanium from 2011 to 2022

Source: Produced by the authors based on UN Comtrade data.

and exports indicates that the supply-demand equilibrium for gallium and germanium may be more strained than expected. The complexity and expense associated with preparing raw materials, coupled with the rapid advancement of compound products, suggest a heightened emphasis on safety considerations.

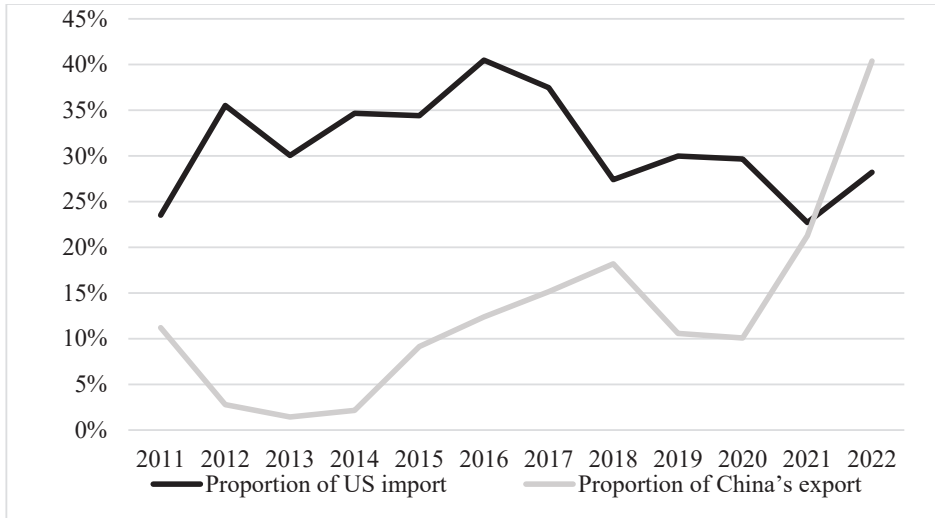


Figure 3: Global Proportion of US Gallium and Germanium Imports and China's Global Proportion of Similar Goods Exports from 2011 to 2022

Source: Produced by the authors based on UN Comtrade data.

Specifically, both China and the United States hold significant positions in the global gallium and germanium import market. Figure 1 illustrates that between 2011 and 2022, the United States' import value of gallium and germanium constituted 25% to 40% of the global total, a low position within the past few years. Conversely, China's market share of gallium and germanium exports has rapidly increased, particularly since 2020, rising from 10.1% to 40.4% in just 2 years. In 2022, the value of US imports for gallium and germanium was \$160 million. However, China's exports of gallium declined by 58% year-on-year in the first eight months of the year. Furthermore, after gallium exports surged to 8.63 tons in July — double the previous month — exports of both gallium and germanium fell to zero in August, as mentioned

in GAC data. Despite a lag in the impact of trade on supply and demand, it is anticipated that in the next stage, market forces will cause the industrial chain to undergo significant adjustments.

D. The United States Uses Technology and Other Advantages to Benefit More from Compound Trade in Gallium and Germanium

Despite the decline in trade for metal products, there has been significant progress in gallium and germanium compounds. American companies have leveraged technological advancements and innovative ideas to import raw materials such as gallium and germanium to satisfy domestic needs, including military needs. These companies then gain additional benefits through compound processing and exportation, thereby gaining control over the global value chain. For instance, gallium nitride, characterized by its high hardness and broad material energy gap, is a crucial material for high-power and high-speed photoelectric components. It is used for producing 405 nm violet laser diodes, indicating a substantial demand for this application. Between January and June 2023, Chinese customs data indicates that gallium nitride (primarily classified under customs codes HS28500019, 38180090, and 38256900) was exported to 64 countries or regions, amounting to a value of \$380 million. The top ten export destinations for gallium nitride, based on export value, are detailed in Table 1. The Republic of Korea emerged as the primary destination for Chinese gallium nitride exports, constituting over a third (34.2%) of China's total gallium nitride exports. This was closely followed by India (13.4%) and Japan (12.9%), with the United States (6.8%) ranking fifth, just behind Taiwan province of China (9.4%). In the first half of 2023, the top ten export destinations collectively accounted for 90.7% of China's total gallium nitride exports. The structure of national and regional gallium nitride exports in China is intricately linked to the trade relationships among its trading partners. Furthermore, the global industrial division of labor significantly influences it. The United States imports a limited amount of gallium nitride products from China. This trade dynamic is further corroborated by the UN Comtrade data. When comparing the trade volume of HS285000, it was observed that in 2022, a total of 49 countries or regions globally exported this commodity. The United

States led the rankings with \$300 million in exports, representing 41.5% of the global market share. China followed in second place, contributing to only 21.7% of the global market share. At the same time, if we compare the gallium nitride exported from the United States with its imported metal gallium and germanium raw materials, it is apparent that American companies have used domestic production and processing in the United States to exert a stronger influence on the supply chain without relying on a large amount of local raw materials.

Table 1: Top Ten Countries or Regions of Gallium Nitride Exported from China from January to June 2023

Number	Trading Partner	Export Amount (US Dollar)	Percent
1	The Republic of Korea	128410652	34.2%
2	India	50174433	13.4%
3	Japan	48429618	12.9%
4	Taiwan Province of China	35223947	9.4%
5	US	25373066	6.8%
6	German	15257232	4.1%
7	Hong Kong SAR of China	9859126	2.6%
8	Austria	9787235	2.6%
9	Singapore	9549916	2.5%
10	Philippines	8586367	2.3%

Source: Prepared by the author based on the GAC database.

III. GALLIUM AND GERMANIUM EXPORT CONTROLS CONTRIBUTE TO THE MAINTENANCE OF NATIONAL SECURITY AND INTERESTS

The national security of a major power is not only significant for its well-being but also has a substantial external influence due to its extensive foreign economic and trade network. The primary motivation behind the export controls of gallium and germanium is to protect China's national security and interests. Furthermore, this measure aligns with the security and development objectives of countries who have close economic and trade ties with China. Beyond the direct security threat that the export of products used as weapons components poses to China, recent global supply chain restructuring has significantly

impacted China's economic security. Threats to supply chain security may arise when some countries disrupt global supply chain synergy and trust, as well as when technological innovation potentially influences the supply-demand relationship of resources. Export controls on gallium and germanium involve their main compounds, which is expected to form a more effective umbrella control and reduce the leakage effect of the policy. Implementing judicious export controls can help alleviate uncertainties in the development of industries related to gallium and germanium, safeguard enterprises and employment, and align with the new innovation-driven developmental paradigm.

A. The Byproduct Status of Gallium and Germanium Directly Affects Its Price Formation Mechanism

The price of a commodity is typically dictated based on the balance between supply and demand, with excess supply leading to decreased prices, and vice versa. However, from an economic perspective, the relationship between supply and demand for gallium and germanium significantly differs from that of bulk metal products such as iron, aluminum, and copper. As byproducts, the supply and demand dynamics of gallium and germanium diverge markedly from those of their main products. In terms of supply, the output of byproducts is depended on the main product. For example, gallium is mainly produced as a byproduct of aluminum when extracted from bauxite or zinc when extracted from zinc ore, and a small amount comes from the recovery of elemental gallium from the charcoal. Regardless of whether this process involves amalgam electrolysis, lime milk, solvent extraction, or ion exchange, most of the world's gallium is currently extracted from seed liquor used in alumina production. Consequently, the production of gallium does not surpass the gallium content of its minerals. If the main product is less produced, the output of byproducts will remain constrained. This disparity in the status of the main product and byproduct implies that an escalation in its market price will not result in a short-term increase in output. Even in the long run, the economic dynamics of byproducts struggle to respond to their supply and demand, leading to an inelastic supply curve.

Under general circumstances, the price of the main product can affect supply and demand, thereby influencing the supply of byproducts. However, if

the price of byproducts rises rapidly and there is a significant profit margin, it may attract investors and promote technological innovation. This could lead to more refined and comprehensive extraction from the main product, increasing production without changing the output of the main product. Another difference between the main and byproducts relates to cost allocation. Only the costs related to the production of byproducts affect their supply cost, while the main product bears the joint costs associated with both main product and byproduct's production. Therefore, the production cost of byproducts is lower. The thinktank of Congressional research service (CRS) in the United States suggests that rare earth elements (REE) are byproducts of iron ore production in China, and their cost will be significantly lower than the cost of producing them as a main product elsewhere in the world.⁹ Byproducts are not necessarily costless in the traditional sense, but may be zero under two circumstances. Firstly, these byproducts must be isolated to generate the main product. Secondly, byproducts can be procured after separation without additional processing.

B. Export Controls on Raw Materials Will Profoundly Impact Global Supply Chains

Economic globalization has led to the effective division of roles in global supply chains. Companies use their strengths to collaborate in global industrial chains, with raw materials, processing capabilities, and markets as the three most direct links that connect and synergize within the global supply chains. Meanwhile, technological research and development (R&D), manufacturing of processing equipment, and trade support services empower the supply chains. Except for raw materials such as uranium, which serve as radioactive fuel but are also utilized for nuclear weapon production, export controls have predominantly been applied in technology development and processing. These radioactive fuels typically do not require extensive processing, and their transformations of forms and functions are constrained. For instance, the United States restrains Chinese semiconductor companies by restricting technology exports and prohibiting exports of photolithography machines and other processing equipment containing American components to China. The United States, Japan, and the Republic of Korea have formed a semiconductor

⁹ *Supra* n. 6, pp. 39–40.

alliance to coordinate policies. On May 23, Japan's Ministry of Economy, Trade and Industry (METI) announced an amendment to the Foreign Exchange Law, adding 23 categories including advanced chip manufacturing equipment to the list of controlled exports, with China being listed as a controlled entity.

The export controls of gallium and germanium differ due to the properties of their raw materials. The two raw materials undergo direct and significant changes in actual use after processing, and the cycle from the two metals to the final product is long, involving many members and the process is also more complicated. Participants in the global supply chain collaborate to leverage their strengths and reap benefits. Similarly, if they encounter threats or risks on the global supply chain, they would take measures to mitigate their impact. China's recent implementation of export controls on gallium and germanium was intended to safeguard its national security and interests. It is noteworthy that according to industrial chain supply-demand relationships, gallium and germanium, along with their compounds, occupy the forefront of the semiconductor supply chain. And regionally, related activities are concentrated in a small group of countries. The export controls of gallium and germanium may have a stronger and more direct impact on global economic trade activities due to their position at the forefront of the global supply chain, and the effects of export controls may therefore be more significant. Additionally, as export controls lead to a reduction in the global gallium and germanium supply, it is possible that in the long term, this could drive up the international market price benchmarks for these elements. This could delay the development of military applications related to gallium and germanium in the United States and promote technological innovation in alternative materials.

C. Continuous Expansion of Uses Can Increase Potential Future Domestic Demand for Gallium and Germanium in China

Gallium and germanium are continuously expanding their new uses beyond traditional ones, leading to increasingly intense global competition in research and application. A report by the CRS argued that China's demand for key mineral resources is rapidly increasing, and this change will pressure the United States to obtain a stable guarantee of key minerals.¹⁰ This report explained

¹⁰ *Supra* n. 4.

that the growth in China's demand for these resources will not be a short-term phenomenon. With the differentiated development of demands (environmental protection, high-strength materials, etc.), regardless of whether China's economy will continue to grow rapidly, the demand for these resources will continue to increase. In fact, both gallium and germanium compounds and metals are constantly being explored for new applications. Gallium nitride, a wide bandgap semiconductor, has the potential to significantly reduce energy consumption in power transmission, thus attracting attention for its possible uses in power and radio frequency (RF) devices. Gallium oxide, the most stable gallium compound, is characterized by its heat resistance, efficiency, and cost-effectiveness. It has emerged as a fourth-generation semiconductor material, garnering global attention and beginning the process of industrialization. Gallium oxide, in comparison to other fourth-generation semiconductor materials such as diamond or aluminum nitride, has made significant progress in size, exceeding a length of over 6 inches. This demonstrates it has a broad spectrum of development potential. A report by Fuji Corporation indicated that the market size for gallium oxide power components was projected to reach 150% of that for gallium nitride power components by the year 2030. Both Japanese and Korean enterprises are actively competing to establish a presence in the gallium oxide industry. Several teams, including those at the School of Microelectronics at the University of Science and Technology of China and the Shanghai Institute of Microsystem and Information Technology at the Chinese Academy of Sciences, have been actively exploring gallium oxide power semiconductors in fields such as energy, information, defense, rail transport, and electric vehicles. The development of this industry will increase China's economic dependence on the supply and security of gallium and germanium raw materials.

Gallium and germanium possess potential applications beyond their use as semiconductors. Gallium, with a low melting point of 29.75 degrees Celsius, has promising prospects in medicine. It can be used not only in gallium indium liquid alloy to create an environmentally friendly thermometer but also to attain pioneering medical breakthroughs. Chinese scientists have utilized gallium indium tin alloy to permeate human nerve tubes, thereby achieving an electrical signal transmission capability nearly identical to that of undamaged nerves.

The physical impact generated by a liquid metal machine, which incorporates gallium as its primary raw material, offers innovative concepts and blueprints for intelligent motors, vascular robots, and fluid pump systems. These are anticipated to have numerous applications. Germanium can be used as a catalyst in some polymerization reactions, and its anti-rust coloring properties can be enhanced by adding precious metals. It also has potential applications in areas of scientific research such as security detection systems, high-energy X-rays, dark matter detectors, and dietary supplements.

The surge in demand may lead to excessive competition in the raw material market, and speculation could cause drastic price fluctuations, impacting all parties and disrupting the industry. In recent years, the market demand for lithium has dramatically risen with the rapid development of electric vehicles. For instance, the market price of lithium carbonate was less than 6,000 yuan per ton in January 2021, but went up to nearly 60,000 yuan by January 2023. The demand guarantee led to a tenfold price increase. Subsequently, it fell to 13,000 yuan in April 2023. The export controls on gallium and germanium are also aimed at guiding market expectations, avoiding a surge in speculation or hoarding due to bullish expectations for resource prices. This is intended to reserve development opportunities for the industry's stable growth.

VI. ENSURING SUPPLY CHAIN SECURITY REQUIRES THE ADOPTION OF DIVERSE AND COLLABORATIVE MEASURES

Historically, the United States has undergone several rounds of adjustments when implementing export controls. From strict regulation of and restrictions on exports to socialist countries, to relaxing these restrictions due to American businesses falling behind their European competitors, and then using export controls to maintain its advantage under the guise of “America First” or “competition”, this cyclical fluctuation of “tight-loose-tight” demonstrates the strong external influence of international politics and economics on export control policies.

In the world today, despite the resurgence of unilateralism and trade protectionism, which mainly comes from countries that originally led the push

for economic globalization and liberalization, it is not easy to change the trend of economic globalization. Technological advancement and the strengthening of international economic dependence have made the international industrial division of labor increasingly clear and distinct. And specialized industry requirements enable each country to effectively exploit its advantages, making it difficult for any of them to technologically invade or seize the advantages of others. Technological advancements have created a more stable, effective, and sustainable environment for economic globalization, putting the collaborative development model of international division of labor more closely in line with market principles. In this context, market forces often prove more enduring and effective than governments, providing crucial support for global supply chain collaboration among all parties. They also advocate against interventions that contravene market principles by applying the “vote with your feet” approach. The export control system is not a “one-size-fits-all” solution but requires systematic coordination and safeguarding. As a global power, China needs to not only express its stance as a major power but also assume its responsibilities. It should maintain its dominance in the gallium and germanium supply chain, providing Chinese enterprises with better and fairer opportunities for development amidst competition. This requires strengthening consultations and cooperation with parties in the following six areas while implementing reasonable and necessary policy measures and institutional arrangements to effectively enhance the resilience of the global supply chain.

Firstly, stakeholders should follow the principle of transparency, strengthen prior communication and coordination on major issues of global interests, and meet procedural requirements. The principle of transparency, as a key principle in the global economic and trading system, focuses on promptly issuing important information, policies or decisions that may affect international economic and trade cooperation. It provides channels for stakeholders, including international investors and traders, to comment and provide feedback. This can be a mechanism to reduce market volatility, stabilize business expectations, and minimize policy impulses. In fact, the WTO has a consensus on transparency, but all parties have been unable to adhere to this important principle. There have also been instances where transparency was used to infringe upon the administrative jurisdiction of other countries and

violate policies on corporate trade secrets, severely impacting the confidence in long-term business development. The policy measures of key the countries in multiple global industries have significantly impacted each industry. When introducing industry policies or practices, it is necessary to strengthen direct and effective communication. While respecting the sovereignty considerations of all parties and adhering to legal procedural requirements, misjudgments should be avoided and the shock that impacts market cooperation when policies are suddenly introduced should be reduced.

Secondly, stakeholders should coordinate its global supply chain strategy and fully consider the two-way impact of policies and measures on the supply chain. Furthermore, China needs to bolster the resilience and stability of the supply chain. The market primarily dictates this chain, and the Chinese government should cautiously consider its scope of legal authorization to prevent exploitation of asymmetric power advantages that could infringe on corporate rights and commercial interests. In burgeoning industry sectors such as semiconductors, customer orders and production cycles are often considered trade secrets. Mandating companies to disclose this information can undermine business trust and disrupt the supply chain. Any new interventions in the supply chain must be lawful and reasonable, with input from stakeholders to minimize their impact on corporate investment willingness. When implementing policy measures that may affect the global supply chain, China must consider not only the downstream impact but also the effect on upstream raw materials and stakeholders in intermediate goods while imposing constraints on end products. Supply chain security should be a shared responsibility among all parties. Simply enhancing the security of one party does not guarantee long-term stability and security; it could potentially backfire, leading to increased insecurity. Therefore, before introducing new policies, China should carefully evaluate the potential impacts and shocks, understand the appropriate degree of policy measures, and improve its ability to maintain stable supply chain development.

Thirdly, stakeholders should implement appropriate adjustments and transitions to guide and encourage the development of domestic industries considering material usage. This will accelerate the cultivation and extension of industrial chains. The imposition of export controls on gallium and germanium

may decrease the volume of other exports, potentially impacting production enterprises that primarily rely on exports for their market. China should mitigate this by strategically managing market expectations to expedite the matching of domestic supply and demand through demand innovation and supply diversification. This will enhance the flexibility of supply-demand relationships and reduce the time required to reach a new equilibrium. During the initial stages of policy implementation, it may be feasible to guide a reduction in the scale of raw material production such as gallium and germanium by integrating it with the production of their main products. This can be achieved by temporarily postponing the separation of byproducts, thereby constricting the production capacity of these metals. This strategy will help to prevent negative impacts on gallium and germanium production enterprises due to insufficient domestic demand. In the medium to long term, efforts should be intensified to build the development capacity of industries, increase demand, and gradually release the production capacity of gallium and germanium raw materials. Establishing a new and higher level of supply-demand balance will provide more robust support for developing domestic semiconductors, optics, and other fields.

Fourthly, stakeholders need to strengthen research and translation by transforming and upgrading its economic industry and enhance security capabilities to expand its application of gallium and germanium. China should convince research institutions and enterprises to proactively investigate the applications of gallium, germanium, and their compounds. By capitalizing on resource and market strengths, China can gain a competitive edge in global endeavors within these fields. China has the potential to enhance interdisciplinary collaboration, thereby fostering an environment conducive to the innovative application of gallium and germanium. This can be achieved by integrating key domestic technology R&D projects into major scientific research initiatives. Furthermore, China could incentivize research institutions to collaborate with downstream partners (including companies and R&D institutions) within the global supply chain of gallium and germanium in the area of technology application. This would expedite the commercialization of specialized technology and strengthen the industrial chain. In China, the combined development benefits of state-owned and private enterprises

necessitate an accelerated effort to foster industry leaders in diverse fields, which includes nurturing “little giants” who possess unique technologies or capabilities. This strategy will not only deepen the industrial chain but also expand the breadth of related industries, providing a more robust foundation for enhancing commercial competitiveness and ensuring national security. China can incentivize enterprises to participate in international innovation collaborations focused on gallium and germanium products, identify mechanisms for synergistic cooperation, as well as contribute towards establishing industry standards that can bolster global competitiveness. As these industries evolve, China should prioritize a sustainable, low-carbon approach, augment its adoption of renewable energy sources, concentrate on green management throughout the product lifecycle, and ensure that its industrial advancement is aligned with policies that promote environmental preservation.

Fifthly, stakeholders need to provide comprehensive support, maximize international rules along with domestic laws and regulations to reduce pressure on enterprise development, as well as lower the cost of synergy. Although China's implementation of export controls aligns with international practices and is a power granted by its domestic laws and regulations, enterprises in related industries may face significant pressure, especially those in the global gallium and germanium supply chain. China must also implement standardized procedures, promptly develop exemplary cases, and transparently report on regulatory advancements while ensuring national safety. These actions will bolster market confidence, reduce information asymmetry, and simultaneously lower compliance costs for both domestic and foreign businesses. The government should enhance collaboration with nations who are significant stakeholders in export controls, which can foster mutual trust and reciprocal actions that advance international regulatory coordination of export control policies. Chinese enterprises should be encouraged to maintain or expand imports of metal or compound resources, including key minerals like gallium and germanium, in line with market principles. They should also actively improve their capacity to acquire or share upstream raw materials through foreign investments to create more favorable conditions for the long-term sustainable development of the domestic gallium and germanium industry.

Sixthly, stakeholders need to strengthen its support of funding and talent,

emphasizing the cultivation of professional and applied talent required for enterprise development and supporting enterprises to catch up with their competitors. The development cycle of gallium and germanium industries is protracted, making it challenging to modify the international division of labor established over nearly a century of semiconductor applications. It is imperative to identify and address the deficiencies in China's gallium and germanium industries, thereby providing more robust guarantees for mastering key technologies and supplementing the industrial and supply chains. China should foster research and application cooperation related to gallium and germanium among Belt and Road Initiative partners. Therefore, it should implement specialized research projects, attract industrial investments to increase capital outlays, incorporate social capital, and stimulate angel investments to provide substantial financial support for industrial advancement. Additionally, China should prioritize specific enterprise needs by encouraging domestic institutions specializing in relevant disciplines to enhance their training and certification of talent with foundational knowledge, skills, and interdisciplinary application ability. This approach is based on discussions with enterprises in the gallium and germanium industry. Emphasizing this will create favorable conditions for the internal mobility of professionals in these fields, thereby reducing recruitment costs for enterprises associated with gallium and germanium.