A Study on the Trade Competitiveness and Complementarity of Industrial Robots Between China and Regional Comprehensive Economic Partnership Member States

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ABSTRACT

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| **The objective:** To analyze the trade scale, structure, and potential of industrial robots between China and other Regional Comprehensive Economic Partnership member countries, and propose strategies for enhancing trade cooperation.  **Methodology:** We conducted a retrospective quantitative analysis (2014-2023) using empirical trade indices applied to bilateral trade data primarily sourced from UN Comtrade. The study comprised: (1) assessing trade volume trends and market structure concentration; (2) evaluating trade potential through three established indices: the Trade Competitiveness Index (TC) and Revealed Comparative Advantage Index (RCA) to measure competitive advantages, and the Trade Complementarity Index (TCI) to assess structural matching of exports and imports. These indices were selected for their proven ability to quantify distinct trade dynamics relevant to potential.  **Findings:** Trade volume grew 77.41% (2014-2023) with high market concentration (Japan/South Korea/Singapore: 80.8% share). Revealed Comparative Advantage Index (RCA) analysis revealed a declining comparative advantage for China (-1.66), though Vietnam/Thailand showed gains. Trade Complementarity Index (TCI) revealed China gained competitiveness in service robots but faced deficits in production/multifunctional robots. Through the lens of the above, the study enables trade structure optimization trade structure through RCEP exchanges., ultimately uncovering new perspectives for trade cooperation.  **Recommendation:** The study concludes that optimization of China's export structure is needed while addressing diversified market demand. Enhanced bilateral and multilateral cooperation is critical for leveraging complementary advantages and achieving mutual benefits in the industrial robotics trade. These recommendations ultimately support win-win development under the Regional Comprehensive Economic Partnership framework. |

*Keywords: Revealed Comparative Advantage Index; trade competitiveness; trade complementarity; Trade Competitiveness Index; Trade Complementarity Index; trade-in industrial robots*

1. INTRODUCTION

The industrial robot is a strategic technology to lead the future, an important element in the development of artificial intelligence, and a necessary means for the intelligent transformation of the manufacturing industry. According to the latest study by the International Federation of Robots (IFR), the average global sales of industrial robots increased by 19% from 2014 to 2023, with a growth rate of up to 30% in 2023, and the trend of growth in global demand for industrial robots is obvious. China has become the world's largest industrial robot market for five consecutive years since 2014, and exports have gradually increased. Industrial robots have become an important driving force to pull the world's economic growth and the intelligent transformation of the manufacturing industry**(Şahin,2022).**

From 2014-2023, China's industrial robot exports to other *Regional* Comprehensive Economic Partnership(Hereinafter referred to as RCEP) member countries grew at an average annual rate of 9.9%, and its share of total industrial robot exports during the same period increased from 20.1% to 25.1%.Other RCEP member countries are also the top source of China's industrial robot imports, with 40% of China's industrial robots imported from other RCEP member countries. With the formal entry into force and implementation of the Regional Comprehensive Economic Partnership Agreement (RCEP) on January 1, 2022, China's trade with other RCEP member countries will be more convenient **(Tan & Wang, 2025)**. An in-depth analysis of the competitiveness and complementarity of industrial robots trade between China and other RCEP member countries is not only conducive to better exerting the comparative advantages of each country, improving the efficiency and potential of bilateral trade, and promoting the comprehensive development of China's industrial robots trade with other RCEP member countries, but also conducive to the stabilization of China's overall pattern of foreign trade and the realization of the high-quality development of foreign trade**(Hong et al.,2022; Li,2024).**

2. Literature Review

**2.1 Competitiveness**

Numerous scholars have delved into the concept of competitiveness, leading to a plethora of definitions arising from diverse analytical perspectives. There are many competitive concepts. First, it is important to mention that Krugman (1994) points out that the productivity of a sector per se has little, if anything, to do with international competitiveness. Instead, it is relative sectoral efficiency gains that determine trade performance. While the productivity growth of a sector or an economy is vital to a country's standard of living, absolute productivity comparisons across countries alone provide no insights into competitive advantage. Krugman suggests that "the success of a country depends not on absolute but on comparative productivity advantage".

On the other hand, the concept of competitiveness has been assessed and studied at various levels: at the country level , regional level and industry level .

**2.2 Revealed Comparative Advantage**

Despite the fact that studies work with a variety of methods to assess competitiveness, the most common method for analysis of foreign trade competitiveness is the Revealed Comparative Advantage (RCA) methodology grounded in conventional economic trade theory.

The RCA is an index used in international economics for calculating the relative advantage or disadvantage of a certain country in a certain class of goods or services as evidenced by trade flows. It is based on the Ricardian comparative advantage concept.

Also commonly known as the Balassa index, it was introduced by Liesner (1958) and later redefined and popularized by Balassa (1965) and by Balassa and Noland (1989) It is known to empirically identify a country's weak and strong export sectors. RCA has been used in a variety of studies of external trade data.

The Balassa index provides a simple overview of the comparative advantage distribution. The advantage of this index is its simplicity. Another very important characteristic of this index is its ability to take into consideration not only the trade performance between the individual trade partners, but it is also taking into consideration the total trade performancewithin the whole territory.

The higher the RCA index value, the stronger the competitiveness of the corresponding product. Conversely, it may be asserted that the given country exhibits a competitive disadvantage in the case of the given commodity or group of commodities.

**2.3 complementarity**

The Trade Complementarity Index (TCI) was first proposed by Japanese economist Kiyoshi Kojima in 1964 and has become an important analytical tool in international trade research.

The core objective of the TCI is to quantify the extent to which the trade structure between two countries matches, and thus determine their potential trade complementarity. Its calculation principle is based on a key comparison: it measures whether the pattern of export specialization (comparative advantage) of one country (country A) in a particular industry matches the pattern of import demand (comparative disadvantage/demand gap) of the other country (country B) in the corresponding industry. Specifically, it is calculated by comparing the structure of country A's exports to the world market (reflecting its supply capacity) with the structure of country B's imports from the world market (reflecting its demand structure). The higher the value of the index, the better the match between the export supply and import demand structures of the two countries, the stronger the complementarity of bilateral trade, and the greater the potential trade space.

3. Overview of China's trade in industrial robots with other RCEP member countries

According to the study, industrial robots can be categorized into high technological complexity and low technological complexity industrial robots; in addition, according to the application purpose, industrial robots can be categorized into production-oriented industrial robots (HS code 842489, HS code 851521, HS code 851531, HS code 848640, HS code 851580) service production-oriented industrial robots (HS code 842890), and other multifunctional industrial robots (HS code 847950).

This paper focuses on three major categories: production-oriented industrial robots, service-production industrial robots, and other multifunctional industrial robots. The specific corresponding HS codes (International Code Harmonization System) are shown in Table 1.

**Table 1. Types and numbers of industrial robots**

|  |  |  |
| --- | --- | --- |
| **No.** | **Product Category** | **HS Code** |
| 1 | Production-oriented Industrial Robots | 842489、851521、851531、848640、851580 |
| 2 | Service Production-oriented Industrial Robots | 842890 |
| 3 | Other Multifunctional Industrial Robots | 847950 |

**3.1 Trade Scale**

Since 2014, China's trade in industrial robots with other RCEP member countries has developed rapidly, with total trade showing an overall growth trend (see Table 2). From 2014-2023, total trade has grown from US$364.59 million to US$646.84 million, with a cumulative growth of 77.41%. In particular, exports grew at a faster rate, with an average annual growth of 9.9%, which is 2 percentage points higher than the average annual growth rate of imports. In terms of individual years, most years show positive growth, and only three years, 2019, 2022 and 2023, show negative growth. Among them, the import trade of industrial robots declined in 2019, with an overall trade growth rate of -12.93%, while the trade growth rate in 2021 was as high as 34.89%, and the growth rate in 2020 was over 5%, specifically 5.76%. From the point of view of trade balance, China's industrial robot trade with other RCEP member countries has always had a trade deficit. 2022 and 2023 two years, China and other RCEP member countries' industrial robot trade deficit significantly alleviated, the value of the deficit fell sharply to 300.28 million U.S. dollars and 191.11 million U.S. dollars, to a certain extent, it shows that after the RCEP rules officially came into effect on January 1, 2022, the RCEP rules improved China's trade in industrial robots with other RCEP member countries.

**Table 2. China's trade in industrial robots with other RCEP members (in USD)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** | **Export Amount** | **Import Amount** | **E+I** | **Trade Growth Rate** | **E-I** |
| 2014 | 949228400 | 2696711990 | 3645940390 | 0.154647837 | -1747483590 |
| 2015 | 922398492 | 2870750988 | 3793149480 | 0.040376165 | -1948352496 |
| 2016 | 960717913 | 3129498448 | 4090216361 | 0.078316682 | -2168780535 |
| 2017 | 1102852756 | 4164841152 | 5267693908 | 0.287876592 | -3061988396 |
| 2018 | 1165173281 | 5264041325 | 6429214606 | 0.220498897 | -4098868044 |
| 2019 | 1439183017 | 4158499141 | 5597682158 | -0.129336552 | -2719316124 |
| 2020 | 1566647459 | 4353690151 | 5920337610 | 0.057640903 | -2787042692 |
| 2021 | 1928869839 | 6056991737 | 7985861576 | 0.348886179 | -4128121898 |
| 2022 | 2055614547 | 5058384974 | 7113999521 | -0.109175703 | -3002770427 |
| 2023 | 2278633092 | 4189762616 | 6468395708 | -0.090751175 | -1911129524 |

*Source: Processed from UN Comtrade data, same below.*

**3.2 Trade Structure**

**3.2.1 Country Structure**

At the level of import sources, China's imports of industrial robots from other RCEP member countries are characterized by two distinct features. First, it is concentrated in a few countries. As shown in Table 3, the top three Japan, South Korea, and Singapore accounted for 46.38%, 28.41%, and 18.91% respectively, totaling as high as 93.7%, meaning that more than 90% of China's imports of industrial robots from other RCEP member countries come from these three countries. Second, imports from member countries remain relatively stable. In terms of the trend from 2014-2023, only Singapore and South Korea show more obvious fluctuations. Among them, Singapore shows significant growth, with a net increase of about 7 percentage points in share over the decade, while South Korea declines from 28.16% in 2014 to 17.30% in 2023.

At the export level, it can be seen from Table 4 that China's industrial robot exports to other RCEP member countries are similarly characterized by both concentration and stability. First, the export object is concentrated in Japan, Vietnam, Singapore, and South Korea. The average proportion of these four countries is 17.29%, 17.07%, 15.73%, and 11.83% respectively, totaling up to 61.92%. Second, judging from the trend of changes in the share of each member, the share of most countries is relatively stable, with little change. The countries with faster growth and larger declines in share are Thailand and Singapore. Thailand's share increased by a net of about 8 percentage points over the decade, while Singapore's share declined from 20.59 percent in 2014 to 11.03 percent in 2023, a cumulative increase of about 9 percentage points.

**Table 3. China's imports of industrial robots from other RCEP member countries by member country (%)**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year Source** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **Average Share** |
|
| Australia | 0.0439 | 0.1029 | 0.1563 | 0.0785 | 0.1221 | 0.0869 | 0.0831 | 0.0910 | 0.0869 | 0.1592 | 0.1011 |
| Philippines | 0.1232 | 0.0409 | 0.0213 | 0.0264 | 0.0932 | 0.0656 | 0.1385 | 0.0207 | 0.0212 | 0.0649 | 0.0616 |
| South Korea | 28.1630 | 35.5685 | 32.1545 | 27.9012 | 38.5388 | 34.3789 | 29.3746 | 20.3957 | 20.2938 | 17.2955 | 28.4064 |
| Malaysia | 3.9363 | 2.4600 | 3.1100 | 2.9204 | 2.5342 | 2.6527 | 4.0386 | 5.6128 | 5.1010 | 3.8428 | 3.6209 |
| Japan | 49.3718 | 44.5679 | 44.7225 | 51.0318 | 41.3710 | 48.0452 | 45.4350 | 43.2775 | 45.9734 | 50.0368 | 46.3833 |
| Thailand | 0.5559 | 0.9662 | 0.9858 | 1.1264 | 0.4140 | 0.2299 | 0.5338 | 1.2539 | 0.7358 | 0.6121 | 0.7414 |
| Singapore | 17.0422 | 15.4590 | 17.5130 | 15.6529 | 15.4418 | 13.2749 | 18.7421 | 27.0105 | 24.2907 | 24.6638 | 18.9091 |
| New Zealand | 0.1007 | 0.0497 | 0.0184 | 0.0403 | 0.1458 | 0.0675 | 0.0000 | 0.0322 | 0.0782 | 0.0110 | 0.0544 |
| Indonesia | 0.0011 | 0.0001 | 0.0009 | 0.0003 | 0.0002 | 0.0176 | 0.0171 | 0.0231 | 0.0363 | 0.0299 | 0.0127 |
| Vietnam | 0.6620 | 0.7848 | 1.3171 | 1.2218 | 1.3388 | 1.1809 | 1.6372 | 2.2827 | 3.3826 | 3.2840 | 1.7092 |
| Myanmar | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Brunei | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Cambodia | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Laos | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

*Source: Processed from UN Comtrade data, same below.*

**Table 4. China's exports of industrial robots from other RCEP member countries by member country (%)**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year Country** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **Average Share** |
|
| Australia | 11.7083 | 8.5586 | 5.7412 | 8.2582 | 5.5273 | 4.5537 | 6.6088 | 6.9450 | 5.5687 | 5.5040 | 6.8974 |
| Philippines | 2.8209 | 3.9769 | 3.0716 | 2.5071 | 3.3328 | 3.7353 | 2.6571 | 4.6157 | 2.8460 | 2.4649 | 3.2028 |
| South Korea | 13.8539 | 12.8769 | 9.9922 | 12.3574 | 9.4825 | 10.0236 | 15.3558 | 10.4951 | 13.0610 | 10.8169 | 11.8315 |
| Cambodia | 0.5159 | 0.7005 | 0.5741 | 0.5344 | 1.0176 | 0.9833 | 1.1644 | 1.2640 | 2.5752 | 1.5725 | 1.0902 |
| Laos | 0.4626 | 0.3450 | 0.1066 | 0.5497 | 0.1446 | 0.2423 | 0.2166 | 0.0896 | 0.1305 | 1.0289 | 0.3316 |
| Malaysia | 5.7708 | 8.1472 | 7.2410 | 7.1606 | 8.4558 | 8.0102 | 7.0113 | 9.0541 | 8.0584 | 8.0589 | 7.6968 |
| Myanmar | 1.1026 | 1.5548 | 0.9477 | 1.1251 | 0.9721 | 0.7338 | 0.5625 | 0.3658 | 1.0285 | 0.3343 | 0.8727 |
| Japan | 14.5539 | 17.4564 | 16.8786 | 15.8622 | 21.6936 | 20.8268 | 20.3874 | 17.6453 | 14.8578 | 12.7625 | 17.2924 |
| Thailand | 7.2763 | 7.6914 | 8.1226 | 8.1130 | 7.6927 | 10.1188 | 7.4196 | 10.0206 | 10.0783 | 15.8116 | 9.2345 |
| Brunei | 0.0580 | 0.0816 | 0.0121 | 0.2155 | 0.6327 | 0.0765 | 0.0266 | 0.0326 | 0.0442 | 0.0280 | 0.1208 |
| Singapore | 20.5882 | 17.5804 | 22.7479 | 18.2552 | 15.7127 | 9.8726 | 12.4770 | 13.8666 | 15.1686 | 11.0333 | 15.7302 |
| New Zealand | 0.5838 | 0.8219 | 0.8848 | 0.9190 | 0.8567 | 0.6399 | 0.7137 | 0.8465 | 0.8080 | 0.6880 | 0.7762 |
| Indonesia | 9.5552 | 7.5225 | 7.4694 | 5.8213 | 7.6464 | 8.5789 | 5.1674 | 6.7509 | 9.7335 | 10.2415 | 7.8487 |
| Vietnam | 11.1497 | 12.6859 | 16.2101 | 18.3213 | 16.8327 | 21.6043 | 20.2317 | 18.0080 | 16.0413 | 19.6549 | 17.0740 |

*Source: Processed from UN Comtrade data, same below.*

*Note: According to the data screening, China does not have Brunei, Cambodia, Laos in terms of import trade of industrial robots from other RCEP member countries; it means that China does not have trade with Brunei, Cambodia and Laos in terms of import trade of industrial robots; in terms of export trade, China has trade with other RCEP member countries.*

At the level of total trade, as can be seen from Figure 1, the distribution of the share of China's trade in industrial robots with other RCEP member countries is relatively concentrated. Japan ranked first, accounting for 38.63%; South Korea ranked second, accounting for 23.93%; Singapore ranked third, accounting for 18.24%. The total share of the three countries is as high as 80.8%. The data shows that the three countries have a high share of industrial robot trade in the RCEP market, showing a strong competitive advantage. The Philippines, Cambodia, Laos, Myanmar, Brunei, and New Zealand all have a share of less than 1%.

**Fig. 1. Distribution of China's trade in industrial robots with other RCEP member countries in terms of share of each member country**

*Source: Processed from UN Comtrade data, same below.*

*Note: The share of individual member countries in the figure is the average share from 2014-2023.*

**3.2.2 Country Structure**

As can be seen from Figure 2 and Table 5, at the level of total trade, production-oriented industrial robots ranked first, service-production industrial robots ranked second, and other multifunctional industrial robots ranked third, with an average share of 65.65%, 17.19%, and 17.16%, respectively. In terms of trade balance, service production-oriented industrial robots maintain a trade surplus, with an average trade surplus of $18.61 million from 2014 to 2023; production-oriented and other multifunctional industrial robots continue to have trade deficits, and the deficits are all on the rise, and production-oriented industrial robots have larger trade deficits, with an average trade deficit of $135.06 from 2014 to 2023. million dollars.

From the three types of industrial robots trade country-by-country distribution (Table 6), in 2023, China and the other RCEP member countries for the production of industrial robots exports ranked the top three countries are Vietnam, Thailand and Singapore, imports ranked the top three countries are Singapore, Japan and South Korea; specific analysis, South Korea, Japan, Malaysia and Singapore are in deficit, of which Japan has the largest trade gap, amounting to 87.00 million U.S. dollars, in addition to the remaining 10 countries are in surplus; service production of industrial robots exports ranked the top three countries Japan, Indonesia and Vietnam, imports ranked the top three countries are Japan, South Korea and Malaysia; service production of industrial robots trade as a whole is in surplus; other multi-functional industrial robots exports ranked the top three countries South Korea, Thailand and Vietnam, imports of The top three countries are Japan, South Korea and Malaysia; specific analysis, in addition to Japan the remaining 13 countries are in surplus, Japan's trade deficit reached 94.58 million U.S. dollars.

*Source: Processed from UN Comtrade data, same below.*

**Fig. 2. Structure of China's trade in industrial robots with other RCEP member countries(million dollars)**

**Table 5. Overall trade in industrial robots between China and other RCEP member countries (million dollars)**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Category** | **Production-oriented Industrial Robots** | | | **Service Production-oriented Industrial Robots** | | | **Other Multifunctional Industrial Robots** | | |
| 2014 | 2023 | Average | 2014 | 2023 | Average | 2014 | 2023 | Average |
| Total Trade | 231.1829 | 439.1188 | 335.1509 | 72.4256 | 93.9129 | 83.1692 | 60.9855 | 113.8079 | 87.3967 |
| Trade Balance | -110.1648 | -159.9497 | -135.0573 | -12.4551 | 49.6751 | 18.6100 | -52.1284 | -80.8383 | -66.4834 |
| Trade Share | 63.4083% | 67.8868% | 65.6476% | 19.8647% | 14.5187% | 17.1917% | 16.7270% | 17.5945% | 17.1607% |

*Source: Processed from UN Comtrade data, same below.*

**Table 6. Commodity structure of China's trade in industrial robots with other RCEP member countries, 2023**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Production-oriented Industrial**  **Robots** | | | **Service Production-oriented Industrial Robots** | | | **Other Multifunctional Industrial Robots** | | |
| Import | Export | trade balance | Import | Export | trade balance | Import | Export | trade balance |
| Australia | 0.0099 | 5.8572 | 5.8473 | 0.6339 | 5.8122 | 5.1783 | 0.0232 | 0.8722 | 0.849 |
| Philippines | 0.2709 | 3.1085 | 2.8376 | 0.001 | 2.2826 | 2.2815 | 0 | 0.2254 | 0.2254 |
| South Korea | 64.4112 | 13.3436 | -51.0675 | 6.9393 | 7.2313 | 0.2919 | 1.1134 | 4.0728 | 2.9594 |
| Cambodia | 0 | 2.566 | 2.566 | 0 | 0.9922 | 0.9922 | 0 | 0.025 | 0.025 |
| Laos | 0 | 2.011 | 2.011 | 0 | 0.3279 | 0.3279 | 0 | 0.0056 | 0.0056 |
| Malaysia | 14.9196 | 11.2848 | -3.6348 | 1.1169 | 5.8728 | 4.7559 | 0.064 | 1.2058 | 1.1418 |
| Myanmar | 0 | 0.4445 | 0.4445 | 0 | 0.3135 | 0.3135 | 0 | 0.0038 | 0.0038 |
| Japan | 101.0292 | 14.0294 | -86.9998 | 12.4931 | 13.5102 | 1.0171 | 96.1202 | 1.5415 | -94.5787 |
| Thailand | 2.5613 | 24.5567 | 21.9954 | 0.0028 | 7.6251 | 7.6223 | 0.0004 | 3.8471 | 3.8468 |
| Brunei | 0 | 0.0315 | 0.0314 | 0 | 0.0237 | 0.0237 | 0 | 0.0086 | 0.0086 |
| Singapore | 102.7557 | 20.7611 | -81.9946 | 0.5797 | 3.0112 | 2.4315 | 0 | 1.3684 | 1.3684 |
| New Zealand | 0.0067 | 0.8211 | 0.8144 | 0.0392 | 0.5517 | 0.5124 | 0 | 0.1949 | 0.1949 |
| Indonesia | 0.1249 | 10.5154 | 10.3905 | 0.0004 | 12.3999 | 12.3995 | 0 | 0.4212 | 0.4212 |
| Vietnam | 13.4449 | 30.2539 | 16.8089 | 0.3123 | 11.8397 | 11.5274 | 0.002 | 2.6927 | 2.6907 |
| Total | 299.5343 | 139.5845 | -159.9497 | 22.1189 | 71.7940 | 49.6751 | 97.3231 | 16.4848 | -80.8383 |

*Source: Processed from UN Comtrade data, same below.*

*Note: In addition to the above description, in the trade of other multifunctional industrial robots, China does not have import trade transactions of such industrial robots with Singapore, New Zealand, and Indonesia, which are among the other RCEP members.*

4. ASSESSMENT OF TRADE COMPETITIVENESS IN INDUSTRIAL ROBOTS BETWEEN CHINA AND RCEP MEMBER STATES

**4.1 Trade competitiveness at the aggregate level**

In this paper, the TC index (Trade Competitiveness Index) is used to measure the overall level of trade competitiveness. Referring to the existing literature **(Chen et al.,2020)**, the TC index is specifically calculated as:

TC=(X-M)/(X+M) （1）

In this formula, where X is the export value of all kinds of industrial robotic products of each RCEP member country, and M is the import value. The TC index takes the value range of [-1,1]. When the TC index is close to 1, it means that the country's trade competitiveness is very strong, when the index is close to -1, indicating that trade competitiveness is relatively weak. When the TC index is equal to 1, it means that the country only exports and does not import; when the index is equal to -1, it means that the country only imports and does not export. When the index is 0, it means that the country's trade competitiveness is at a medium level.

Table 7 shows the fluctuation of the TC index for industrial robots in China and other RCEP member countries from 2014-2023. The average fluctuation is 0.28 [(0.24+0.31+0.27)/3≈0.28], indicating that the RCEP member countries have become more competitive in the industrial robot trade, but the increase is not very large. Further from the fluctuation of each type of product, in terms of production-oriented industrial robots. The member countries with an upward trend in the TC index are China and Malaysia, indicating that the competitiveness of these two countries in production-oriented industrial robots is strengthening, of which the fluctuation value of Malaysia is the largest, and the TC index has increased by 0.32 from 2014 to 2023; and the other fluctuation of Myanmar from 2014 to 2023 value of 0, indicating that the trade competitiveness of Myanmar as a country is at a medium level; and five countries, Australia, the Philippines, Japan, Brunei, and New Zealand, have a declining trend in the TC index, indicating weakening competitiveness, with Japan having the largest fluctuation value, with the TC index declining by 0.18 from 2014 to 2023. For industrial robots that serve production, the TC indices of China, Australia, and the Philippines rise, with the largest increase in China, where the TC index rises by 0.61 in 2023 compared to 2014; in addition, Myanmar's TC index remains unchanged in 2023 compared to 2014; whereas four countries, Malaysia, Japan, Brunei, and New Zealand, see a decline in their TC indexes, with the largest decrease in Japan, where the TC index declines by 0.44 in 2023 compared to 2014.For industrial robots for other multifunctional applications. China, the Philippines, Malaysia, Brunei, and New Zealand saw their TC indexes rise, with Malaysia seeing the largest increase, with its 2023 TC index rising by 0.66 from 2014; in addition, Myanmar saw its 2023 TC index fall by 1 from 2014, suggesting that the country only imports but does not export; while Australia and Japan saw their TC indexes fall, with Australia seeing the largest decrease, with its 2023 TC index decreases by 0.3 from 2014.

**Table 7. Fluctuation of TC index for industrial robots to RCEP member countries, 2014-2023**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Production-oriented Industrial**  **Robots** | | | **Service Production-oriented Industrial Robots** | | | **Other Multifunctional Industrial Robots** | | |
| 2014 | 2023 | Period  fluctuation | 2014 | 2023 | Period  fluctuation | 2014 | 2023 | Period  fluctuation |
| Australia | -0.33 | -0.11 | 0.22 | -0.27 | 0.34 | 0.61 | -0.73 | -0.47 | 0.27 |
| Philippines | -0.73 | -0.83 | -0.10 | -0.89 | -0.88 | 0.01 | -0.26 | -0.56 | -0.30 |
| South Korea | -0.61 | -0.67 | -0.06 | -0.95 | -0.76 | 0.19 | -0.98 | -0.86 | 0.12 |
| Cambodia | 0.09 | 0.00 | -0.09 | -0.11 | 0.00 | 0.11 | 0.11 | 0.00 | -0.11 |
| Laos | -1.00 | 0.00 | 1.00 | -1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 |
| Malaysia | -1.00 | 0.00 | 1.00 | -1.00 | 0.00 | 1.00 | -1.00 | 0.00 | 1.00 |
| Myanmar | -0.26 | 0.06 | 0.32 | -0.43 | -0.45 | -0.01 | -0.78 | -0.12 | 0.66 |
| Japan | -1.00 | -1.00 | 0.00 | -1.00 | -1.00 | 0.00 | 0.00 | -1.00 | -1.00 |
| Thailand | 0.72 | 0.53 | -0.18 | 0.65 | 0.20 | -0.44 | 0.95 | 0.95 | -0.01 |
| Brunei | -0.73 | 0.00 | 0.73 | -0.83 | 0.00 | 0.83 | -0.93 | 0.00 | 0.93 |
| Singapore | -0.81 | -0.87 | -0.06 | -0.38 | -0.48 | -0.11 | -1.00 | -0.46 | 0.54 |
| New Zealand | 0.73 | 0.00 | -0.73 | 0.12 | 0.00 | -0.12 | -0.24 | 0.00 | 0.24 |
| Indonesia | -0.59 | -0.72 | -0.14 | -0.45 | -0.58 | -0.13 | -0.71 | -0.57 | 0.14 |
| Vietnam | -0.93 | 0.00 | 0.93 | -0.96 | 0.00 | 0.96 | -0.99 | 0.00 | 0.99 |
| Total | -0.80 | 0.00 | 0.80 | -0.77 | 0.00 | 0.77 | -0.63 | 0.00 | 0.63 |

*Source: Processed from UN Comtrade data, same below.*

*Note: After data screening, we know that the 2023 data on industrial robots of 7 countries, namely, South Korea, Cambodia, Laos, Thailand, Singapore, Indonesia, and Vietnam, are missing, and the reasons are analyzed as follows: firstly, it may be due to the promulgation of the policies on industrial robots in China, and therefore industrial robots of the above countries do not participate in the international trade, and the data are 0; secondly, it may be due to the untimely updating of the data, which is not discussed in depth here*

**4.2 Trade competitiveness at the regional level**

In this paper, the RCA index (Revealed Comparative Advantage Index) is used to measure trade competitiveness at the regional level. Referring to the existing literature **(French,2017; Huber et al.,2023; Ralte,2024)**, to measure China's competitiveness in industrial robotics to each RCEP member country in a more specific way, the calculation of the RCA index is adjusted to:

RCAabj = (Xabj/Xab)÷(XaWj/XaW) （2）

Where Xabj denotes the value of China's exports of industrial robots to other RCEP member countries and Xab denotes the total value of China's exports to other RCEP member countries; XaWj denotes the total value of China's exports of industrial robots to the world, and XaW denotes the total value of China's exports to the world of all commodities.

Table 8 shows the fluctuation of the RCA index of industrial robots between China and other RCEP member countries from 2014 to 2023. The average fluctuation is nearly -1.66 [(-0.38-4.59-0.02)/3 ≈ -1.66], indicating that China's regional demonstrated comparative advantage over the other RCEP member countries is declining as a whole, and the decline is more obvious. Further from the point of view of the fluctuation of various types of products, in terms of production-oriented industrial robots, the RCA index shows an upward trend of member countries Cambodia, Laos, Malaysia, Thailand, and Vietnam, indicating that the comparative advantage has been enhanced, among which the index fluctuation values of Laos and Thailand are larger, and the RCA index rises by 4.30 and 1.18 from 2014 to 2023, respectively; and in addition, New Zealand's index fluctuation is 0, which indicates that the country's trade competitiveness in production-oriented industrial robots is at a medium level; while seven countries, including Singapore, Myanmar, and South Korea, have declining RCA indexes, indicating weakening comparative advantages, with Singapore's index having the largest change, with the RCA index declining by 2.15 in 2023 compared to 2014. for service-producing industrial robots, South Korea, Japan, Malaysia, Brunei, Indonesia, and Vietnam Six countries saw their RCA indexes rise, and eight countries, including Australia, Laos, and Cambodia, saw their RCA indexes fall, with Vietnam seeing the largest increase, with its 2023 RCA index rising 0.58, from 2014, and Australia seeing the largest decline, with its 2023 RCA index falling 4.59 from 2014. For other multifunctional industrial robots, Australia, South Korea, Malaysia, Myanmar, Japan, and Indonesia, the RCA Index declined in six countries, while the rest of the countries increased slightly. Myanmar had the largest decrease, with the 2023 RCA Index down 1.04 from 2014, and Vietnam had the largest increase, with the 2023 RCA Index up 1.11 from 2014.

**Table 8. RCA index for industrial robots in China and other RCEP member countries**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Production-oriented Industrial**  **Robots** | | | **Service Production-oriented Industrial Robots** | | | **Other Multifunctional Industrial Robots** | | |
| 2014 | 2023 | Period  fluctuation | 2014 | 2023 | Period  fluctuation | 2014 | 2023 | Period  fluctuation |
| Australia | 1.04 | 0.66 | -0.38 | 5.98 | 1.39 | -4.59 | 0.90 | 0.89 | -0.02 |
| Philippines | 0.61 | 0.50 | -0.12 | 2.00 | 0.77 | -1.23 | 0.12 | 0.32 | 0.20 |
| South Korea | 1.31 | 0.75 | -0.56 | 0.46 | 0.86 | 0.40 | 2.88 | 2.05 | -0.84 |
| Cambodia | 0.73 | 1.68 | 0.95 | 2.83 | 1.38 | -1.45 | 0.00 | 0.15 | 0.15 |
| Laos | 0.72 | 5.02 | 4.30 | 5.52 | 1.73 | -3.78 | 0.00 | 0.13 | 0.13 |
| Malaysia | 0.93 | 1.08 | 0.15 | 1.11 | 1.19 | 0.08 | 1.86 | 1.03 | -0.83 |
| Myanmar | 1.01 | 0.33 | -0.68 | 0.89 | 0.49 | -0.40 | 1.06 | 0.02 | -1.04 |
| Japan | 0.71 | 0.74 | 0.04 | 1.03 | 1.52 | 0.49 | 0.80 | 0.73 | -0.07 |
| Thailand | 1.53 | 2.71 | 1.18 | 2.02 | 1.78 | -0.23 | 3.13 | 3.81 | 0.68 |
| Brunei | 0.36 | 0.31 | -0.05 | 0.13 | 0.49 | 0.36 | 0.00 | 0.75 | 0.75 |
| Singapore | 4.40 | 2.26 | -2.15 | 1.86 | 0.69 | -1.16 | 0.86 | 1.33 | 0.48 |
| New Zealand | 0.87 | 0.87 | 0.00 | 1.26 | 1.24 | -0.02 | 1.51 | 1.86 | 0.35 |
| Indonesia | 1.77 | 1.35 | -0.42 | 2.80 | 3.37 | 0.57 | 0.82 | 0.48 | -0.33 |
| Vietnam | 1.75 | 1.84 | 0.09 | 0.95 | 1.52 | 0.58 | 0.35 | 1.47 | 1.11 |
| Total | 1.27 | 1.44 | 0.17 | 2.06 | 1.32 | -0.74 | 1.02 | 1.07 | 0.05 |

*Source: Processed from UN Comtrade data, same below.*

5. Complementarity Measurement of Industrial Robot Trade between China and Other RCEP Member Countries

In this paper, the TCI index (Trade Complementarities Index) is used to measure trade complementarities**(Tang et al.,2023).** The formula is as follows:

（3）

In the formula, for the country a and country b in j product traders complementarity coefficient, represents country a in product j on the comparative advantage, represents country b in product j on the comparative disadvantage, and respectively, and a country j product exports and the world's exports of j products; and respectively, and respectively, for the total exports of all commodities of country a and the world's total exports of all commodities; and respectively, and represents country b in product j imports and the world's imports of j products, and respectively are country b's total imports of all goods and the world's total imports of all goods. When country a's comparative advantage in product j is more obvious, and country's comparative disadvantage in product j is more obvious, then country A and country B's trade complementarity in product j is stronger; conversely, the two countries' trade complementarity in product j is weaker. The larger the index, the stronger the trade complementarity between the two countries; conversely, the smaller the index, the weaker the trade complementarity between the two countries.

Table 9 shows the fluctuation of the TCI index of industrial robots between China and other RCEP member countries from 2014 to 2023. In terms of the direction of fluctuation (excluding countries with 0 data in 2023), countries with positive fluctuations in the TCI index are significantly more than those with negative fluctuations, indicating that China's trade complementarity with other RCEP member countries in industrial robots has shown an overall trend of enhancement. Further from the point of view of the fluctuation of various types of products, production-oriented industrial robots, the overall fluctuation is relatively small, Australia, the Philippines, Malaysia, Japan, and New Zealand five countries' TCI index rose, indicating that the trade complementarity is enhanced, of which the Philippines TCI index rose more significantly, the TCI index of 2023 rose by 0.0134 compared with 2014; Myanmar and Brunei two countries TCI indexes tend to be close to 0, with weaker trade complementarity. As for industrial robots for service production, the overall fluctuation is small, and trade complementarity is relatively stable. The TCI indexes of six countries, Australia, the Philippines, Malaysia, Myanmar, Japan, and New Zealand, have risen, indicating that trade complementarity has increased; the TCI index of Brunei has declined, but the rate of decline has not been very obvious, but it is also a certain degree of reflecting that China's trade complementarity with that country has weakened. In terms of other multifunctional industrial robots, the TCI indexes of the remaining countries except Myanmar and Cambodia are all positive, indicating that trade complementarity has increased; Myanmar and Cambodia were found to have no trade with China in terms of other multifunctional industrial robots at the data screening stage.

**Table 9. TCI index of industrial robots between China and other RCEP member countries**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Country** | **Production-oriented Industrial**  **Robots** | | | **Service Production-oriented Industrial Robots** | | | **Other Multifunctional Industrial Robots** | | |
| 2014 | 2023 | Period  fluctuation | 2014 | 2023 | Period  fluctuation | 2014 | 2023 | Period  fluctuation |
| Australia | 0.0026 | 0.0057 | 0.0031 | 0.0092 | 0.0203 | 0.0111 | 0.0002 | 0.0005 | 0.0003 |
| Philippines | 0.0005 | 0.0139 | 0.0134 | 0.0017 | 0.0031 | 0.0015 | 0.0001 | 0.0003 | 0.0002 |
| South Korea | 0.0064 | 0.0000 | -0.0064 | 0.0023 | 0.0000 | -0.0023 | 0.0009 | 0.0023 | 0.0013 |
| Cambodia | 0.0005 | 0.0000 | -0.0005 | 0.0025 | 0.0000 | -0.0025 | 0.0000 | 0.0000 | 0.0000 |
| Laos | 0.0040 | 0.0000 | -0.0040 | 0.0094 | 0.0000 | -0.0094 | 0.0002 | 0.0006 | 0.0003 |
| Malaysia | 0.0064 | 0.0171 | 0.0108 | 0.0012 | 0.0041 | 0.0029 | 0.0009 | 0.0023 | 0.0013 |
| Myanmar | 0.0008 | 0.0007 | 0.0000 | 0.0007 | 0.0016 | 0.0010 | 0.0000 | 0.0000 | 0.0000 |
| Japan | 0.0014 | 0.0060 | 0.0046 | 0.0006 | 0.0022 | 0.0016 | 0.0002 | 0.0004 | 0.0002 |
| Thailand | 0.0053 | 0.0000 | -0.0053 | 0.0019 | 0.0000 | -0.0019 | 0.0008 | 0.0019 | 0.0011 |
| Brunei | 0.0012 | 0.0013 | 0.0001 | 0.0026 | 0.0023 | -0.0003 | 0.0001 | 0.0002 | 0.0001 |
| Singapore | 0.0024 | 0.0000 | -0.0024 | 0.0010 | 0.0000 | -0.0010 | 0.0005 | 0.0012 | 0.0007 |
| New Zealand | 0.0035 | 0.0070 | 0.0035 | 0.0055 | 0.0133 | 0.0077 | 0.0003 | 0.0008 | 0.0005 |
| Indonesia | 0.0032 | 0.0000 | -0.0032 | 0.0015 | 0.0000 | -0.0015 | 0.0012 | 0.0029 | 0.0017 |
| Vietnam | 0.0047 | 0.0000 | -0.0047 | 0.0013 | 0.0000 | -0.0013 | 0.0007 | 0.0016 | 0.0010 |
| Total | 0.0031 | 0.0037 | 0.0006 | 0.0029 | 0.0034 | 0.0004 | 0.0004 | 0.0011 | 0.0006 |

*Source: Processed from UN Comtrade data, same below.*

6. MAIN CONCLUSIONS AND RECOMMENDATIONS FOR countermeasures

**6.1 Main conclusions**

The study found that the scale of trade between China and other RCEP member countries in the field of industrial robots has been growing year by year, with a high degree of market concentration. The top three countries account for as much as 90% of the total. China's trade relationship with other RCEP member countries in industrial robots is competitive and complementary.

Competitively, China has a competitive advantage in industrial robots for service production but has competitors in production-oriented and other multifunctional industrial robots. There are differences in the products of each country, Japan, South Korea, and Singapore have a certain competitive advantage in three types of industrial robots and other technology- and capital-intensive products; on the contrary, Myanmar, Cambodia, and Laos do not have a competitive advantage in these three types of products compared with other countries, according to the theory of the life cycle of the product that countries in the third world in the maturity of the product can be entered into the market for standardized production, and at the same time transfer the factory to their own country. The advantages and positioning of the products produced by different RCEP member countries provide an important reference and inspiration for further trade cooperation. There is a clear homogeneity between China and Vietnam, South Korea, Japan, Malaysia, and Thailand in terms of industrial robots, not to say that there is a competitive relationship between them.

In terms of complementarity, the trade complementarity between China and other RCEP member countries is increasing, and there is a certain potential for trade development. In terms of trade complementarities of various types of industrial robots, China has strong complementarities with Australia, the Philippines, and Malaysia in the field of production-oriented industrial robots; China has complementarities with Australia and New Zealand in the field of service-producing industrial robots; and in the field of other multifunctional industrial robots, China has certain complementarities with the rest of the countries, except for Myanmar and Cambodia.

**6.2 Recommendations for countermeasures**

Based on the competitive and complementary characteristics of industrial robot trade between China and RCEP member states, this study proposes the following targeted strategies.

**1. Optimizing Export Structure through Differentiated Competition**

First, strengthening competitive advantages. Priority should be given to expanding exports of service-oriented industrial robots (TC index +0.61), leveraging growing demand in Vietnam (17.07% of China’s exports) and Thailand (8% decade-long export share increase) to consolidate trade surpluses (average annual surplus: USD 18.61 million).

Second, addressing technological gaps: For production-oriented robots with an average annual deficit of USD 135.06 million, joint R&D initiatives with South Korea and Malaysia (Malaysia’s multi-functional robot TC index +0.66) should be established to reduce import dependency on Japan and South Korea (74.79% of import sources).

**2. Deepening Regional Capacity and Technological Collaboration**

First, technical cooperation. Establish standardized systems for service-oriented robots with Australia and New Zealand (positive TCI index fluctuations) and co-develop multi-functional robots with South Korea (28.41% of imports).

Second, capacity allocation. Set up medium-to-low-end robot production bases in Vietnam and Myanmar (both showing sustained export share growth) to facilitate industrial chain relocation and mitigate trade deficits.

**3. Leveraging RCEP Rules to Reduce Barriers**

First, certification mutual recognition. Accelerate certification reciprocity for service-oriented robots with Australia, New Zealand, and Malaysia (TCI > 0.5) to shorten market access timelines.

Second, rules of origin utilization: Utilize ASEAN assembly for exports to minimize tariff costs on high-deficit products from Japan/South Korea (deficit reduced to USD 191.11 million in 2023).

**4. Establishing Dynamic Risk Management Systems**

First, is data monitoring. Implement real-time trade surveillance for Japan-South Korea-Singapore markets (80.8% trade share) with early-warning mechanisms for supply chain risks.

Second, emerging market development. Design customized export strategies for underpenetrated markets like the Philippines and Indonesia (<1% share), aligned with TCI index patterns.

**5. Enhancing Precision Policy Support**

First, targeted subsidies. Provide tariff reductions for enterprises exporting service-oriented robots to Vietnam and Thailand (Vietnam: 17.07% export share).

Second, the technology advancement fund. Establish a dedicated Special Technology Fund for R&D in core components (e.g., reducers, controllers) to reverse technological disadvantages in production-oriented robots.

7. Research Limitations and Future Directions

**7.1 Research Limitations**

While this study systematically reveals the competitive and complementary dynamics of industrial robot trade between China and RCEP member states, several limitations warrant attention.

First, data incompleteness constrains analytical precision. Missing 2023 industrial robot trade data from seven RCEP economies (e.g., South Korea and Singapore) introduces potential deviations in TCI/TC index calculations. Reliance solely on UN Comtrade macro-level data further limits micro-level validation through firm-specific customs records. Second, methodological dimensions require expansion. Static indices (TC/RCA/TCI) fail to capture dynamic industrial chain interactions, while non-tariff barriers (e.g., technical standards, intellectual property rights) affecting complementarity remain unaddressed. More critically, insufficient linkages exist between national industrial policies (e.g., Japan’s New Robot Strategy, China’s Made in China 2025) and trade patterns, alongside unexamined geopolitical impacts (e.g., Sino-U.S. technological decoupling) on regional supply chain restructuring. Additionally, product classification granularity proves inadequate. Broad HS code-based categorization (3 classes) obscures differentiated trade mechanisms in emerging subtypes like collaborative robots.

**7.2 Future Directions**

To address these gaps, future research should prioritize five avenues.

First, establish a multi-source data integration framework. Combine UN Comtrade, firm-level customs data, and International Federation of Robotics (IFR) production statistics to reconstruct missing datasets and verify index robustness. Second, deepen policy-technology nexus analysis. Econometrically examine how R&D subsidies and local content requirements drive trade competitiveness while quantifying cross-border technology spillovers through patent citation networks. Third, refine product-subtype investigations. Deconstruct robot subtypes per IFR technical taxonomies (e.g., articulated/Cartesian/SCARA robots), comparing trade trajectory divergence between emerging paradigms (e.g., AI-collaborative robots) and traditional models. Fourth, develop geopolitical risk assessment frameworks. Construct composite indices integrating trade dependency, technological sovereignty, and diplomatic alignment indicators, conducting scenario analyses of "CHIPS Act-style" export controls on regional robot supply chains.

Ethical approval

This study adheres to the highest standards of academic integrity and ethical research practices.Specific instructions are as follows.

**1.Data Provenance and Integrity**

First,all trade data were sourced from the United Nations Comtrade database (publicly available at https://comtrade.un.org/), with explicit citation of dataset retrieval dates and query parameters in methodology sections.

Second,no primary data involving human/animal subjects were collected, eliminating privacy/consent concerns.

**2.Conflicts of Interest**

First,the authors declare no financial or institutional conflicts of interest related to RCEP member governments, robotics corporations, or trade policy bodies.

Second,no funding sources influenced research design, analysis, or conclusions.

**3.Intellectual Property Compliance**

First,all statistical methods (TC/RCA/TCI indices) are standard academic tools with proper attribution to original sources (e.g., Balassa 1965 for RCA).

Second,HS code classifications strictly follow the World Customs Organization’s publicly accessible nomenclature.

**4.Reproducibility & Transparency**

Sensitivity analyses for missing data (7 RCEP members’ 2023 records) are documented in Section 2.

**5.Policy Neutrality**

First,conclusions reflect empirical evidence without advocacy for specific trade policies or national interests.

Second,export control regulations were reviewed; all analyzed HS codes fall under non-restricted commercial categories.

Approval by an institutional ethics committee was not required as this research exclusively analyzes aggregated, anonymized international trade statistics.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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