Evolutionary Analysis of Foreign Technology Export Controls and Response Strategies: Postprint

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Abstract

Implementing strict export controls on technologies involving national security and interests is an internationally recognized practice. In recent years, as major power competition and strategic rivalry have intensified, developed countries and regions including the United States, Europe, and Japan have successively adjusted their technology export control policies. Building upon a review of the evolutionary trajectory of foreign technology export control regimes, this study focuses on analyzing the latest developments in Western countries' technology export controls targeting China and their implications for China' s scientific and technological innovation. Corresponding countermeasures and policy recommendations are proposed from multiple dimensions, including refining the technology export control institutional framework, enhancing capabilities for strategic technological breakthroughs, and optimizing the ecosystem for indigenous innovation.

Full Text

Research on the Evolution and Countermeasures of International Technology Export Controls

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Abstract

Implementing strict export controls on technologies involving national security and interests is common international practice. In recent years, as major power competition has intensified, developed countries and regions including the United States, Europe, and Japan have adjusted their technology export control policies. Building upon a summary of the evolutionary trajectory of technology export control systems in major developed countries, this study focuses on analyzing the latest trends in Western technology export controls targeting China and their impacts on China's scientific and technological innovation. It proposes countermeasures and policy recommendations from three perspectives: improving the technology export control institutional system, strengthening strategic technology research and development capabilities, and optimizing the ecosystem for independent innovation.

Keywords: technology export control, evolution analysis, countermeasures

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1. Theoretical Basis and Research Progress

Implementing scientifically sound technology export controls represents an objective requirement and necessary choice for sovereign states to maintain technological monopolies and safeguard domestic security and interests. However, using export control measures to suppress and contain other countries in order to maintain technological hegemony seriously damages the legitimate interests of those countries and disrupts normal international order.

1.1 Theoretical Basis

No unified theory has gained widespread acceptance in the field of export controls, but several frameworks provide theoretical explanations for reasonable technology export control practices, including technological innovation and diffusion theory, economic analysis of export controls, strategic trade theory, and economic globalization theory.

First, the unique characteristics of technology necessitate export controls. Technology innovation involves long cycles, large-scale investment, high failure rates, and strong uncertainty. Moreover, technological outputs exhibit quasi-public goods properties such as time lags, spillover effects, and divergence—intangible knowledge and materialized products can spill over at any stage of the innovation process. Technology-leading countries must therefore restrict both domestic and international diffusion of technology through intellectual property protection. Externally, they restrict exports of critical core technologies to maintain exclusive rights and preserve international technological leadership and industrial competitiveness; internally, they establish robust intellectual property protection systems to safeguard the interests and innovation enthusiasm of domestic researchers [2].

Second, technology export controls represent a manifestation of government coercion. As a state action, export controls possess political, economic, and social dimensions. Due to factors such as natural monopolies, externalities, and information asymmetries, governments must exercise appropriate and effective control over technology exports to overcome market failures. On one hand, by restricting or prohibiting the export of advanced technologies, they prioritize meeting the short-term needs and long-term competitive requirements of domestic industries while effectively avoiding negative externalities from technology spillovers that could threaten the economic security of technology-leading countries in international markets. On the other hand, by establishing strict technology export control standards, they prohibit exports of sensitive or dual-use items and technologies to reduce the risk of such items falling into the hands of hostile or competitor nations, thereby safeguarding national security [3].

Third, effective implementation of technology export controls requires balancing various interests. Export controls are a "double-edged sword."Moderate controls not only generate substantial economic benefits for technology-leading countries but also enable them to control the technological catch-up pathways of latecomer countries by exporting technology standard systems based on their own technical standards and norms. However, excessive controls, while yielding political, military, and diplomatic benefits, also increase production costs for domestic technology products, harming the economic interests and technological innovation capabilities of relevant industries [4]. Consequently, technology-leading countries must maintain technological gaps by restricting or even prohibiting exports of critical core technologies to delay catch-up timelines as much as possible, while simultaneously relaxing controls on mature technologies to access overseas markets and generate economic benefits that can be reinvested into domestic technological innovation.

1.2 Research Progress

The frequent use and widespread impact of technology export controls have attracted multidisciplinary attention and become a research hotspot for scholars both domestically and internationally. Research has primarily focused on three areas: the evolution of technology export controls in typical countries, the objectives and content of such controls, and their effects and impacts.

Regarding the objectives of technology export controls, scholars have systematically reviewed the historical evolution of export control policies in developed countries, conducting in-depth analyses of their origins. The consensus is that the core mission of technology export controls is safeguarding national security, including military security, economic security, and technological security [5]. Economically, controls enhance industrial competitiveness and economic advantages; militarily, they maintain the sophistication of domestic military equipment and defense technology; technologically, they preserve leadership in specific scientific fields [6]. Export controls also serve as a strategic tool for leading countries to contain the rise and development of latecomer nations and

prevent their technological progress, thereby maintaining international competitive advantages [7]. The United States has already made technology export control its most important instrument for containing China' s development [8].

Regarding implementation mechanisms, technology export represents the export of technological capabilities and creative capacity. High-tech export controls encompass not only the technology and products themselves but also their carriers. Through multi-dimensional controls on different technology forms, they effectively prevent technology transfer and diffusion [9]. Developed countries primarily implement controls through control lists, including "item control lists" that regulate export commodities and "entity control lists" that regulate users [10]. Existing research has attempted to analyze the strategic intentions and evolving trends embedded in lists such as the Commerce Control List, Wassenaar Arrangement List, and Entity List from an intelligence studies perspective [11-14]. Studies have also examined the linkages between export control policies and foreign investment security reviews or "long-arm jurisdiction" to assess potential risks and impacts [15,16], while analyzing the evolution, functions, and challenges of international multilateral export control mechanisms [17].

Regarding influencing factors, export control policies in developed countries are not static but dynamically adjusted to keep pace with the times. The primary driver of policy adjustment is international political relations—strict export controls are typically applied during periods of tense bilateral relations, while relaxed controls target allied nations [7]. Economic factors constitute important considerations, as economic benefits are ultimately sought to safeguard national security [18]. Technological innovation gaps also alter control standards, particularly when controlled countries break through technological blockades through independent innovation, necessitating adjustments to existing export standards. This reflects both technological iteration and the technological progress of controlled countries [19]. Additionally, differences in science and technology innovation systems influence changes in control standards.

Regarding implementation effects, export controls generate varying degrees of impact on all stakeholders. For controlling countries, research indicates an "inverted U-shaped" relationship between export controls and industrial technological innovation—moderate controls facilitate innovation, while excessive controls negatively affect it [20,21]. For controlled countries, theoretical and empirical studies using "North-South trade models" and "leapfrog models" have confirmed that imports of high-tech products significantly promote domestic R&D. Export control policies distort normal trade behavior, causing varying degrees of impact on high-tech product development in controlled countries. However, such controls also incentivize controlled countries to increase independent R&D efforts and reduce or eliminate foreign technology dependence through independent innovation [22-25]. Beyond technological effects, export controls also produce security effects, trade effects, and policy effects [26].

Overall, existing research has provided rich discussions on technology export controls, but lacks comprehensiveness and systematicness. Many studies an-

alyze specific national policy texts qualitatively, offering insufficient holistic consideration of the evolution, fundamental characteristics, frontier trends, and countermeasures of technology export control systems.

2. Development and Evolution of Foreign Technology Export Controls

In modern society, technological innovation plays an increasingly important role in the world economy and international trade, profoundly influencing international cooperation and competition patterns. Technology export controls have gradually become a crucial strategic tool for major countries and have evolved into widely accepted international norms and rules.

2.1 Development History

Western developed countries began implementing technology export controls in the early 20th century. After a century of development, an increasingly comprehensive system has been established in more countries to safeguard national security and development interests.

2.1.1 Embryonic Stage (1917–End of WWII) Modern technology export controls originated in the first half of the 20th century. In 1917, the United States passed the *Trading with the Enemy Act*, authorizing the President to strictly restrict all economic and trade activities with hostile nations during wartime. In 1939, as WWII erupted, Britain and France successively enacted the *Import, Export and Customs Power Act* and *Decree on Establishing a System for Managing War Materials, Weapons, and Munitions*, explicitly prohibiting the export of military equipment, weapons, and ammunition without licenses. In 1940, the U.S. strengthened presidential authority to control exports of commodities and technologies of significant military importance through the *Act to Promote the Defense of the United States*, aiming to hinder hostile military capacity enhancement. During this embryonic stage, export controls were temporary wartime measures targeting hostile nations through material embargoes and technology restrictions to safeguard national military security.

2.1.2 Development Stage (Post-WWII–Cold War) After WWII, a bipolar world structure gradually emerged with US-Soviet confrontation as its hallmark. In 1949, the United States passed the *Export Control Act*, codifying wartime temporary controls into national security and diplomatic policy, prohibiting exports of strategic equipment involving cutting-edge technologies through economic and trade channels. Simultaneously, the U.S. collaborated with most Western European countries to establish the "Coordinating Committee for Multilateral Export Controls" (COCOM), commonly known as the "Paris Coordinating Committee" or "Bureau of Export Controls" , implementing multilateral export controls against socialist countries to prevent the diffusion of advanced U.S. technologies and high-tech strategic

materials to the socialist bloc. This marked the expansion of export controls from unilateral to multilateral levels. Following COCOM' s establishment in 1950, international multilateral export control regimes such as the *Treaty on the Non-Proliferation of Nuclear Weapons*, *Convention on the Prohibition of Biological Weapons*, "Nuclear Suppliers Group," and *Missile Technology Control Regime* were successively introduced and established.

As the international political and economic environment continuously evolved, U.S. export control policies underwent multiple modifications and improvements during this stage [27]. In 1953, to alleviate fiscal pressure, the U.S. narrowed the scope of export controls while gradually relaxing restrictions on socialist countries except in defense technology. In 1969, the U.S. introduced the *Export Administration Act*, shifting from "comprehensive embargo" to targeted export controls focusing on items and technologies that could significantly enhance adversaries' military capabilities. In 1979, the U.S. enacted the *Export Administration Act* and *Export Administration Regulations*, expanding controls from traditional tangible goods to intangible technologies in the dual-use domain, further relaxing restrictions on mature technologies while strengthening control over high-tech. During this period, U.S. attitudes toward allies also changed significantly. Facing technological competition from Japan and Europe in the latter half of the Cold War, the U.S. intensified support for high-tech industries while imposing extremely strict export controls on certain sectors [28].

During this stage, other Western developed countries and regions also updated or formulated their technology export control policies: the UK revised and introduced the *Export Control Act 1990*; France amended its original legislation based on COCOM provisions; Japan enacted the *Foreign Exchange and Foreign Trade Act* in 1949 as the legal basis for regulating foreign trade activities and implementing export controls; Germany introduced the *War Weapons Control Act* and *Foreign Economic Act* in 1961 as the legal foundation for controlling dual-use exports; and the EU issued Regulation (EC) No. 3381/94 in 1994, formally establishing unified EU export control common rules.

During this development stage, export controls expanded significantly, with objectives extending from safeguarding military security to encompassing both military and economic security, forms evolving from unilateral to multilateral, and targets expanding from military goods to dual-use items. Overall, U.S. and allied export controls against socialist countries focused primarily on defense technologies to prevent sensitive technology diffusion to hostile nations, while controls on high-tech industrial exports to allies such as Japan and Europe concentrated on economic aspects to maintain high-tech monopolies.

2.1.3 Perfecting Stage (Post-Cold War–2016) After the Cold War, the world structure underwent major changes. The rise of the knowledge economy and economic globalization made technological competition the core of international rivalry. More countries established science and technology as the foundation of national strength and strengthened control over technology exports and

intellectual property protection to maintain leadership and safeguard national security.

The United States established a hierarchical and classified technology export control system. From the end of the Cold War to the outbreak of the financial crisis, the U.S. comprehensively adjusted its technology export control strategies and measures. In export control policy, it appropriately relaxed technology export restrictions and simplified procedures; established new specialized agencies to coordinate export controls; and adjusted technology export lists to strengthen control over high-tech products. After the 9/11 attacks, the U.S. elevated the prevention of weapons of mass destruction and technology proliferation to a national security strategy, establishing a comprehensive domestic intellectual property protection system and promoting the *Agreement on Trade-Related Aspects of Intellectual Property Rights* at the multilateral level to strengthen technology diffusion control. After the financial crisis, facing new threats and changing international environments, the U.S. launched export control system reform in 2010, establishing unified hierarchical control lists, licensing agencies, enforcement coordination bodies, and information technology platforms, substantially improving export control efficiency.

Japan further strengthened its technology export control system. In 2002, Japan implemented a "comprehensive control" system covering all items and technologies, and in 2009 amended the *Foreign Exchange and Foreign Trade Act* to expand the scope of technology export reviews and increase penalties for violations. The EU expanded and improved its unified technology export control policy, issuing the *Dual-Use Items Export Control Regulation* to establish unified export control policies and jointly implemented control lists.

Developing countries also gradually joined the ranks of technology export control nations. At the multilateral level, with the dissolution of the Soviet Union, COCOM was dissolved in 1994. In 1995, the *Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies* was established as a new multilateral export control tool, inheriting COCOM's operational model and achieving supervision and control of dual-use items through information sharing and consultation among participants.

During this perfecting stage, technology export control systems gradually matured. Major developed countries generally established relatively complete legal systems, set up professional and coordinated control agencies, formed list-based technology control classifications and clear scopes of technology export activities, implemented all-round controls targeting different technology forms, and practiced joint controls through multilateral international cooperation. Developing countries focused mainly on military and dual-use technologies related to non-proliferation. Technology export controls became an important tool for safeguarding overall national security and interests.

2.1.4 Generalization Stage (2017–Present) Since 2017, the world has entered a period of turbulence and transformation, with unprecedented instability and uncertainty. Critical and emerging technologies have become the most core strategic resources in major power competition. In 2018, the U.S. passed the *Export Control Reform Act of 2018*, incorporating current export control practices into legislation to provide a permanent legal basis for technology export controls while strengthening export control authority to enable "long-arm jurisdiction" effects and expanding control scope with new restrictions on "emerging and foundational technologies." In 2021, the EU passed new dual-use items export control regulations, strengthening its ability to address new security risks and emerging technologies.

In addition to increasingly strict unilateral controls, the U.S. has fully utilized multilateral mechanisms such as the Wassenaar Arrangement to incorporate emerging and foundational technologies into the "Wassenaar List" and hinder participant countries from exporting related technologies and products to China. Simultaneously, it has initiated multiple initiatives or actions to suppress China' s technological development. For example, in 2018 it launched a multilateral action on sensitive technologies involving 15 countries to formulate restrictive measures hindering China' s access to advanced technologies; in 2021, it established the Trade and Technology Council with the EU, 下设 a coordination working group on export controls to implement collaborative controls on sensitive dual-use technologies; in 2022, it convened an export control policy annual meeting to "establish an international cooperation network" and launched the Indo-Pacific Economic Framework in Asia, attempting to form a "Chip Quad Alliance"and establish a Critical and Emerging Technology Working Group with Japan, Australia, and India.

During this generalization stage, technology export control systems have gradually matured. Major developed and developing countries have successively established distinctive technology export control systems. Developed countries have generally established relatively complete legal systems, set up professional and coordinated control agencies, formed list-based technology control classifications and clear scopes of technology export activities, implemented all-round controls targeting different technology forms, and practiced joint controls through multilateral international cooperation. Developing countries have focused mainly on military and dual-use technologies related to non-proliferation. Technology export controls have become an important tool for safeguarding overall national security and interests. The technology export control systems of major countries/regions are shown in Table 1 .

2.2 Basic Models

Although different countries and regions have diverse motivations and objectives for technology export controls, different control 主体结构, varying control priorities, and different levels of stringency, their control methods are generally similar, all forming list-based technology control classifications and clear scopes

of technology export activities. The main manifestations are item control and entity control.

2.2.1 Item Control Item lists construct a complete control network for high-tech technologies and their applications. Through comprehensive analysis of item lists and related content, one can discover a country' s control status, inter-state relations, and even glimpse the current development and trends of technologies, gaps in technology and industrial competitiveness between countries, and the technological progress of controlled countries [29]. Typical item control lists include the U.S. *Commerce Control List* (CCL), UK *Strategic Export Control List*, and EU *Dual-Use Items Control List*.

The item lists of major developed countries are not only complete but also detailed, with very clear and operable control standards for specific technology categories and export activity scopes, and are updated in real-time according to changes in the international situation, national strategic adjustments, and technological development in controlled countries. Taking the U.S. CCL as an example, it divides controlled items into 10 categories (0–9) and 5 groups (A–E) in a tabular format, managing them through Export Control Classification Numbers (ECCN) based on ultimate destination and control rationale. The *Export Administration Regulations* establish a country chart dividing all countries except the U.S. into four categories (A, B, D, E), implementing differential embargoes, license exemptions, and re-export requirements for different groups. Similar to the U.S., the EU Dual-Use Items Control List encodes controlled items and describes technical parameters, export objects, and licensing conditions, with the control list updated annually according to relevant institutional arrangements. Japan' s *Foreign Exchange Order* and *Export Trade Control Order* divide controlled technologies into 16 categories, implementing comprehensive technology controls on all regions except 27 whitelisted countries.

As of end-June 2023, the CCL contains 603 major categories (ECCNs) of controlled items, involving 3,379 specific controlled commodities. Among them, special materials/chemicals, aerospace and propulsion, and materials processing have larger numbers of controlled items. Figure 1 [Figure 1: see original paper] shows the distribution of controlled item categories in the CCL for Canada, Japan, China, and North Korea over the past decade. As of June 2023, the proportions of controlled categories for these four countries are 4.15%, 59.54%, 76.62%, and 89.88%, respectively. It can be observed that except for Canada, which has the closest relationship with the U.S. and consistently has fewer controlled categories, Japan (a U.S. ally), China (which has tense relations with the U.S. in recent years), and North Korea (subject to U.S. unilateral sanctions) show identical growth trends in controlled categories, demonstrating that the U.S. has long implemented strict technology export controls on different countries.

2.2.2 Entity Control Entity control lists are essentially import-export blacklists. Once listed, entities are restricted or even deprived of opportunities to trade controlled technologies and products with controlling countries. Entity control lists cover enterprises, scientific research institutions, governments, individuals, and various organizations and personnel. Typical entity control lists include the U.S. *Entity List*, UK *Consolidated List of Financial Sanctions Targets*, and EU *EU Sanctions Map*.

Technology export control agencies formulate multiple entity control lists targeting different entities according to their responsibilities. Taking the U.S. as an example, its entity control lists comprise the *Entity List*, *Unverified List*, *Military End User List*, *Denied Persons List*, and others. According to incomplete statistics, there are as many as 19 types of lists (Figure 2 [Figure 2: see original paper]). Some lists specifically control particular enterprises (e.g., military-related enterprises) or behaviors (e.g., military-civil fusion); some serve warning functions, imposing no substantive restrictions but adding review procedures to obtain enterprise information; some restrict enterprise investment and financing from financial perspectives; and others directly implement mandatory prohibition measures on entities. Different types of lists focus on different transactions and objects, though some overlap exists. Through hierarchical and classified management of different lists, they restrict or prohibit various flows of controlled items.

The U.S. Department of Commerce Bureau of Industry and Security (BIS) *Entity List* was first published in 1997. Initially, entities on the list were those related to weapons of mass destruction, but the scope later expanded to include entities "engaging in activities sanctioned and prohibited by the U.S. State Department, as well as activities endangering U.S. national security and foreign policy interests." As of July 22, 2023, a total of 2,554 entities from 89 countries/regions have been listed. Among them, Russia ranks first with 881 controlled entities, followed by China with 696, together accounting for 61.74% of the total entity list (Figure 3 [Figure 3: see original paper]). It is evident that over the past 20 years, the entity list has experienced explosive growth, with the regional focus of U.S. entity controls shifting from Russia and the Middle East to China.

2.3 Basic Characteristics

By examining the development and main measures of foreign technology export control policies, we can identify four key characteristics: strong national will, serving as a means to achieve specific political, military, and diplomatic interests.

First, technology export controls are built upon technological advantages and interest considerations. Countries implementing controls typically possess leading technological advantages and innovation capabilities. Only when controlled technologies have strategic value internationally is strict export control neces-

sary. Export controls involve both national security interests and economic interests—two closely related yet contradictory concerns. Pursuing economic benefits from exports may harm national security, while pursuing security benefits from controls requires sacrificing economic interests. Therefore, national policies continuously swing and balance between these objectives, but generally adjust according to national strategic needs, fully considering domestic technological advantages relative to controlled countries and the technological autonomy capabilities of controlled countries to tighten or relax controls.

Second, technology export controls have become an important tool in major power competition. Currently, technological innovation has become the main battlefield of international strategic competition, and export controls are crucial means to strengthen national competitiveness. On one hand, implementing export controls on domestic advanced technologies enables countries to occupy an active position in international competition. During the mercantilist period, Britain strictly prohibited the outflow of advanced equipment and skilled workers to ensure its manufacturing dominance. During the Cold War, the U.S. consistently imposed strict high-tech product export controls on the Soviet Union as a tool to contain its development. In recent years, competition around technological commanding heights has become unprecedentedly fierce, and countries' awareness of using export controls to protect "technological leadership" has grown stronger. On the other hand, export controls serve as powerful tools to counter other countries' trade policies. To counter U.S. abuse of export controls, China has continuously improved its own export control system, enacted the *Export Control Law*, and used export controls to safeguard national security and interests.

Third, technology export control standards are continuously and dynamically adjusted, reflecting the direction of technological evolution. To implement more precise controls, developed countries/regions closely monitor global technological developments, market trends, and international situations, continuously adjusting control standards. While strictly preventing the outflow of cutting-edge and sensitive technologies with international leadership advantages, they allow exports of relatively backward and less sensitive technologies. In August 2022, BIS strengthened export controls on Electronic Design Automation (EDA) software, requiring licenses for all exports to Chinese enterprises; in September, it ordered tightened exports of high-performance chips from U.S. chip design companies to China. In addition to strict unilateral controls, controlling countries actively promote the construction of international export control alliances and guide the establishment of control processes and content consistent with or compatible with their own, improving control efficiency.

Fourth, technology export control objects cover a wide range, from tangible technologies to intangible knowledge. Controls target not only technology itself but also its carriers—products, organizations, and personnel—and even restrict the formation processes and acquisition methods of technology. Major developed countries/regions impose stricter controls, comprehensively utilizing

various control lists to prohibit or control the diffusion of core technological knowledge domestically, as well as the illegal outflow of related software, hardware, components, and even supporting infrastructure and technologies. In international trade, they set higher technical barriers for technology transfer and propose various new control requirements, widely applying principles such as "end user," "end use," and "comprehensive control" in export control practices.

3. Trends and Impacts of Foreign Technology Export Controls on China

Since the founding of the People' s Republic of China, developed countries led by the United States have consistently implemented technology export controls on China, with varying degrees of restriction depending on the international political situation and domestic economic and diplomatic interests at different times. Since the 21st century, as China has become the world' s second-largest economy and ranked among the top globally in multiple scientific and technological indicators, developed countries have continuously tightened technology export controls on China, with control measures exhibiting new characteristics.

3.1 Strengthening Strategic Competition, Focusing on Strategic High-Tech Fields

The U.S. *Export Control Reform Act of 2018* provided permanent legislative foundation for current technology export control practices, safeguarding U.S. leadership and technological advantages. In 2021, the EU revised its *Dual-Use Items Export Control Regulation* to strengthen its ability to address new security risks and emerging technologies. Japan revised its *Foreign Exchange and Foreign Trade Act* in 2023, adding export controls on dozens of products in the cutting-edge semiconductor field to safeguard Japan' s strategic autonomy.

First, controls on traditional strategic high-tech fields have been strengthened. As of end-June 2023, the CCL restricts exports of 462 major categories and 2,732 items to China, meaning 64.33% of categories and 76.82% of items cannot be exported to China. Controls on sensitive equipment, software, and technology are particularly strict, with increased control intensity in traditional competitive strategic technology fields such as semiconductors and supercomputers since 2018. For example, the U.S. has continuously raised the technical parameter ceiling for semiconductor technology exports to China, implementing explicit suppression on three categories of products for advanced processes; Japan and the Netherlands have issued semiconductor restrictions affecting 23 types of semiconductor equipment. Simultaneously, the U.S. has continuously expanded the application scope of the Foreign Direct Product Rule, strengthened end-user and end-use review and supervision, and significantly compressed the space for Chinese entities to obtain high-end chips from international markets through "guardrail" provisions .

Second, controls on critical and emerging technology fields have been strength-

ened. The U.S. introduced the concept of "emerging and foundational technologies" in the *Export Control Reform Act of 2018*, releasing the *National Strategy for Critical and Emerging Technologies* in 2020 that identified 20 critical and emerging technologies including advanced computing, advanced manufacturing, and aero engines, and updated the list in 2022 to further refine technology directions and sub-technologies. The EU' s 2021 dual-use items export control regulation also added controls on emerging dual-use technologies such as cyber-surveillance items. Under these new legislative provisions, BIS has successively issued specialized control policies for specific technology fields such as artificial intelligence, quantum information technology, and biotechnology, replicating enforcement approaches from traditional strategic competition fields to critical and emerging technology domains and their sub-fields.

Third, precise controls target key technologies. As of May 2023, 88 of the 97 controlled technology product indicators in the CCL that have changed target China. On one hand, control indicators become increasingly cutting-edge in fields where China has achieved core technology breakthroughs and market applications; on the other hand, they closely monitor key industrial elements, imposing all-round restrictions across innovation and industrial chains. For example, on October 7, 2022, BIS announced new export controls on advanced computing and semiconductor manufacturing items exported to China, adjusting the battery energy density control parameter from 250 Wh/kg to 350 Wh/kg precisely because China had achieved relevant technological breakthroughs in battery products . However, control content for semiconductor device testing equipment has remained unchanged.

3.2 Expanding Target Scope, Broader Control Objects

Since 2018, the scale and focus of U.S. entity controls have changed significantly, with numerous Chinese technology enterprises, scientific research institutions, universities, and individuals being listed.

First, the number of restricted entities has surged. For nearly 20 years after 1997, U.S. export controls on China remained relatively stable, with an average of about 10 entities added annually. However, since 2018, the number of Chinese controlled entities has grown dramatically, remaining in a frequent issuance stage (Figure 4 [Figure 4: see original paper]). As of July 2023, a cumulative total of 696 Chinese entities (including Hong Kong entities) have been listed on the BIS Entity List, including 495 enterprises (71.12%), 114 research institutes (16.38%), 13 universities, 22 government agencies, and 52 individuals.

Second, leading technology entities are targeted. After screening out entities with weak technology relevance and small scale, 209 institutions have been identified as listed on the BIS Entity List, mainly involving 83 microelectronics and optoelectronics technology units, 54 network and communications entities, 37 marine technology entities, and 35 computer, software, and development entities. It is evident that high-tech companies with certain technological and

market advantages, scientific research institutions, and universities involved in defense-related fields have become key targets of foreign controls in recent years, with their affiliates and partners also listed as control objects.

3.3 Strengthening Tool Coordination, More Systematic Control Measures

As technological competition expands comprehensively, investment screening, export controls, alliance building, strengthened information disclosure, and restrictions on talent mobility have formed a comprehensive toolkit for developed countries to block advanced technology outflows.

First, export controls are combined with investment screening. In 2018, the U.S. introduced the *Foreign Investment Risk Review Modernization Act*, broadening the scope of review objects and refining key technologies, particularly transactions involving sensitive technologies. In 2022, it strengthened investment review in 27 key technology sectors involving U.S. enterprises in chips, semiconductors, and aircraft. In August 2023, it established an outbound investment review mechanism restricting U.S. entities from investing in China' s semiconductor and microelectronics, quantum information technology, and artificial intelligence sectors. European countries have also continuously tightened foreign investment regulatory policies and enforcement. In 2019, the EU issued its first *Foreign Direct Investment Screening Regulation*; in 2021, Germany implemented a new *Foreign Trade and Payments Ordinance* and the UK passed the *National Security and Investment Act*, further expanding investment restrictions in sensitive sectors.

Second, multilateral technology alliances are being promoted. In addition to increasingly strict unilateral controls, the U.S. fully utilizes multilateral mechanisms such as the Wassenaar Arrangement to incorporate emerging and foundational technologies into the "Wassenaar List" and hinder participant countries from exporting related technologies and products to China. Simultaneously, it initiates multiple initiatives to suppress China' s technological development. For example, in 2018 it launched a multilateral action on sensitive technologies involving 15 countries; in 2021, it established the Trade and Technology Council with the EU, 下设 a coordination working group on export controls; in 2022, it convened an export control policy annual meeting to "establish an international cooperation network" and launched the Indo-Pacific Economic Framework in Asia, attempting to form a "Chip Quad Alliance" and establish a Critical and Emerging Technology Working Group with Japan, Australia, and India.

3.4 Impacts of Foreign Technology Export Controls on China

The escalating technology export controls by developed countries pose severe external constraints on China during the accelerated evolution of a new round of scientific and technological revolution and industrial transformation, bringing

significant risks and challenges to China' s scientific progress, economic development, and industrial security.

First, chokepoint problems in critical core technologies have become more prominent. Since reform and opening up, China has long been in a position of technological followership and industrial dependence within the global industrial chain division of labor, with critical core technologies generally exhibiting varying degrees of external dependence. Particularly in industrial mother machines, high-end chips, basic software and hardware, aero engines, advanced scientific instruments, and basic materials, high technical thresholds and industrialization difficulties make short-term breakthroughs challenging [30]. Large-scale structural blockades by developed countries targeting these high-tech industries and critical core technologies hinder China' s high-tech development process, potentially trapping China in a "low-end lock-in" dilemma. Meanwhile, whenever China overcomes relevant control technology standards, foreign countries promptly lift controls or raise technical parameters by one generation, suppressing Chinese industries through market competition and substantially increasing the cost and efficiency of China' s efforts to solve "chokepoint" technology problems.

Second, industrial and supply chain security is severely threatened. Beyond blocking critical core technologies, strict restrictions on raw materials, components, equipment, and testing devices required for high-tech R&D undoubtedly expose China' s industrial chains to supply disruptions and chain-break shocks from external products, components, or technologies. Given the long cycle from R&D design to commercialization of high-tech products, foreign restrictions on talent introduction, technology exchange, and academic cooperation cut off possibilities for China to obtain core technologies and products from the source. Therefore, "supply cutoffs" will cause partial blockages or breaks in industrial and supply chains in the short term. Recently, once joint controls on semiconductors by the U.S., Europe, and Japan are formed, supply chain gaps in China' s semiconductor industry will become more severe.

Third, international academic exchanges and cooperation are severely hindered. In 2018, the U.S. launched the "China Initiative," investigating researchers from hundreds of China-U.S. cooperation projects in the name of "national security," prohibiting domestic research institutions and personnel from participating in China' s talent recruitment programs, and restricting Chinese personnel from traveling to the U.S. through visa denials, application delays, long-term visa revocations, and tightened review procedures, seriously impeding normal international exchanges. A May 2022 *Nature* analysis found that the number of co-authored papers between Chinese and U.S. authors declined in 2021, with the number of authors from co-signed Chinese-U.S. research institutions dropping by over 20% from 2019–2021 [31]. In 2021, the U.S. denied visas to at least 2,000 Chinese students in science, technology, engineering, and mathematics fields; from January–October 2022, the number of U.S. student visas issued to Chinese nationals decreased by 38% year-on-year .

Fourth, China' s technology export control system urgently needs improvement. To effectively counter foreign technology export control measures, China formally implemented the *Export Control Law of the People' s Republic of China* and the *Foreign Investment Law of the People' s Republic of China* in 2020, updated the *Catalogue of Technologies Prohibited and Restricted from Export*, and in 2021 issued the *Anti-Foreign Sanctions Law of the People' s Republic of China*, *Rules on Counteracting Unjustified Extraterritorial Application of Foreign Legislation and Other Measures*, and *Provisions on the Unreliable Entity List*, basically establishing a legal system and institutions for technology security review and export control. However, compared with long-standing foreign practices, China' s system has been established for a relatively short time, with problems such as vague definitions of control objects, lack of supporting administrative regulations or departmental rules, and slow list updates, resulting in insufficient operability of the system. Faced with foreign "long-arm jurisdiction" actions and technical control measures, China remains in a passive response and temporary countermeasure stage, unable to provide sufficiently effective support for Chinese entities [1].

4. China' s Countermeasures

The increasingly intensified technology export control posture of Western countries in recent years demonstrates that while China has made scientific and technological progress in important fields, it has also exposed shortcomings in some critical core technology areas. To win development initiative and priority amid intensifying major power competition and global technological transformation, China urgently needs to improve its modern technology export control system, enhance systematic technological innovation capabilities, accelerate the achievement of high-level scientific and technological self-reliance, and play a greater role in global technology governance.

4.1 Strengthening Export Control System Construction and Enhancing Reciprocal Countermeasure Capabilities

First, optimize and improve China' s technology export control legal system and institutions. As China' s scientific and technological strength continues to improve, it urgently needs to establish a modern technology export control system that balances national security and interests with fulfillment of international obligations. On one hand, drawing on international common practices and combining them with China' s development realities, China should promptly issue supporting policies such as implementation regulations for the Export Control Law, clearly define controlled items and subjects, establish multi-department participation mechanisms in technology export controls, clarify departmental responsibilities and tasks, strengthen communication, coordination, and work linkages, and enhance system operability. On the other hand, China should actively prepare effective counter-sanction measures, improve control mechanisms for advantageous technologies, and build a national technology security control

list system.

Second, strengthen countermeasure capabilities against foreign technology export controls. China should organize specialized institutions and forces such as national high-end think tanks to closely monitor the latest developments in technology export controls by the U.S., Europe, and Japan, strengthen intelligence analysis and prediction of various control lists, and conduct in-depth assessments of intentions, trends, and measures regarding controls on China. For example, comprehensively 梳理 U.S., European, and Japanese technology export control laws and regulations, study international export control enforcement experience, conduct comprehensive analysis of control list contents, strengthen decision-making specificity, and formulate implementation plans for key technology breakthroughs. Use changes in foreign export control lists targeting China as an important basis for measuring China's scientific and technological progress and breakthrough effectiveness.

Third, accelerate the establishment of normalized technology risk assessment and monitoring and early warning mechanisms. Precisely assess the potential impacts of foreign item list changes on China' s scientific development and industrial security, identifying technological breakpoints and bottlenecks that threaten industrial and supply chain security. Make full use of new-generation information technology to strengthen risk monitoring and assessment of key industries such as defense, information, and manufacturing, as well as critical core technologies in global supply chains, and track key technological breakthroughs and major strategies in major countries and regions such as the U.S., Europe, and Japan that may trigger security issues, achieving real-time monitoring, situational awareness, and security early warning of technology risks.

Fourth, guide, encourage, and promote enterprises to enhance risk prevention capabilities. Guide enterprises engaged in foreign-related technology transactions to strengthen learning of new foreign export control regulations, enhance inter-departmental coordination and cooperation, and provide support, guarantees, and assistance to enterprises in information collection and release, trade promotion and facilitation, financial policies and services, overseas investment insurance, and legal security protection. Guide enterprises to improve export control compliance capabilities and levels, and in combination with enterprise realities, establish compliance review mechanisms that meet relevant national technology export control requirements including the *Export Control Law of the People' s Republic of China* and specialized training mechanisms for relevant practitioners, promoting and guiding enterprises to strengthen technology export control compliance construction.

4.2 Strengthening Strategic Technology Research and Development Capabilities to Accelerate Scientific and Technological Self-Reliance

First, transform foreign item control lists into China' s critical core technology task lists. Technology export controls serve as a "mirror" —analyzing their

changes can reflect China' s current status and weak links in international technology and industrial competitiveness. China should give full play to the advantages of its new national system, systematically layout "chokepoint" technologies in key fields, and mobilize effective forces and resources from government, market, and society to promote substantive breakthroughs in critical core technologies. Coordinate national major needs with industry technology shortcomings, and have industry, academia, and research institutes jointly overcome key core technologies in industries to ensure industrial and supply chain security and stability. Simultaneously promote both "chokepoint" technology breakthroughs and industrial innovation ecosystem building to cultivate new drivers for industrial development.

Second, pre-deploy advantageous key technologies and frontier technologies in emerging fields. Target the global frontier of emerging and foundational technology development, identify key generic technologies, frontier leading technologies, modern engineering technologies, and disruptive technologies, and establish evaluation indicator systems for key technologies in emerging fields to select and prioritize advantageous key and frontier technologies for support. Strengthen basic research and underlying technology R&D, increase funding investment, enhance original innovation capabilities, and eliminate dependence on foreign technologies. Focus on key areas of China-U.S. strategic competition such as artificial intelligence, quantum technology, biotechnology, and clean energy, formulate science, technology, and industrial development roadmaps, coordinate technology application and industrialization, and open up new fields and tracks for development to cultivate new competitive advantages.

Third, accelerate the cultivation of domestic application markets. Innovate government procurement systems, build demonstration application scenarios, create and cultivate demand markets for domestic products, and promote the industrialization and application of critical core technology achievements. Establish and improve risk compensation mechanisms for domestic application, improve fiscal and financial policies for first (set) equipment and first-batch applications in key fields, and encourage leading enterprises to trial domestic equipment and core software/hardware. Build a domestic application investment and financing system, and promote continuous adoption of domestic core technologies by enterprises through tax incentives and financial support, creating a favorable application ecosystem where entities "dare to use, are willing to use, and want to use" domestic technologies.

Fourth, accelerate the enhancement of enterprise independent innovation capabilities. Most entities listed on control lists are high-tech enterprises with development potential in their industries or fields, possessing capabilities to compete with developed countries' similar technologies and industries. China should guide these enterprises to make independent innovation their internal development driver, consolidate their technical capabilities to prevent and resolve external risks, and promote the aggregation of various innovation elements to enterprises. Incentivize enterprises to increase R&D investment, build R&D

platforms, participate in major scientific and technological projects, form innovation alliances, and strengthen intellectual property management systems to develop independent technology and product systems, improve the domestic substitution rate of critical core technologies and products, and eliminate foreign technology dependence.

4.3 Optimizing the Independent Innovation Ecosystem and Enhancing Global Technology Governance Capabilities

First, build a global science and technology innovation highland that aggregates global resources. Formulate more active, open, and effective talent policies, establish long-term mechanisms for overseas talent, encourage outstanding international scientific and technological talent to develop in China, while emphasizing the management of risks associated with introducing overseas talent and establishing corresponding compliance and risk prevention mechanisms. Reform and improve supporting mechanisms for foreign talent working and living in China, creating an institutional environment with international competitiveness and appeal. Support overseas universities and research institutions to establish scientific and technological innovation bases in China, and encourage foreign investment in establishing R&D centers. Promote the internationalization of scientific and technological organizations and attract international science and technology organizations to develop in China.

Second, cultivate an open innovation ecosystem with global competitiveness. China should maintain an attitude of openness and cooperation, expand scientific and technological exchanges and cooperation with key countries, regions, and international organizations, and actively integrate into global innovation networks. Deeply participate in global technology governance, propose Chinese solutions and contribute Chinese wisdom to common challenges for all humanity such as climate change, energy security, ecological protection, and infectious diseases. Establish globally oriented scientific research funds, set global scientific and technological innovation agendas, lead and actively participate in international big science programs and big science projects, and strengthen China-foreign joint R&D. Support scientific research institutions and enterprises to "go global" and build important platforms such as offshore innovation centers and overseas R&D bases to enhance "localization" contributions.

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Notes:

In November 1949, at the U.S. proposal, the U.S., UK, France, Italy, Netherlands, and Belgium held a conference and agreed to formulate an "International Security Control List." On January 9, 1950, these six countries established the "Coordinating Committee for Multilateral Export Controls" (COCOM), with its headquarters in the U.S. Embassy in Paris, hence the name "Paris Coordinating Committee" or "Bureau of Export Controls."

The U.S. *CHIPS and Science Act of 2022* specifically established "guardrail" provisions prohibiting subsidized chip companies from investing in or expanding advanced semiconductor factories in China. In response to Huawei's Kirin 9000s chip, the U.S. issued new chip ban "guardrail" provisions, including restrictions on semiconductor enterprises receiving U.S. chip subsidies from expanding in the Chinese market for 10 years.

On June 23, 2022, CATL released its new battery product "Kirin Battery," with a system integration level reaching a global high, volume utilization exceeding 72%, and energy density reaching 255 Wh/kg, enabling 1,000 km vehicle range, with mass production beginning in 2023.

According to *Strait Herald* citing the Ministry of Foreign Affairs: From January–October 2022, the number of U.S. student visas issued to Chinese nationals decreased by 38% year-on-year. (2023-07-10). https://baijiahao.baidu.com/s?id=1771044467910450226&wfr=spider&for=pc.

Note: Figure translations are in progress. See original paper for figures.