Export Controls, Innovation, and The Development of The Semiconductor Industry

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Abstract. The development of China's semiconductor industry has become an essential aspect of high-quality growth in the new stage. The vulnerability of the semiconductor supply chain has emerged as a crucial indicator of the industry's progress. This piece of writing presents an evaluation of the effectiveness of U.S. export restrictions on China's technology. To this end, it examines updates to the entity list, and analyzes monthly trade data for semiconductor manufacturing products from 2018 to 2021 to assess the impact of these controls on China's semiconductor supply chain vulnerability. The article also delves into the role of innovation in this mechanism. The study shows that US export control measures unexpectedly reduced China's semiconductor supply chain vulnerability. External supply and import demand of China's semiconductor manufacturing products subject to control were significantly reduced, with limited impact on the industry's development. US investment in the Asia-Pacific ICT industry contributed to this outcome, and export controls stimulated China's independent innovation.

Keywords: Export Controls; Semiconductor Industry; Supply Chain Vulnerability; List of entities.

1 Introduction

As China's technological prowess catches up to the United States, Its concern about the country's rise as a global competitor has grown. The U.S. has taken measures to limit China's progress in high-tech industries and maintain its dominance. The semiconductor industry has been a particular area of focus. The U.S. Bureau of Industry and Security has added several Chinese entities to its "Entity List" for export controls. However, trade data shows that the U.S. has not entirely stopped exporting high-tech products to China and has even seen an increase in exports since 2018. Meanwhile, China has increased the number of countries or regions it imports from for semiconductor manufacturing intermediates by 6.63% from 2018 to 2021.

Some experts believe that U.S. export controls on high-tech products to China are the primary cause of the trade imbalance between these two nations[1]. In contrast,

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Zhang has put forth an argument suggesting that the United States' export control policy on China is becoming more stringent[2]. The topic of supply chain vulnerability has been extensively discussed, with a focus on its definition and influencing factors. The term was first introduced by Svensson G. in 2000, who saw it as a type of "random disturbance," and emphasized the importance of creating a scientifically rigorous theoretical model[3]. According to Blackhurst, supply chain vulnerability occurs when the network experiences various disruptions that hinder trade between suppliers and lead to breakdowns in overall operations [4]. Besides, sudden major events can also contribute to supply chain vulnerability [5].

This paper introduces several innovations compared to previous studies: (1) It utilizes the "entity list," which is the primary export control tool used by the United States, to measure the intensity of export control. (2) The study analyzes how export controls affect supply chain vulnerability, with a focus on external supply and import demand. (3) The semiconductor industry is used as an example of a high-tech industry, and the study investigates the impact of US technology export control to China on the vulnerability of the supply chain of controlled products in China's semiconductor industry.

2 Theoretical Analysis and Research Hypotheses

Export control is an important trade protection tool that restricts the investment activities of multinational corporations from the controlling countries in the controlled countries, thereby hindering technology transfer. To further their interests, they complete their investment in third-party countries. The theory of the technology spillover effect suggests that the outflow of OFDI from developed countries can promote the diffusion of technology in the international arena, and enhance competitiveness.

Innovation channels are crucial for a country to overcome the challenges associated with the "neck" of core technology in key industries[6]. Independent innovation and control of a country's supply chain are essential for reducing risks and enhancing the level of independent innovation. However, export control policies can have an uncertain impact on a country's innovation level. While it may force relevant enterprises to improve their level of independent innovation and scientific and technological strength, firms with financing constraints may opt for low-level technology instead[7]. Therefore, export control can either reduce or increase supply chain vulnerability depending on its impact on the innovation levels of the regulated countries.

H1: US export controls on China can reduce supply chain vulnerability by increasing investment in the ICT industry in the Asia-Pacific region; and H2: US export controls on China can impact supply chain vulnerability through innovation.

3 Indicator measurement, data description, and modeling

3.1 Variable Setting and Indicator Construction

Export control Intensity Indicator construction

The Entity List data provides a direct measure of the severity and changes in US technology export controls on China. To determine the strength of US technology export controls on China, check the percentage of Chinese entities listed in the Entity List over a specific period.

Supply chain vulnerability

This paper analyzes supply chain vulnerability based on ELLOIT et al [8]. Vulnerability is the state of the supply chain system that suffers damage and is difficult to recover from due to inherent instability and external disruptions. The vulnerability index is calculated using import market concentration and external supply concentration.

Import Market Concentration Index. The Herfindahl-Hirschman Index is used to measure China's supply chain vulnerability from an import demand perspective.

$$H_{\mathrm{kt}} = \sum_{i=1}^{n_{\mathrm{kt}}} \left(\frac{m_{\mathrm{ikt}}}{\sum_i m_{\mathrm{ikt}}} \right)^2 \tag{1}$$

Where i represent China's import partner countries, k denotes the product, $\mathrm{m_{ikt}}$ represents the total value of China's imports of product k from country i in period t, and $\mathrm{n_{kt}}$ is the number of source countries of China's imports of product k in the period. This indicator shows how much a country depends on a particular source for its imports. A higher value means there are fewer alternatives for the country if there are supply chain shocks. This makes the supply chain vulnerable and risky.

External Supply Concentration Index. The index can measure China's transnational supply chain vulnerability based on the export centrality index based on CUI Xiaomin[9].

$$C_{\mathrm{ikt}} = \sum_{i \neq j}^{N_{kt}-1} \frac{m_{ijkt}}{\sum_i m_{ijkt}/N_{jkt}} \tag{2}$$

where i represents the exporter and j represents the importing country, but I ≠ China, k represents the product; $\mathrm{N_{kt}}$ represents the total number of all countries importing product k in period t; $\mathrm{m_{ijkt}}$ represents the total amount of imports of product k by country j from country i in period t; and $\mathrm{N_{jkt}}$ represents the total number of all importing countries of origin of country j on product k in period t.

$$C_{\mathrm{kt\_}}C\mathrm{hina} = \sqrt{\frac{\sum_i (c_{\mathrm{ikt}} - \bar{c}_{\mathrm{kt}})^2}{N_{kt}-1}} \tag{3}$$

Where $\bar{c}_{\mathrm{kt}}$is the mean value of export centrality of different countries for product k in period t. The concentrated external supply of a product reduces the number of nations where resources are available, limiting options and increasing supply chain risk.

3.2 Description of data sources and Estimated model setup

This article analyzes China's global supply chain vulnerability using monthly global bilateral import data from January 2018 to December 2021. The basis for determining whether a product is subject to control is whether the product exists on the U.S. Department of Commerce's list of export-restricted goods, i.e., whether there is an ECCN code. The physical list's pertinent information was taken from publicly accessible records on the Bureau of Industry and Security's website.

The following model is used in this article to examine the impact of US export regulations on the vulnerability of China's semiconductor supply chain:

$$Y_{kt} = \alpha + \beta EC_t * D_k + \lambda_t + \xi_k + \varepsilon_{kt} \quad (4)$$

In equation (4), the explained variable includes the overall external supply concentration index $C_{kt\_}China$ and import concentration index H_{kt}. $EC_t$is the intensity of U.S. technology export controls on China, D_k is a dummy variable for the regulated product, which takes 1 when the product is on the U.S. Department of Commerce's list of export-restricted goods. λ_t denotes time fixed effects; ξ_k denotes product-level fixed effects, and ε_{kt} is the perturbation term of the model.

4 Empirical results and analysis

4.1 Base regression estimate

Table 1 displays Equation (4) regression results, indicating that regulated products in China's supply chain have a lower vulnerability index than unregulated products.

The regression coefficients of columns (1) and (2) indicate a significant negative trend, pointing to a decrease in China's controlled item imports and external supply. By implementing export control measures, China has reduced vulnerability in its supply chain for restricted products related to import demand and external supply.

Table 1. Impact of U.S. Export Controls on China's Semiconductor Supply Chain Vulnerability

	(1) Hkt	(2) Ckt China
ECt *Dk	-0.0363***	-0.6433***
	(0.0118)	(0.2147)
constant term (math.)	0.5734***	10.8687***
	(0.0123)	(0.2231)
time fixed effect	YES	YES
product fixed effect	YES	YES
observed value	3408	3408
R^2	0.789	0.989

Note: p-values in parentheses. *, ** and *** indicate significance at the 1%, 5% and 10% levels.

4.2 Mechanism test

Testing the Mechanism of U.S. FDI in the Asia-Pacific Region

Table 2 shows that U.S. technology export controls on China have increased the importance of the Asia-Pacific region in U.S. OFDI in the ICT industry. The regression coefficients of the explanatory variables have decreased significantly compared to those in the base regression of Table 1 when the mechanism variables were not added, indicating that the U.S. government's export controls have compelled U.S. semiconductor multinationals to invest more in the Asia-Pacific region. This strategy has reduced the vulnerability of China's semiconductor supply chain.

Table 2. Mechanism test regression results

VARIABLES	(1) *FDI*	(2) *Ckt_China*	(3) $Growth_{kt}$	(4) H_{kt}
$ECt*D_k$	0.1130***	-1.8961***	0.4327***	-0.0037
	(0.0076)	(0.2559)	(0.0251)	(0.0065)
FDI		-4.9687***		
		(0.9389)		
$Growth_{kt}$				-0.0190***
				(0.0043)
constant term	0.2583***	16.7276***	10.2502***	0.7701***
	(0.0115)	(0.4285)	(0.0397)	(0.0453)
product fixed effect	YES	YES	YES	YES
time fixed effect	YES	YES	YES	YES
observed value	1136	1136	3408	3408
R^2	0.172	0.987	0.082	0.785

Note: p-values in parentheses. *, ** and *** indicate significance at the 1%, 5% and 10% levels..

Autonomous Innovation Mechanism Test

The findings indicate that export control has a positive effect on China's level of independent innovation, as demonstrated by the significantly positive coefficient of column (3). Furthermore, the study suggests that stronger innovation capacity leads to more decentralized imports and a lower vulnerability of the supply chain, with a significantly negative coefficient of the mechanism variable in column (4). After adding the mechanism variable, the original core explanatory variable becomes insignificant, suggesting that improving independent innovation capacity is one of the ways export control can reduce the vulnerability of China's supply chain. This result supports hypothesis 3, and highlights the importance of promoting independent innovation to enhance China's export control and supply chain security.

5 Conclusions

The research found that these controls have significantly affected the vulnerability of China's supply chain, leading to increased external supply diversification and decentralized import sources. The following are the primary policy considerations based on the preceding findings:

Firstly, diversify import sources and limit product concentration by exploring new opportunities for cooperation and development. The Regional Comprehensive Economic Partnership Agreement (RCEP) and other regional institutions can help to develop product import channels in Southeast Asia, East Asia, and other regions. The RCEP rules of origin can enable the state party to expand the procurement channels of key products, which is of great importance to stabilizing the source of imports related to the semiconductor manufacturing industry and bypassing the U.S. trade embargo.

Secondly, to reduce the United States' containment of China, we need to collaborate with "swing countries" globally. We should establish R&D centers in intermediary nations, embed ourselves in cutting-edge semiconductor industry research, and break through the U.S. blockade on China's high-tech industry. We must expand market access, implement stable foreign investment policies, leverage China's market advantage, attract foreign investment, and maintain cooperation with "swing countries."

Finally, to strengthen the semiconductor manufacturing industry, focus on local competitive advantages through increased innovation, R&D efforts, and independent research.

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