Security Prediction and Path Analysis of China's Robot Industry Chain Based on Double Difference Estimation

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Abstract. The world situation is constantly changing, the import and export industry chain is closely related to a country's foreign relations. The recent Sino-US trade war has had a profound impact on the pattern of China's import and export industry. As a strategic industry in China's national economy, the robotics industry is a pillar industry that ensures the security of China's industrial and supply chains. There is a lack of specialized research on robots and quantitative analysis based on customs import and export data in existing domestic papers related to the industrial chain. Papers on the China US trade war mostly rely on existing data for analysis, with few establishing evaluation models and constructing relevant safety indices. Therefore, in order to study the current security status of the robot industry chain, analyze its potential risks and the connection with the US China trade war, and find a path to resist the impact of external factors on the industry chain, we used the HS8-bit code of China's robot industry chain from January 2018 to December 2022 to construct the HHI index to characterize the security status of the robot industry. We used a difference in differences estimation model to evaluate the impact of the US China trade war on the robot industry chain, and concluded that the impact of the US China trade war will significantly increase the risk of the robot industry chain. On this basis, we further established a model to analyze the path of China's robot industry chain to resist the China US trade war. The results show that expanding the scale of high-quality introduction of foreign investment, promoting the construction of a national market, and enhancing independent innovation capabilities can all to some extent resist the negative effects of the China US trade war on the robot industry chain.

Keywords: Double Difference Estimation, Import concentration, Robot Industry Chain.

1. Introduction

Currently, the century long changes are intertwined with US sanctions, geopolitical conflicts continue to ferment, and the wave of anti-globalization has led to global uncertainty and instability. Robots, as representatives of cutting-edge technology and carriers of emerging technologies, are important indicators for measuring a country's level of scientific and technological innovation and high-end manufacturing industry[1],With its intelligent and automated technology applications, it plays an important role in fields such as manufacturing[2]. The development speed of China's robot industry is fast, with strong international competitiveness, and has become an important global market for robot production and consumption[3]. Focusing on the pain points, application bottlenecks, and innovation difficulties of the robot industry chain in the new era, and striving to improve the resilience and safety level of the robot industry chain supply chain, is a strategic choice to adapt to the adjustment of global division of labor.

With the rapid development of artificial intelligence and robotics technology, China's robotics industry is facing unprecedented opportunities and challenges. According to Liu Ran's (2024) research[4], The market size of China's robotics industry continues to grow, technological innovation continues to break through, and the industrial cluster effect is gradually emerging, promoting the rapid development of the industry. However, the industrial foundation is still weak, with insufficient high-end supply and data security issues remaining bottlenecks that restrict the development of the industry. Liu Ran pointed out that the government, enterprises, and all sectors of society need to strengthen investment in technology research and development to promote the enhancement of the core competitiveness of industries. At the same time, Leren Qian (2024) [5] conducted an in-depth exploration of the robotics industry from a supply chain perspective and believed that optimizing the supply chain is crucial for the healthy development of the industry.

From previous research, existing domestic papers on robots mostly start from theory. Most papers on the China US trade war start from a macro perspective, with few establishing evaluation models and constructing relevant security indices. On the basis of previous research, this article selects the import index data of the robot industry chain from the China Customs Statistics Department (customs.gov.cn), and uses the HHI index to conduct risk assessment of the robot industry chain. The structure of this article is as follows: Chapter 2 introduces the data situation and preprocessing methods for subsequent measurement and evaluation. Chapter 3 depicts the risk status of the robot industry chain from three dimensions, analyzes the impact of the China US trade war on the security of the Chinese robot industry chain, and further conducts a path analysis of the robot industry chain to resist the impact of the China US trade war. Chapter 4 presents the final conclusion and recommendations.

2. Related theories

2.1. Variable Description

This article uses customs import data from January 2018 to December 2022 at the level of China's HS8 products, source countries, and provinces to construct an industrial chain security index and measure it. At the same time, it is connected with data on the development of China's industrial chain before and after the Sino US trade friction, and uses difference in differences estimation to test how the Sino US trade friction affects the security of the robot industry chain, thus proposing feasible paths to ensure the security of the robot industry chain supply chain.

Based on the HS8-bit encoding and the robot industry chain structure diagram which showed in Figure 1 , this article selects 48 products from the panoramic view of the robot industry chain and downloads the import data of related products from the official website of the General Administration of Customs.

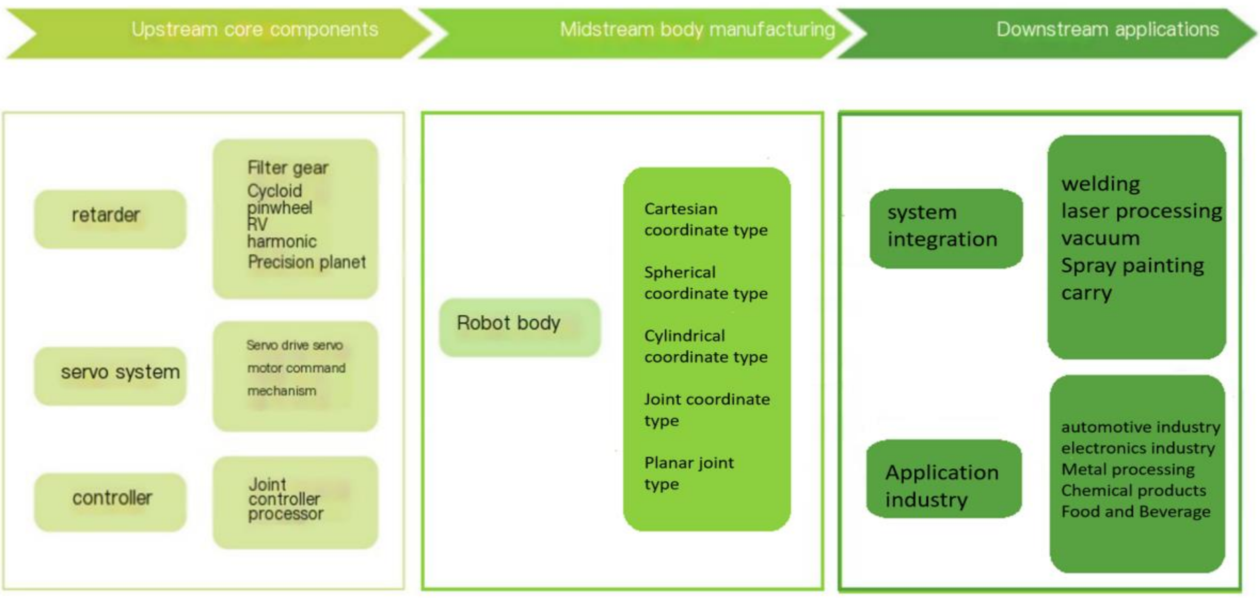

Figure 1. Panorama of the Robot Industry Chain

This article aims to predict the security of the robot industry chain. Based on existing statistical data, it collected information on import volume, trade mode, import province, import partner, HS code, registered address of the sender and receiver, import time, etc GDP Scale of investment attraction and number of invention patents. The data used is shown in the following table 1:

Table 1. Data Explanation Table

Name	Variable	Unit	Time Range	Frequency	Source
Import amount	Y	dollar	2018.1-2023.12	daily	Customs head office
Importing Province	X_2	\	2018.1-2023.12	daily	Customs head office
HS code	X_3	\	2018.1-2023.12	daily	Customs
Trading partners	X_4	\	2018.1-2023.12	daily	Customs head office
Total GDP	X_5	trillion yuan	2018.1-2023.12	year	EPS database
Investment scale	X_6	Ten thousand dollars	2018.1-2023.12	year	EPS database
patents	X_7	individual	2018.1-2023.12	year	EPS database

2.2. Theoretical Introduction

The difference in differences (DID) estimation method is a relatively mature analytical approach for policy research, and its principle of action is similar to that of natural experiments. It regards the implementation of a certain policy as a natural experiment, which has significant advantages compared to other models of the same type in this study. DID can control the bias caused by unobservable heterogeneity before policy implementation, by comparing the changes in the affected and unaffected groups before and after sanctions, and eliminating the interference of potential confounding variables. The assumptions of the DID model are clear and easy to verify, and the robustness of the estimation results is ensured through parallel trend testing, providing higher credibility for subsequent policy analysis.

3. Experiments

This article systematically sorts out the structural characteristics and overall situation of China's robot industry chain security based on historical data, in order to accurately evaluate the real situation of China's robot industry chain supply chain security.

3.1. Main indicators for measuring the security and risks of the industrial chain

Herfindahl-Hirschman index(HHI):

$$\mathrm{HHI} = \sum_{i=1}^{n} S_i^2 \tag{1}$$

Among them, S_i represents the market share of the i-th company. HHI can be used to measure the concentration of the industrial chain. If the HHI index score is close to 0, it indicates that the industrial chain is moving towards perfect competition; If the score is close to 1, it indicates that the concentration of the industrial chain is high and tends towards a monopolistic environment.

By calculating the HHI index from 2018 to 2022, Figure 2 can show that the overall concentration of the robot industry chain and the national average has shown a downward trend, but the import concentration of China's robot industry chain is still higher than the national average level.

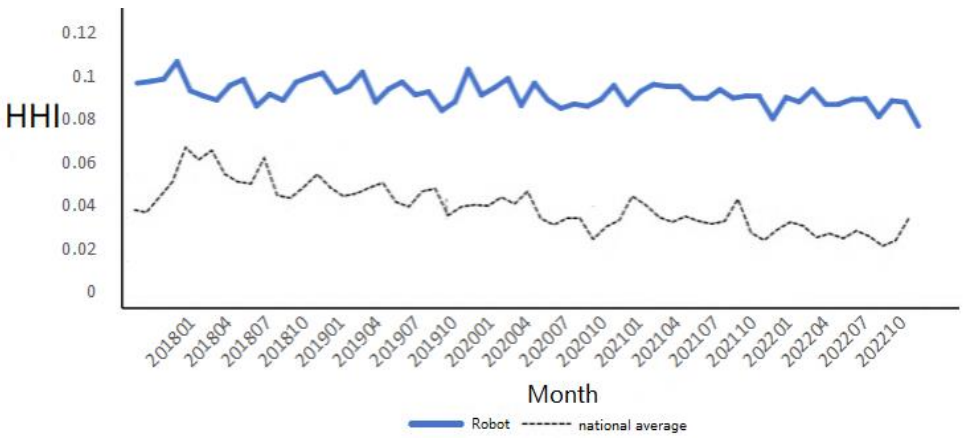

Figure2: Comparison chart of robot industry chain risks and national average

Further analysis of the upstream, midstream, and downstream of the industrial chain reveals that the concentration of robot imports in the downstream is significantly higher than in the upstream and midstream, characterized by dynamic changes. In contrast, the import concentration of upstream and midstream shows a relatively stable downward trend. Through the horizontal comparison of data in Figure3, it is found that the downstream faces relatively greater risks, mainly due to the high concentration of automation and intelligence demands in downstream fields such as automobile manufacturing, 3C electronics, logistics and warehousing.

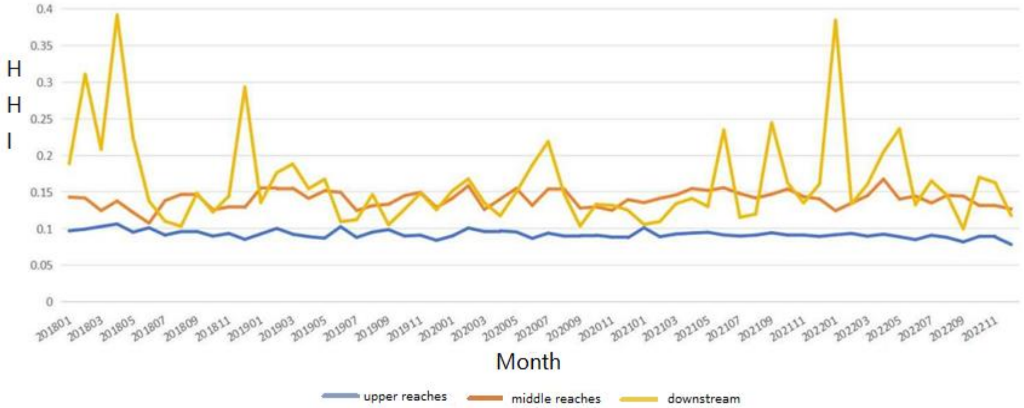

Figure3: Comparison of Risks in Various Stages of the Robot Industry Chain

3.2. Robot Industry Chain Security Assessment: Taking the Upstream of the Industry Chain as an Example

This article analyzes the upstream of the robot industry chain from a temporal perspective and Figure 4 show the trend of HHI. From early 2018 to early 2019, the HHI value fluctuated greatly, and the market was relatively dispersed but had significant fluctuations. At this time, China is undergoing industrial restructuring and technological innovation, while also facing external environmental challenges. China's imported robots and related products are affected, resulting in fluctuations in HHI values.

From early 2019 to early 2020: The change in HHI value was relatively stable. Major enterprises have begun to stabilize their supply chains and gradually formed a relatively stable import model. From early 2020 to early 2021: The COVID-19 pandemic has ravaged the world, causing significant impacts on China and global supply chains. From a data perspective, the HHI value surged in February 2020, when the pandemic caused supply chain tension and the Chinese market became more reliant on a few suppliers, leading to an increase in HHI value. But subsequently, with China's effective control of the epidemic and the recovery of production, the HHI value gradually declined.

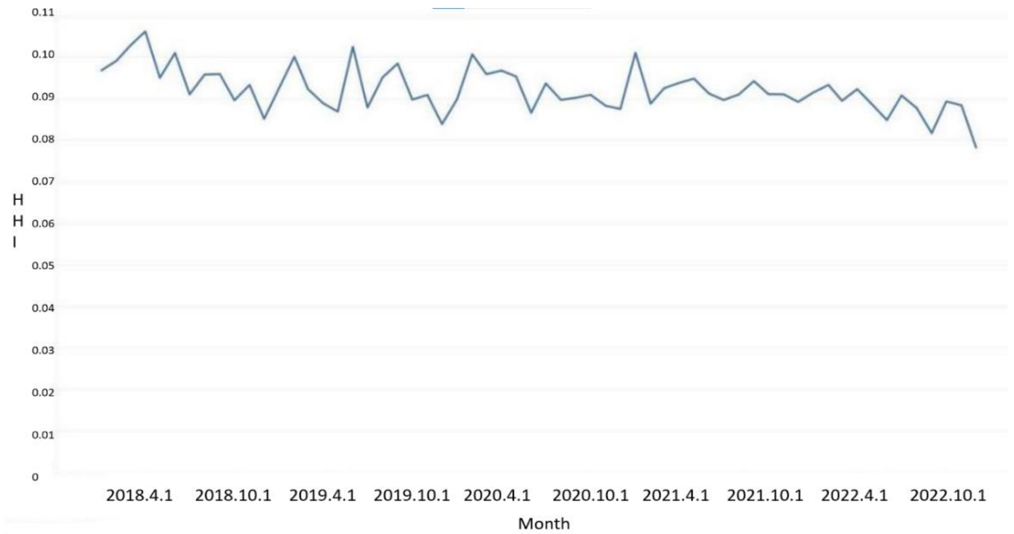

Figure4: Concentration of China's Robot Industry Chain from 2018 to 2022

The United States has long been a leader in global technological innovation[6], while China's rapid development in the field of technological innovation in recent years is seen by the United States as a challenge to its technological hegemony[7]. Therefore, the United States has taken a series of strategic measures, including sanctions, to disrupt China's high-tech industry chain and hinder China's technological development[8] .

The United States has strengthened export controls and investment review mechanisms, such as the Committee on Foreign Investment, to restrict China's investment in high-tech companies within the United States, which are often pioneers in the development of robotics technology[9].

3.3. Difference-in-Differences Model, Variable Description, and Data Sources

Difference-in-Differences is a method used to study treatment variables under the premise that the control group and the treatment group satisfy the parallel trends assumption. The standard DID model is as follows:

$$\mathrm{Y_{it}} = \alpha + \delta \mathrm{D_i} + \lambda \mathrm{T_t} + \beta(\mathrm{D_i} \times \mathrm{T_t}) + \varepsilon_{\mathrm{it}} \tag{2}$$

In reality, policies are not fully implemented at a specific point in time but are instead piloted and gradually rolled out. This means that there are differences in the intervention points of the policy across different regions. In such cases, a staggered Difference-in-Differences model is often used:

$$\mathrm{Y_{it}} = \alpha + \beta \mathrm{D_{it}} + \mu_{\mathrm{i}} + \gamma_{\mathrm{t}} + \varepsilon_{\mathrm{it}} \tag{3}$$

The two-way fixed effects model is a special case of the staggered Difference-in-Differences model, and differences in intervention points across regions cannot be disentangled [10].

This paper constructs a Difference-in-Differences estimation model based on the degree to which China's imported products are affected by U.S. sanctions to identify the impact of U.S. sanction shocks on the security of China's robotics industry chain.

$$\mathrm{HHI_{pict}} = \alpha + \beta \mathrm{post_{ct}} + \ln(\omega_{\mathrm{it}}) + \ln(\mu_{\mathrm{pt}}) + \ln(\nu_{\mathrm{ic}}) + \ln(\theta_{\mathrm{pi}}) + \xi_{\mathrm{pict}} \tag{4}$$

Here, p represents the province, i represents the stage of the industry chain, mainly including upstream, midstream, and downstream, c represents the country, and t represents the month in the time dimension. The core explanatory variable HHI_{pict} is the import concentration at the province-industry chain stage-country (region)-month level.

The dependent variable (HHI_{pict}). This paper uses HHI_{pict} to represent the level of security of the robotics industry chain.

Explanatory variable ($post_{ct}$). This paper uses $post_{ct}$to represent U.S. sanctions. Using January 2020 as the time cutoff point, for countries (regions) that are subject to U.S. sanctions before this time point, $post_{ct}$ is assigned a value of 1; otherwise, it is assigned a value of 0. For all other countries (regions), $post_{ct}$ is consistently assigned a value of 0, serving as the control group.

4. Conclusion

The empirical results regarding the impact of the U.S.-China trade war on the security of China's robotics industry chain are reported in Table 2. In Table 3, (1), (2), and (3) represent different models or conditions. The coefficients of $post$ and the standard errors (numbers in parentheses) indicate the magnitude and statistical significance of the impact of U.S. sanctions on the security of the robotics industry chain. The numbers in parentheses represent the standard errors; ***, **, and * denote significance levels at 1%, 5%, and 10%, respectively. The same applies to the table 3.

Table 2: The Impact of U.S. Sanctions on the Security of the Robotics Industry Chain

Project	-1	-2	-3	-4	-5
Post	0.048*** (0.001)	0.031*** (0.004)	0.031** (-0.01)	0.009 (-0.005)	-0.029** (-0.01)
Industry Chain—Month	F	T	T	T	T
Province—Month	F	F	F	T	T
Industry Chain—Country	F	F	F	F	T
Province—Industry Chain	F	F	F	F	F
Clustering Hierarchy	None	None	Country	Country	Country
Observation Value	46080	46080	46080	46080	46080
R^2	0	0.0055	0.0055	0.0247	0.0903

In Column (1), the coefficient of the core explanatory variable $post$ is significant and positive, indicating that the U.S.-China trade war shock reduces the security of the robotics industry chain. Column (2) incorporates a dimension of fixed effects, namely Industry Chain Segment—Month Fixed Effects (ω_{it}), with the coefficient remaining significantly positive. Column (3) further clusters the standard errors at the country level for regression, and the coefficient of the core explanatory variable remains significantly positive. This suggests that all else being equal, the U.S.-China trade war shock would lead to a 3.1% increase in the import concentration of China's robotics industry chain.

4.1. Path Analysis of the Resilience of China's Robotics Industry Chain to Withstand U.S. Sanctions

This paper will explore potential paths to withstand U.S. sanctions from three perspectives: attracting capital, promoting the construction of a national unified market, and enhancing independent innovation capabilities. To study these paths, the model is set as follows:

$$\mathrm{HHI_{pict}} = \alpha + \beta \mathrm{post_{ct}} + \delta \mathrm{post_{ct}} \times \mathrm{factor_{pt}} + \omega_{\mathrm{pt}} \tag{5}$$

The scale of attracting capital($scale$), is represented by the logarithm of the number of foreign-invested enterprises registered at the end of the year by region, with data sourced from the China Statistical Yearbook from 2018 to 2022. The unified national market($market$)is represented by the logarithm of the marketization index at the provincial level provided by Wang Xiaolu. The level of independent innovation ($tech$) Measured by the logarithm of the total number of invention patent applications at the provincial level, with data sourced from the China National Intellectual Property Administration.

The empirical analysis results of the resilience paths of the robotics industry chain to U.S. sanctions shocks are shown in Table 3.

Table 3: Resilience Path of the Robotics Industry Chain to U.S. Sanctions Shocks

Project	(1)	(2)	(3)
post	0.402*** (0.769)	0.687*** (0.132)	0.832*** (0.138)
post ×scale	-0.050*** (0.014)	\	\
post ×market	\	-0.286*** (0.064)	\
post ×tech	\	\	-0.669*** (0.013)
Province—Year Fixed Effects	T	T	T
Observation Value	155	155	155
R^2	0.357	0.369	0.399

Columns (1) to (3) of Table 3 respectively include the interaction terms between the core explanatory variable ($post$) and the scale of attracting capital, the unified national market, and the level of independent innovation. The estimation results show that the coefficients of the interaction terms are all highly significant and negative, indicating that under the impact of the U.S.-China trade war, these three paths help significantly reduce the risks to the robotics industry chain caused by U.S. sanctions. They offset some of the negative effects of the U.S.-China trade war on the security of China's robotics industry chain, thereby enhancing its security level and ability to withstand risks.

5. Conclusion

In this paper, we conduct a systematic study on the security issues of China's robotics industry chain using the import concentration index and Difference-in-Differences estimation. We find that the downstream segments face higher risk compared to the upstream and midstream segments, and they exhibit greater dynamic instability. There are also significant differences in the security of the various segments of the industry chain, with particularly high risks in the key components upstream and specific robot applications downstream. This indicates that there are still deficiencies in China's robotics in terms of whole-machine manufacturing and practical application. Additionally, the study verifies that the U.S.-China trade war has further intensified these challenges, having a significant negative impact on the security of China's robotics industry chain. In the future, the model could be applied to the industry chains of new energy vehicles and drones to quantitatively describe and depict the security index of the industry chain, providing a solid foundation for its healthy development.

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