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Trade competitiveness analysis of the Chinese medical device industry

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Abstract: Competitive advantage in international trade is indicated by a country's ability to gain benefits from foreign trade. These benefits can be achieved by expanding export volumes or improving trade structure and core competitiveness based on excellent quality and high-technology content. This paper analyses the trade competitiveness of the Chinese medical device industry by using the trade competitiveness (TC) index, revealed comparative advantage (RCA) index, competitive advantage (CA) index, and Grubel and Lloyd (GL) index. The different trade indices provide a measure of the competitive status of the Chinese medical device industry and its evolving trends. The results from this study imply that the competitiveness of Chinese medical devices has gradually weakened from 2007 to 2019. In detail: medical dressings, health protection and recovery products have a competitive advantage in the global market; whilst medical disposable products, dental equipment and materials have no obvious competitive advantage; medical diagnosis and treatment devices do not have a competitive advantage. Positive measures are being taken by the Chinese government to ameliorate the current deterioration in the competitiveness of Chinese medical devices.

Keywords: biomedical industry; China; international competitiveness; medical device market; performance indices; trade competitiveness.

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1 Introduction

Trade competitiveness or international competitiveness is the ability of a country or region to participate in the international market by exporting its products globally, success in this reflects the current effectiveness and potential of economic development at a particular point in time. Trade competitiveness plays an important role in measuring and evaluating a country's international competitiveness. The Chinese medical device market is a huge, constantly evolving market with many opportunities for expansion. Although, in 2019, the Chinese medical device market was the second largest market in the world, foreign companies have dominated with an 80% share of the high-end medical device market in China (Boyer et al., 2015). Nevertheless, the scope of China's international trade in medical devices is gradually expanding. Segmentation of the Chinese medical device market gives us a better understanding of which segments have competitive advantages, and which segments have competitiveness disadvantages. The aim of this study is to analyse the current status of the international trade in Chinese medical devices and clarify its trade competitiveness in the global marketplace. Past studies have been conducted on the international competitiveness in many industries, but

there is little literature pertaining to the international competitiveness of the medical device industry, or the Chinese medical device industry. This study offers insights into the international competitiveness of trade and bridges the gap in the medical device industry research.

2 Theoretical background and hypotheses

The classical theory of International trade was first developed by Adam Smith and known as the theory of absolute advantage. This theory argued that countries differ in their ability to produce products efficiently (Hill, 2015) and the country has an absolute advantage when it has good labour productivity, which means it uses less labour or resources to produce the number of units of output than other countries (Pugel, 2016). Adam Smith's theory of absolute advantage proposed the determination of competitiveness from the supply side of the market (Carbaugh, 2015) and revealed that the products with absolute cost advantage are competitive in international trade, which means foreign trade competition is driven by absolute advantage (Chen and Ouyang, 2012). Smith advocated that free trade (open markets) will enhance the global production efficiency, which promotes the international division of labour. The theory of absolute advantage states that a country will export goods with an absolute cost advantage and import goods with an absolute cost disadvantage. David Ricardo supports Smith's theory on free trade, but also states that it is beneficial for two countries to trade even if one has an absolute advantage in the production of all products; what matters is not the absolute cost of production but the relative efficiency with which it can produce the products (Cavusgil et al., 2017), which means that mutually beneficial trade can happen whether countries have an absolute advantage or not (Carbaugh, 2015). Like the absolute advantage theory, the theory of comparative advantage emphasised the supply side of the market. Heckscher and Ohlin built the factor endowments (or proportions) theory, and predicts that each country exports the commodity that is intensive in its relatively abundant factor of production, while importing commodities that are intensive in their relatively scarcity factor of production (Appleyard et al., 2010; Kreinin, 2010). Like Ricardo's theory of comparative advantage, the Heckscher-Ohlin (H-O) theorem argues that there is a benefit for free trade. Unlike Ricardo's theory of comparative advantage, the H-O theorem argues that the international trade pattern is determined by differences in factor endowments, rather than differences in productivity (Hill, 2015).

Based on the H-O theory, as a developing country, the trade pattern of China's medical devices should be: export its labour-intensive (low-end) products while import capital- and technology-intensive (high-end) products. However, the trade statistics only illustrate a rough summary of the trade pattern between China and other countries, which does not prove the validity of the H-O theory (Carbaugh, 2015). Thus, the study evaluates the validity of the international trade theories in the Chinese medical device industry. Therefore, the arguments lead to the following hypotheses:

H1: The international competitiveness indices may generate a positive impact on medical dressings; health protection and recovery products (low-end medical products), which means the Chinese low-end medical products have competitive advantages in the global market.

H2: The international competitiveness indices may generate a negative impact on medical diagnosis and treatment device (high-end medical products), which means the Chinese high-end medical products have competitive disadvantages in the global market.

The product life cycle theory stresses the standardisation process for products (Kreinin, 2010), comparative advantage may shift over time from one country to another (Husted and Melvin, 2013). The international trade theories presented so far are similar in that they pre-suppose a given and unchanging difference in technology. In Vernon's point of view, technological innovations play an important role in foreign trade, which can affect comparative advantage and the pattern of trade. The initial comparative advantage of innovative products and the loss of comparative advantage formed by technology transfer and diffusion, determine the pattern of change in international trade, thus promoting the evolution of a country's industrial structure (Carbaugh, 2015). The consequence of the product life cycle trends for the pattern of trade is that over time US switches from being an exporter to an importer as production becomes located in lower-cost countries (Hill, 2015).

All the trade theories we have discussed above found that the source of comparative advantage is emphasised on the supply side. Stefan Linder proposed the similarity of preferences theory, which can be described as international trade in differentiated manufactured products, which will be more intense between countries with similar *per capita income* levels (Linder, 1961). Linder's hypothesis presents a demand oriented theory of trade, which is in contrast to the supply oriented theories of trade. Linder's hypothesis contends that the developed (rich) countries will tend to trade with other developed (rich) countries, and developing (poor) countries are more likely to trade with other developing (poor) countries, because countries with similar *per capita income* will have overlapping demand structures and demand the similar types of manufactured products. Linder's hypothesis applies only to differentiated manufactured products, it cannot explain the trade in raw materials or agricultural products (which can be explained by the H-O theorem), and it cannot explain why developing countries tend to have more trade with the developed countries today. However, it provides an explanation for the phenomenon in international trade: intra-industry trade (IIT),[1] which is the two-way trade (the simultaneous export and import) in a similar product made within the same industry. IIT can be explained by economies of scale and product differentiation (Carbaugh, 2015; Appleyard et al., 2010; Gerber, 2011; Salvatore, 2012). IIT occurs in order to take advantage of important economies of scale in production (Salvatore, 2012), because average costs reduce as production expands (Gerber, 2011).

For two centuries, the economics literature has focused on the notion of comparative advantage (factor endowments; technology) while the business literature has recently developed the concept of competitive advantage. Moreover, Michael Porter's competitive advantage provided some useful information to policy makers. But the concept of comparative and competitive advantage have much in common (Beaudreau, 2016). Compared with the traditional trade theories (a static theoretical system), competitive advantage theory has a dynamic perspective when analysing a country's advantages and disadvantages. Porter (1980) believes that a country's competitive advantage is determined by its industrial innovation and upgrading ability. The positional advantage a company has in the market leads to superior performance by creating value and offering dynamic capabilities (Porter, 1980; Ofori and Appiah-Nimo, 2021).

3 Methodology

3.1 Theoretical model

The trade competitiveness (TC) index is also called the trade specialisation coefficient, which indicates whether a country's product has a competitive advantage over the same product supplied in the world market (China National Center for Biotechnology Development, 2010). The TC index is commonly used to measure the international competitiveness.

The TC index is a method to demonstrate the product life cycle, the change of the TC index reflects the process of a product from the import stage, domestic production (import substitution) stage, export expansion stage, mature stage and against imports[2] stage.

The formula for the TC index is described in (Wang, 2010; Chen and Ouyang, 2012):

$$TC = \frac{X_{ij} - M_{ij}}{X_{ij} + M_{ij}} \tag{1}$$

where: X_{ij} is the export volumes of product *i* in country *j*;

M_{ij} is the import volumes of product *i* in country *j*.

The range of the TC index is between [–1, 1]. The upward movement from –1 to 1 reflects the changing process from net import to net export and vice versa. Generally speaking, if the TC index is close to 1, it means that the total amount of exports far exceeds the total amount of imports, the product has a competitive advantage in the international market. On the contrary, if the TC index is close to –1, it means that import volumes are much higher than the export volumes and the competitiveness of the product is weak in the international market (Wang, 2010; China National Certer for Biotechnology Development, 2010; Jiang and Lin, 2019).

The revealed comparative advantage (RCA) index is an indicator of comparative advantage of a country, which is reflected in its export volumes. The RCA index was broadly adopted by the international organisations, including the World Bank (Zhang and Li, 2004). The formula for the RCA index is: (Balassa, 1965)

$$RCA = \frac{X_{ij} \big/ X_j}{X_{wi} \big/ X_w} \tag{2}$$

where: X_{ij} is the export volumes of product *i* in country *j*;

X_j is the total export volumes of country *j*;

X_{wi} is the world export volumes of product *i*;

X_w is the total export volumes of the world.

If $RCA > 1$, it is assumed that country *j*'s product *i* has comparative advantage in the global market. If $RCA \leq 1$, it indicates that country *j*'s product *i* does not have comparative advantage in the global market (Wang, 2010).

Competitive advantage (CA) index is an extension of the RCA index, which involves both export volumes and import volumes. The revised formula for the CA index is from (Vollrath and Vo, 1988)

$$CA = RCA - \frac{M_{ij} \diagup M_j}{M_{wi} \diagup M_w} = \frac{X_{ij} \diagup X_j}{X_{wi} \diagup X_w} - \frac{M_{ij} \diagup M_j}{M_{wi} \diagup M_w} \tag{3}$$

where: M_{ij} is the import volumes of product i in country j

M_j is the total import volumes of country j

M_{wi} is the world import volumes of product i

M_w is the total import volumes of the world.

If $CA > 0$, it indicates that country j's product i has comparative advantage in the global market. If $CA < 0$, it shows that country j's product i does not have comparative advantage in the global market. The higher the CA index, the stronger the international competitiveness.

IIT refers to the two-way trade in which one country both exports and imports the same or similar products/commodities within the same industry (Grubel and Lloyd, 1975; Pugel, 2016). The formula for the IIT is defined as:

$$\text{IIT} = \left(X_{ij} + M_{ij}\right) - \left|X_{ij} - M_{ij}\right| \tag{4}$$

where X_{ij} is the value of exports of product i in country j

M_{ij} is the is the value of imports of product i in country j.

To measure the IIT as a share of total trade in the product, Grubel and Lloyd designed the following formula (Grubel and Lloyd, 1975), called the GL index or IIT index (Sawyer and Sprinkle, 2006).

$$\text{GL} = \frac{\left(X_i + M_i\right) - \left|X_i - M_i\right|}{X_i + M_i} = 1 - \frac{\left|X_i - M_i\right|}{X_i + M_i} \tag{5}$$

The range of the GL index is between [0, 1] or [0, 100] to express the index as a percentage. If the GL index is equal to 0, this means that a country has only exports or imports in a certain industry ($X_i = 0$ or $M_i = 0$); if the GL index is equal to 1, it means that a country's exports or imports in a certain industry are equal. The closer the GL index is to 0, the lower the level of IIT; the closer the GL index is to 1, the higher the level of IIT (Zhang, 2017; Ren, 2017; Sawyer and Sprinkle, 2006).

3.2 Theoretical applications

We summarise some applications of the theoretical models in Table 1.

Table 1 Trade theoretical applications in analysing international competitiveness

Authors and year	*Field*	*Methods used*
Moshiirian et al. (2005)	Banking services	IIT/GL
Laursen (2015)	22 sectors	RCA and revealed symmetric comparative advantage (RSCA)
Yusefzadeh et al. (2015)	Pharmaceutical industry	TC; export propensity index; import penetration ratio; RCA; CA and GL
Anderson et al. (2016)	Wine market	IIT/GL
Jiang and Lin (2019)	Services industry	International market share (IMS); RCA and TC
Guan et al. (2019)	Textile and clothing industry	IMS; TC and RCA
Pitoňáková (2020)	59 classes	RCA and RSCA

Source: Authors' listed

3.3 Data

Data on the value of exports and imports of medical devices in China from 2007 to 2019 were collected from the General Administration of Customs, China (General Administration of Customs. People's Republic of China, 2020); Department of Foreign Trade, Ministry of Commerce of the People's Republic of China (Department of Foreign Trade. Ministry of Commerce of the People's Republic of China, 2008-2019) and China Chamber of Commerce for Import & Export of Medicines & Health Products (CCCMHPIE) (China Chamber of Commerce for Import & Export of Medicines & Health Products, 2008-2020), which is shown in Appendix Table A1. Data on the China total merchandise exports and imports value; worldwide total merchandise exports and imports value were collected from the World Trade Organization (WTO) database (World Trade Organization, 2008–2019), which are described in Appendix Tables A2 and A3. Data on the value of exports and imports of medical devices worldwide were extracted from the United Nations, UN Comtrade Database under different HS Code (United Nations, 2007–2019), which is shown in Appendix Table A4, respectively.

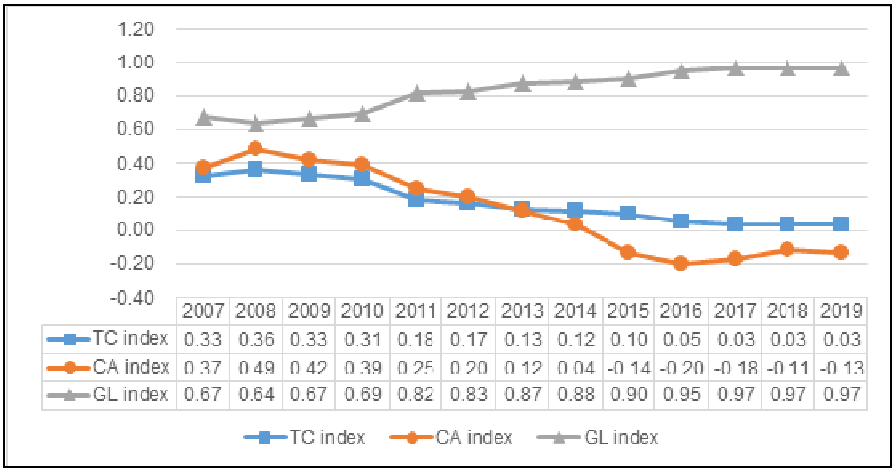
4 Results

Based on equation (1) and data in the Appendix Table A1, we can evaluate the TC index; based on equation (3) and data in the Appendix Tables A1–A4, we can evaluate the CA index; based on equation (5) and data in the Appendix Table A1, we can evaluate the GL index. All the results for the TC, CA and GL indices are shown in Figure 1.

The range of the TC index is between [–1, 1]. This range was subdivided to analyse the trade: if the value of the TC index is between [–1, –0.6], it means that the product has great competitive disadvantage; if the value of the TC index is between [–0.6, –0.3], it means that product has a competitive disadvantage; if the value of the TC index is between [–0.3, 0], it means that the product has a weak competitive disadvantage. If the value of the TC index is between [0, 0.3], it means that product has a weak competitive

advantage; if the value of the TC index is between [0.3, 0.6], it means that the product has a competitive advantage; if the value of the TC index is between [0.6, 1], it means that product has great competitive advantage (Chen and Ouyang, 2012).

Figure 1 TC index, CA index and GL index of China's trade in medical devices from 2007 to 2019 (see online version for colours)



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
TC index	0.33	0.36	0.33	0.31	0.18	0.17	0.13	0.12	0.10	0.05	0.03	0.03	0.03
CA index	0.37	0.49	0.42	0.39	0.25	0.20	0.12	0.04	-0.14	-0.20	-0.18	-0.11	-0.13
GL index	0.67	0.64	0.67	0.69	0.82	0.83	0.87	0.88	0.90	0.95	0.97	0.97	0.97

Source: Author's Calculations, based on data from the General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE; WTO and UN Comtrade Database

According to Figure 1, the decreasing trend of the TC index from 2007 to 2019 reveals that the Chinese medical devices' competitiveness is weakening year by year in the global market. The declining trend goes from 0.33 (competitive advantage) to 0.03 (weak competitive advantage) showing that Chinese medical devices have no obvious competitive advantage in the global market, and that the competitive advantage has gradually weakened.

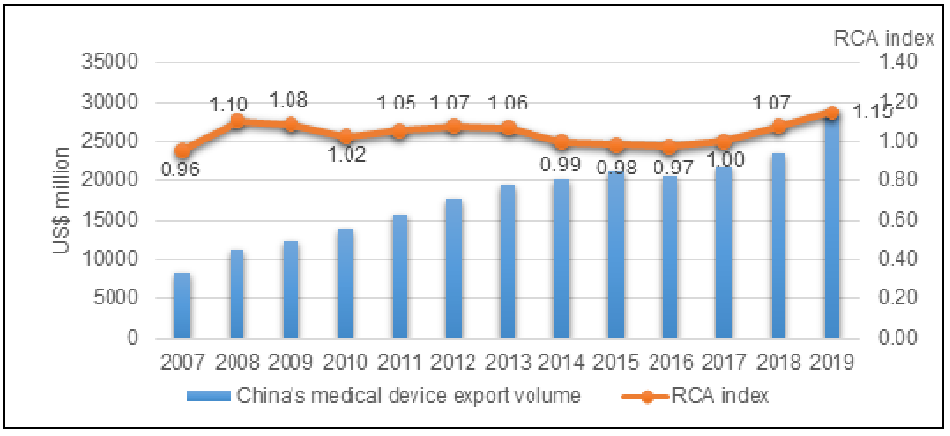
According to the following conventions: if $CA > 0$, it means that the product has competitive advantage; if $CA < 0$, the product does not have competitive advantage in the global market, the results of the CA index (Figure 1) reveals that the Chinese medical devices do not have a competitive advantage from 2015 to 2019, despite having a competitive advantage from 2007 to 2014.

The GL index has an increasing trend from 2008 to 2019, which was closer to 1, year by year. These results illustrate that the Chinese medical device market has a very high degree of IIT. This objectively proves that an equal amount of medical devices are exported and imported, as medical devices are the examples of highly differentiated products. The GL index for simple or non-differentiated products (these products may have a strong competitive advantages or disadvantages) presents a lower ratio, while for the complicated or highly differentiated products (regardless of the degree of competitive advantages) it displays a higher ratio (Caves et al., 2007).

Based on equation (2), the RCA index is described in Figure 2. Generally speaking, if $RCA > 1$, the product has a competitive advantage; if $RCA \leq 1$, the product does not have competitive advantage in the global market. More specifically, when $RCA < 0.8$,

the competitiveness of the product is low; when $0.8 < RCA < 1.25$, the product has medium competitive advantage; when $1.25 < RCA < 2.5$, the product has a relatively strong competitive advantage; when $RCA > 2.5$, the product has an extremely strong competitive advantage (Jiang and Lin, 2019). Figure 2 shows the value of the RCA index is between 0.96 and 1.15 from 2007 to 2019, which indicates that the Chinese medical devices have medium competitive advantage in the global market.

Figure 2 China's medical device export volumes and the RCA index from 2007 to 2019 (see online version for colours)



Source: Author's calculations, based on data from WTO and UN Comtrade Database

5 Discussion

The results of the TC index reveal that the Chinese medical device market has a weak competitive advantage in the global market (Figure 1). Moreover, the results of RCA show that the Chinese medical devices have medium comparative advantages in the global market (Figure 2). The RCA index examines the comparative advantages of commodities from the perspective of a country's exports. Because the RCA index only chooses export data and its value is asymmetrical, there are some limitations in its utility, which does not objectively reflect the Chinese medical devices actual comparative advantages (Laursen, 2015). The results of the GL index illustrate that the Chinese medical device market has a high degree of IIT. When IIT prevails in one industry, the comparative advantage of an industry measured by the RCA index is not objective, and cannot be used to predict trade development. In addition, the RCA index ignores the role of imports. The limitations of the RCA index suggest some conditions for its subsequent revision and improvement. The CA index is one of the improvement methods. The CA index results show that the Chinese medical device market has competitive advantage from 2007 to 2014, from 2015 to 2019 it does not have a competitive advantage in the global market. In general, the competitiveness of the Chinese medical devices has gradually weakened from 2007 to 2019. According to Figure 2, the export volumes of China's medical devices have an increasing trend from 2007 to 2019, except for a small

drop in 2016. Let's find out why the Chinese medical devices have an upward trend of exports but with a weakening competitiveness in the global market.

The medical devices were categorised under five headings by CCCMHPIE, which include:

1 medical dressings

2 medical disposable products

3 medical diagnosis and treatment devices

4 health protection and recovery products

5 dental equipment and materials.

Defining these categories in more detail:

1 The purpose of medical dressings is to promote healing and protect the wound from further harm. Medical dressings including natural materials (lint; gauze; bandage and cotton wool, etc.); synthetic materials (semi-permeable film dressing, which is a transparent film made up of polyurethane; hydrocolloid dressing; hydrogel dressing; semi-permeable foam dressing; alginate dressing, etc.) and medicated dressings (medicated ointment dressings; traditional Chinese medicine oil dressings; surgical disinfection dressings, etc.); etc. (Dhivya et al., 2015).

2 Medical disposable products including disposable medical catheter; disposable medical gauze and bandage; disposable medical disinfection supplies; syringe; medical suture materials and equipment, etc.

3 Medical diagnosis and treatment device including computed tomography (CT), magnetic resonance imaging (MRI), ultrasound and other medical imaging devices.

4 Health protection and recovery products including wheelchair; hearing aid; electrotherapy devices and magnetic therapeutic devices, etc.

5 Dental equipment and materials including all the devices and materials related to dental treatment.

Due to the different statistical calibre between the CCCMHPIE and UN Comtrade database, we choose:

1 HS Code 3005[3] for the medical dressings

2 HS Code 4015_11;[4] HS Code 9018_31[5] and HS Code 9018_32[6] for the medical disposable products

3 HS Code 9018[7] and HS Code 9022[8] for the medical diagnosis and treatment device

4 HS Code 9019[9] for the health protection and recovery products

5 HS Code 3306;[10] HS Code 9018_41[11] and HS Code 9018_49[12] for dental equipment and materials.

Based on the volumes of exports and imports of these categories (see Appendix Tables A4 and A5), the TC index, CA index and GL index are shown in Tables 2–4. The changing trends for these products are shown in Figures 3–5, respectively.

Table 2 TC index of medical products in China

Year / TC index	Medical dressings	Medical disposable products	Medical diagnosis and treatment device	Health protection and recovery products	Dental equipment and materials
2007	0.89	0.53	–0.13	0.92	0.33
2008	0.90	0.51	–0.08	0.93	0.34
2009	0.92	0.45	–0.14	0.93	0.33
2010	0.92	0.37	–0.13	0.88	0.31
2011	0.85	0.41	–0.10	0.52	0.26
2012	0.82	0.29	–0.11	0.78	0.22
2013	0.79	0.22	–0.11	0.55	0.16
2014	0.77	0.18	–0.12	0.55	0.17
2015	0.74	0.15	–0.13	0.53	0.15
2016	0.75	0.11	–0.19	0.55	0.07
2017	0.74	0.10	–0.22	0.53	0.03
2018	0.71	0.05	–0.20	0.47	0.05
2019	0.67	0.13	–0.20	0.48	0.13

Source: Author's calculations, based on data from General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE

Table 3 CA index of medical products in China

Year / CA index	Medical dressings	Medical disposable products	Medical diagnosis and treatment device	Health protection and recovery products	Dental equipment and materials
2007	5.13	2.04	–0.22	2.86	0.09
2008	5.69	2.26	–0.17	3.50	0.08
2009	7.69	2.14	–0.26	3.19	0.12
2010	7.45	1.74	–0.23	2.97	0.14
2011	3.41	2.19	–0.20	2.87	0.17
2012	3.06	1.76	–0.25	3.66	0.13
2013	2.69	1.25	–0.26	2.93	0.09
2014	2.65	0.65	–0.31	2.66	0.07
2015	2.29	0.19	–0.45	2.15	–0.01
2016	2.12	0.07	–0.52	2.38	–0.07
2017	2.14	0.29	–0.52	2.37	–0.87
2018	2.12	0.30	–0.45	2.20	–0.04
2019	1.98	0.85	–0.49	2.21	0.04

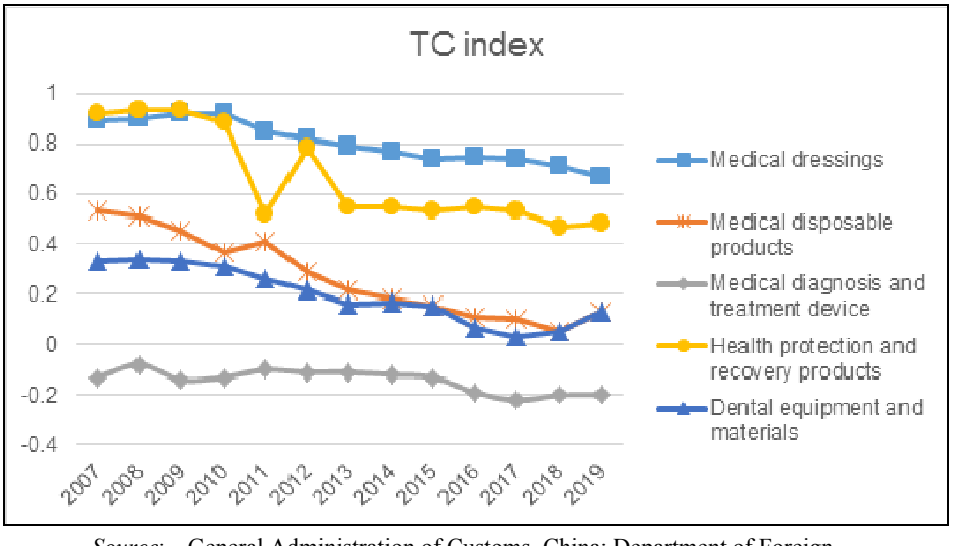
Source: Author's calculations, based on data from General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE and UN Comtrade Database

Table 4 The GL index of medical products in China

Year / *GL index*	*Medical dressings*	*Medical disposable products*	*Medical diagnosis and treatment device*	*Health protection and recovery products*	*Dental equipment and materials*
2007	0.11	0.47	0.87	0.08	0.67
2008	0.10	0.49	0.92	0.07	0.66
2009	0.08	0.55	0.86	0.07	0.67
2010	0.08	0.63	0.87	0.12	0.69
2011	0.15	0.59	0.90	0.48	0.74
2012	0.18	0.71	0.89	0.22	0.78
2013	0.21	0.78	0.89	0.45	0.84
2014	0.23	0.82	0.88	0.45	0.83
2015	0.26	0.85	0.87	0.47	0.85
2016	0.25	0.89	0.81	0.45	0.93
2017	0.26	0.90	0.78	0.47	0.97
2018	0.29	0.95	0.80	0.53	0.95
2019	0.33	0.87	0.80	0.52	0.87

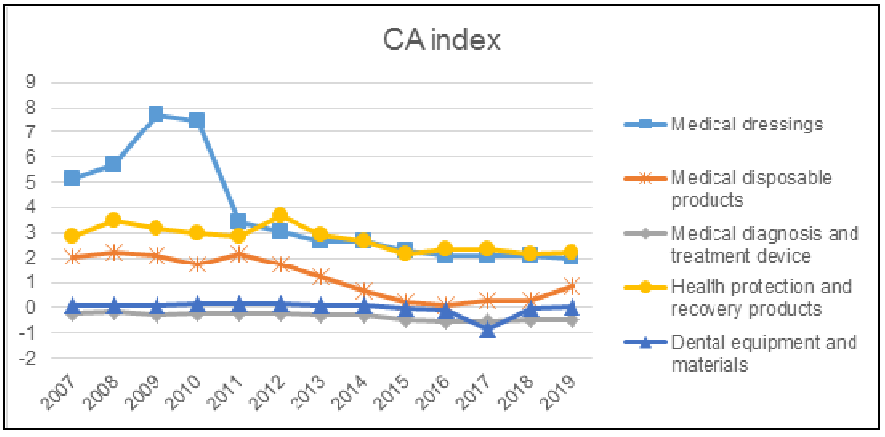
Source: Author's calculations, based on data from General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE

Figure 3 TC index comparison among different medical products in China (see online version for colours)



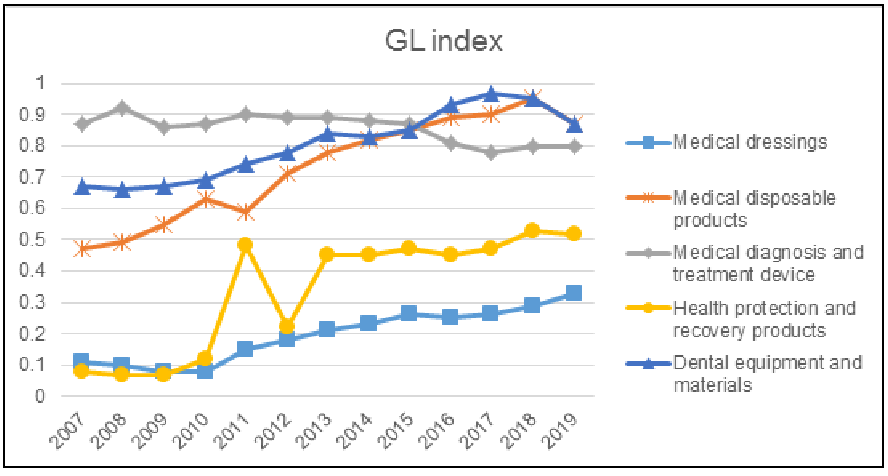
Source: General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE

Figure 4 CA index comparison among different medical products in China (see online version for colours)



Source: General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE

Figure 5 GL index comparison among different medical devices (see online version for colours)



Source: General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE

According to Table 2, medical dressings have a great competitive advantage in the global market. Despite the TC index of health protection and recovery products drop from 0.92 to 0.47, the products still have a competitive advantage. The TC index of medical disposable products and dental equipment and materials declined to almost no obvious competitive advantages. The TC index of medical diagnosis and treatment devices shows that these devices have no competitive advantages in the global market, and the competitiveness trend has been weakening. Figure 3 describes the declining trends of all categories in China from 2007 to 2019. Medical dressings, health protection and recovery products still have competitive advantages (TC indices are above 0.4); the trend of TC

indices of medical disposable products, dental equipment and materials tend towards zero, which means that these devices do not have obvious competitive advantages. Only medical diagnosis and treatment devices do not have competitive advantages through 2007 to 2019.

The results of the CA index show that although medical dressings have decreasing trends, health protection and recovery products have fluctuating trends, nevertheless they still have competitive advantages. The CA indices of medical disposable products, dental equipment and materials tend towards zero, do not have an obvious competitive advantages. The decreasing trend of the CA index of medical diagnosis and treatment devices reveals that these devices do not have a competitive advantage in the global market. Figure 4 clearly describes the trends for medical devices in China from 2007 to 2019.

The results of the TC index and CA index revealed similar features: medical dressings, health protection and recovery products have competitive advantages; medical disposable products, dental equipment and materials have no obvious competitive advantages; medical diagnosis and treatment devices do not have competitive advantage in the global market. Therefore, this result confirms the hypothesis H1 and hypothesis H2, which are that the low-end medical products (medical dressings; health protection and recovery products) have competitive advantages, while the high-end medical products (medical diagnosis and treatment devices) has competitive disadvantages in the global market.

The comparative advantage basically conforms to the H-O theory, which is the factor-endowment theory: a country will export the product that uses the relatively abundant resource, while it will import the product that uses the relatively scarce resource (Carbaugh, 2015; Pugel, 2016). The H-O theory predicts that the developed countries will export to China medical devices for which there is a relatively large amount of technology and skilled labour, while China will export labour intensive medical products to other countries (Zhang, 2018), like low-end medical products such as: medical dressings has great competitive advantages (average TC index = 0.81, Table 2). The Chinese high-end medical device market is dependent upon imports and dominated by foreign companies' products (Zhang et al., 2016). The TC index and CA index of medical diagnosis and treatment devices has never been above zero, the competitiveness of these devices is weak in the international market. The trade pattern of the Chinese medical device market appears to match with the predictions of the H-O theorem. That is, the exports are mainly low-end medical devices, while imports are mainly high-end medical devices, which indicates that the low-end products with high resource or labour consumption are competitive, while the high-end products with high technical content have no competitiveness in the global market, which confirms the hypothesis H1 and hypothesis H2.

The trends of the TC index and CA index illustrate that the competitiveness of the Chinese medical devices has gradually weakened. This is because the product structure of exported medical devices is being adjusted and continuously optimised. China's export of medical products relies mainly on medical dressings and disposable consumables, as before, but the proportion of exported medical devices such as medium- to high-tech medical equipment and high value-added products is increasing now. The diagnostic devices have the highest growth rate in exports from 2011 (Torsekar, 2018). Moreover, US FDA and the EU directives have raised market access standards for the Chinese medical dressings, making it more difficult to enter the market, this is one of the reasons

that the competitiveness of medical dressings declined. Furthermore, China has experienced rapid growth in its economy and been remarkably successful, the workers have become harder to find and keep, resulting in increasing pressure for higher wages. Higher wages will make it more difficult for China's low-end exports of medical products as it continues to rely on its low production costs and price advantages. In addition, a lower currency can boost China's exports by making them relatively cheap compared with competitors. However, appreciation of RMB (yuan) has brought challenges that will affect export trade, a main driver of China's economic growth (Carbaugh, 2015).

The TC index and CA index illustrates that medical dressings, health protection and recovery products have competitive advantage while medical disposable products, dental equipment and materials, medical diagnosis and treatment device have competitive disadvantage in the global market. On the contrary, the GL index of these medical devices with competitive disadvantage has a high level of IIT, especially for medical diagnosis and treatment devices (Table 4). The traditional international trade theories such as H-O theory find it difficult to explain the results of low TC index with high GL index, because the H-O theory provides a basis for inter-industry trade but not IIT. IIT implies that a country simultaneously has a comparative advantage and a comparative disadvantage with the same product (Sawyer and Sprinkle, 2006).

According to Figure 5, medical diagnosis and treatment devices have a high GL index, for: medical disposable products, dental equipment and materials with an increasing trend of the GL index. On the one hand, the results of the GL index reveal a similar situation with the results of the TC index and CA index. That is, medical diagnosis and treatment devices, medical disposable products, dental equipment and materials do not have competitive advantage in the global market, these devices need more international trade activities (exports and imports). On the other hand, the relatively low GL index reveals that medical dressings, health protection and recovery products have competitive advantage in the global market, the export volumes of these devices are much higher than the import volumes (Appendix Table A5). This result also confirms hypothesis H1 and hypothesis H2.

Ricardo's theory of comparative advantage provides the theoretical basis for developing countries to participate in the international division of labour and international trade. The developing countries tend to fall behind when compared with the developed countries, but from the perspective of the developing countries themselves, analysis tells them which industries are relatively less backward, which are the industries with comparative advantages. The developing countries can benefit from international exchange of these industries. The Chinese medical device industry is one of the most promising and fastest growing industries (Zhang et al., 2015), being ranked 1st in the market potential index in the world from 2014 to 2017 (International Business Center at Michigan State University, 2017). Although there has been a slowdown in exports of China's medical devices from 2014 to 2018 (Appendix Table A1), imports have grown due to strong domestic demand. The continuously growing aging population is adding to the demand for medical devices.

The H-O theory is useful in explaining a wide range of observed phenomena, such as the trade competitiveness of the Chinese medical device industry. Although the Chinese high-end medical devices rely on imports from the developed countries, developing countries such as China can improve the technological content of products and their position in international trade through independent innovation (Hang, 2017). The

promulgation of national science and technology policy, improvement of medical device regulations, increased research and development (R&D) input and standardisation of innovative technology, has created a Chinese medical device industry that has an excellent innovation environment. The Chinese government encourages and cultivates the domestic medical device companies transition from 'frugal manufacturer' to 'innovation developer', which are vying for a share of the fastest growing medical device market. Meanwhile, the Chinese government has made the healthcare system a national priority and plans to solve the challenge of affordability and accessibility to basic healthcare services by 2020, the last year of the 13th Five-Year Plan.[13]

Overall, the Chinese medical device industry is still in its growth stage, with a relatively large space for development. The Chinese government has issued multiple initiatives such as 'Healthy China 2030' and 'Made in China 2025' to support innovation in many areas, including the expansion of high-end medical device production, and thereby fundamentally changed the competitive landscape (KPMG International, 2018; National Manufacturing Strategy Advisory Committee (NMSAC) and Chinese Academy of Engineering, 2018).

The limitation of this study is that there are many ways to measure the Chinese medical devices trade competitiveness, we only choose: TC index, RCA index, CA index and GL index. Every method has its own pros and cons. For example, the RCA index only reflects the relative proportion of exports, it does not consider the impact of imports on competitiveness. Moreover, the RCA index is a relative measure indicating a strong focus on some industries but less on others, which have high values of RCA index for some industries and low values for other industries (Laursen, 2015). For the medical device industry in China, the RCA index shows a positive result compared to the other methods (Appendix Table A6). Furthermore, we extracted the different HS Codes from the UN Comtrade database for the exports/imports of medical devices worldwide, which has differences in statistical calibre when compared with the Chinese data.

6 Conclusion, recommendations and further research

On the basis of trade competitiveness measures, this paper examines: medical dressings, medical disposable products, medical diagnosis and treatment devices, health protection and recovery products, dental equipment and materials to assess the international competitiveness of the Chinese medical device industry based on data from 2007 to 2019. The results of this study show that in general the competitiveness of the Chinese medical devices has gradually weakened from 2007 to 2019. More specifically, medical dressings, health protection and recovery products have a competitive advantage in the global market; while medical diagnosis and treatment devices, medical disposable products, dental equipment and materials do not have a competitive advantage. The TC index and CA index illustrate that the trade pattern of the Chinese medical device market appears to match with the predictions of the H-O theory, which is that exports are mainly low-end medical products (resource- or labour-intensive), while imports are mainly high-end medical devices (technology- or capital-intensive).

China can no longer rely on cheap labour as a basis for manufacturing; higher wages and RMB appreciation has brought not only challenges but also opportunities to China's economy, as well as the Chinese medical device market. The Chinese medical device market is in a transitional period, although it has become the second largest market in the

world. The Chinese medical device manufacturers have steadily penetrated medium- to high-end sections of the global marketplace. The export volumes of the Chinese medical devices reached $21,703 million (Appendix Table A1) in 2017, US is the largest trading partner, which contributes $5,838 million in import volumes from China, this accounted for about 27% of the Chinese medical devices export volumes (Fang and Sang, 2019). US proposed import tariffs of approximately $50 billion on the Chinese commodity export, which affected the biomedical materials and medical devices. US has recently imposed a 25% tariff on the Chinese medical devices, including medium- to high-end devices, as a result: exports of medium- to high-end devices to US will decrease. Such medical devices mainly rely on price advantage to seize US market share, after the 25% tariff is imposed, the price advantage will no longer exist. In this intensely competitive market, competitive advantage is increasingly difficult to establish; a long-term competitive advantage is hard to maintain. It is a complex procedure to improve the competitiveness of China's medical device industry, especially the medical diagnosis and treatment devices, which have no competitive advantages. This complex process requires a significant long-term investment plan, with a long payback period, which should coordinate all the essential elements from companies; research institutes; universities and government.

In the medical device industry, China relies on US, Japanese and European suppliers for: sensors, drives and key parts, especially the high-end chips. In the context of trade friction between China and US, it is particularly important to focus on the structures required for independent innovation. The Chinese government cultivates and supports technology innovation capacity among domestic enterprises from the aspect of funding and policies, to improve the level of industrialisation and technology integration. The Chinese medical device companies should strengthen the R&D of core technologies and key components, improve their integrated innovation ability and manufacturing facilities. They also need to accelerate the deep integration of the medical device industry and new generation of information technology.

Technological innovation provides the power to maintain the sustainable development of medical devices, involving the safety, reliability, availability and other aspects of medical device testing and design. In the Chinese medical device industry, the basic research into biomedical materials has reached the international advanced level. However, due to the professional technical barriers and lack of experience in manufacturing techniques, high value consumables and devices are still imported from abroad. For example, thin-walled metal tubes for vascular stents; metal wires for defibrillator or pacemaker are completely dependent on imports. Furthermore, high strength ultra-fine grained titanium alloy bars for dental implants and other devices rely on imports. Compared with the foreign medical devices, China's medium-high-end medical products have a gap in process stability and quality control. It is suggested that central and local government should support the development of industrial design, manufacturing processes, testing and validation in the medical device industry, and promote the development of technology transformation and industrialisation.

The high-end medical devices are mainly dependent on imports, which is one of the reasons why it is expensive to see a doctor in China. Promoting the application of domestic medical devices is the way to solve this problem. The government should deepen and optimise the application environment of domestic medical device innovation, promote the application and upgrading of domestic devices in all the different level

hospitals, build an application and promotion system for China's domestic innovative medical devices.

The government should encourage social capital investment in science and technology, drive financial capital and private investment into the R&D of high-end medical devices. Guide social capital to set up multi-level venture capital schemes in the medical device industry at all different stages of R&D, form a multi-channel science and technology financing system. Finally, the Chinese medical device market is set to remain an attractive market for many investors, this will increase its competitive advantages in the global market.

Future studies could benefit by comparing data pattern developments in different industries and countries. How might trade trends in the Chinese medical device products change in the coming year? Can this be compared with other industrial sectoral patterns of development? Further studies need to be conducted for the changing trends in China. The Chinese medical device market may gradually shift from export of low-end products to high-end products in the future.

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Notes

[1]The opposite of intra-industry trade is inter-industry trade, which means international trade occurs between two different industries.

[2]This is the expansion model of Flying Geese, which was introduced by Ippei Yamazawa. Against imports means the investment country transfers the production base of a product to foreign countries through foreign direct investment (FDI), and then imports this product from its foreign branches.

[3]HS Code 3005: Wadding, gauze, bandages (dressings, adhesive plasters, poultices), impregnated or coated with pharmaceutical substances or in forms of packing for retail sale, for medical, surgical or veterinary use.

[4]HS Code 4015_11: Rubber; vulcanised (other than hard rubber), surgical gloves.

[5]HS Code 9018_31: Medical, surgical instruments and appliances; syringes, with or without needles.

[6]HS Code 9018_32: Medical, surgical instruments and appliances; tubular metal needles and needles for sutures.

[7]HS Code 9018: Instruments and appliances used in medical, surgical, dental or veterinary sciences, including scintigraphic apparatus, other electro-medical apparatus and sight testing instruments.

[8]HS Code 9022: X-ray, alpha, beta, gamma radiation apparatus; X-ray tubes, X-ray generators, high tension generators, control panels and desks, screens, examination or treatment tables, chairs and the like.

[9]HS Code 9019: Mechano-therapy, massage appliances; psychological aptitude testing apparatus.

[10]HS Code 3306: Oral or dental hygiene preparations; including fixative pastes and powders; yarn used to clean between teeth, in individual retail packages.

[11]HS Code 9018_41: Dental instruments and appliances; dental drill engines, whether or not combined on a single base with other dental equipment.

[12]HS Code 9018_49: Dental instruments and appliances; other than dental drill engines.

[13]The Five-Year Plan (FYP) is an important part of China's national economic and social development project, which as to set goals and directions for the long-term development of national economy and launch reforms. First FYP: 1953-1957. 11th FYP is from 2006-2010, 12th FYP is from 2011-2015, 13th FYP is from 2016-2020.

Appendix

Table A1 China's exports and imports of medical devices. (US$ million)

Year	*Exports*	*Imports*
2007	8,415	4,282
2008	11,067	5,216
2009	12,250	6,105
2010	13,859	7,336
2011	15,711	10,887
2012	17,590	12,472
2013	19,335	14,975
2014	20,023	15,771
2015	21,170	17,319
2016	20,505	18,405
2017	21,703	20,360
2018	23,630	22,165
2019	28,702	26,785

Source: General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE

Table A2 China's total merchandise exports and imports volumes, trade with the world (US$ million)

Year	*Exports*	*Imports*
2007	1,220,456	956,116
2008	1,430,693	1,132,567
2009	1,201,612	1,005,923
2010	1,577,754	1,396,247
2011	1,898,381	1,743,484
2012	2,048,714	1,818,405
2013	2,209,005	1,949,990
2014	2,342,290	1,959,230
2015	2,273,468	1,679,566
2016	2,097,632	1,587,925
2017	2,263,346	1,843,792
2018	2,487,045	2,135,905
2019	2,499,482	2,078,409

Source: WTO database

Table A3 Worldwide total merchandise exports and imports volumes (US$ million)

Year	*Exports*	*Imports*
2007	14,032,003	14,268,847
2008	16,170,529	16,496,984
2009	12,565,091	12,714,737
2010	15,303,993	15,438,092
2011	18,343,601	18,438,364
2012	18,514,486	18,657,296
2013	18,969,946	18,966,119
2014	19,011,072	19,060,809
2015	16,558,147	16,733,507
2016	16,045,249	16,211,194
2017	17,742,931	17,985,896
2018	19,550,439	19,836,342
2019	19,014,680	19,284,167

Source: WTO database

Table A4 Worldwide exports and imports of subcategory medical products under different HS Code (US$ million)

	Medical dressings		*Medical disposable products*						*Medical diagnosis and treatment device*			
	HS Code 3005		*HS Code 4015_11*		*HS Code 9018_31*		*HS Code 9018_32*		*HS Code 9018*		*HS Code 9022*	
Year	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*
2007	4,984	4,904	655	1,144	3,328	3,099	1,219	1,616	62,994	70,908	18,407	17,415
2008	5,769	5,779	785	1,356	3,694	3,576	1,424	1,866	70,554	81,441	19,932	19,146
2009	5,370	5,638	807	1,431	3,532	3,607	1,470	1,873	79,020	77,448	18,053	17,251
2010	5,784	5,644	1,033	1,655	3,480	3,592	1,516	1,975	89,293	85,023	19,859	19,376
2011	6,376	6,500	1,196	1,853	4,141	4,047	1,709	2,219	96,388	94,549	21,900	21,672
2012	6,075	6,469	1,207	1,812	4,275	3,951	1,775	2,246	99,853	97,616	22,397	22,482
2013	6,646	6,954	1,199	1,766	4,825	4,640	1,982	2,169	106,036	103,774	21,704	21,565
2014	6,880	7,399	1,288	1,817	5,050	4,811	2,159	2,397	112,654	108,377	21,354	21,213
2015	6,675	6,956	1,225	1,792	4,614	4,480	2,265	2,414	107,839	104,191	20,441	20,475
2016	6,936	7,239	1,289	1,791	4,742	4,723	2,224	2,495	111,391	109,303	20,235	20,617
2017	7,266	7,447	1,404	1,943	4,916	4,769	2,273	2,829	116,706	113,955	21,679	21,768
2018	7,793	7,919	1,421	2,146	5,131	5,244	2,562	3,201	115,998	114,193	23,277	23,619
2019	7,958	8,193	1,485	2,133	5,297	5,608	2,805	3,345	131,626	133,810	23,299	23,534

	Health protection and recovery products		*Dental equipment and materials*						*Medical device worldwide*	
	HS Code 9019		*HS Code 3306*		*HS Code 9018_41*		*HS Code 9018_49*		*Total*	
Year	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*
2007	6,486	6,884	3,241	3,424	361	414	3,161	2,957	**104,836**	**112,765**
2008	7,061	7,771	4,333	3,963	398	471	3,731	3,307	**117,681**	**128,676**
2009	6,811	7,600	3,898	3,855	370	401	3,293	3,023	**122,624**	**122,127**
2010	7,415	8,480	4,193	4,226	375	419	3,371	3,301	**136,319**	**133,691**
2011	7,967	9,215	4,783	4,804	449	492	3,876	3,781	**148,785**	**149,132**
2012	8,175	9,515	4,896	5,018	416	482	4,022	3,777	**153,091**	**153,368**
2013	8,718	9,809	5,392	5,464	467	536	4,300	4,072	**161,269**	**160,749**
2014	9,482	10,342	5,456	5,627	386	411	4,387	4,192	**169,096**	**166,586**
2015	9,847	10,411	4,960	5,274	347	336	4,362	4,040	**162,575**	**160,369**
2016	10,449	11,071	5,138	5,492	383	343	4,457	4,324	**167,244**	**167,398**
2017	11,661	12,517	5,584	5,896	471	444	4,835	4,702	**176,795**	**176,270**
2018	12,788	13,446	5,959	6,315	437	435	5,180	5,021	**180,546**	**181,539**
2019	13,547	14,033	5,992	6,237	538	459	5,528	5,312	**198,075**	**202,664**

Source: UN Comtrade Database

Table A5 The volumes of export and import of medical devices in China (US$ million)

	Medical dressings		*Medical disposable products*		*Medical diagnosis and treatment device*		*Health protection and recovery products*		*Dental equipment and materials*	
Year	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*	*Exports*	*Imports*
2007	2,405	136	1,425	436	2,746	3,569	1,694	68	145	73
2008	3,113	162	1,854	600	3,616	4,275	2,283	81	201	99
2009	4,136	163	1,920	720	3,771	5,014	2,169	82	248	126
2010	4,688	208	1,922	881	4,544	5,945	2,416	149	289	153
2011	2,462	196	2,659	1,119	6,750	8,229	3,384	1,072	455	270
2012	2,290	221	3,272	1,803	7,744	9,650	3,772	471	511	327
2013	2,381	275	3,666	2,362	8,482	10,682	4,184	1,202	624	454
2014	2,629	340	3,203	2,232	8,955	11,394	4,582	1,337	653	468
2015	2,615	395	3,334	2,445	9,661	12,453	4,851	1,506	708	520
2016	2,357	337	3,293	2,632	9,031	13,349	5,111	1,473	713	614
2017	2,426	368	3,607	2,930	9,402	14,630	5,433	1,650	8,340	7,780
2018	2,608	435	3,937	3,535	10,077	15,126	6,019	2,165	989	903
2019	2,716	544	5,488	4,191	12,456	18,665	6,711	2,353	1,330	1,031

Source: General Administration of Customs, China; Department of Foreign Trade, Ministry of Commerce of the People's Republic of China; CCCMHPIE

Table A6 RCA results of each subcategory of medical products in China

Year / *RCA index*	*Medical dressings*	*Medical disposable products*	*Medical diagnosis and treatment device*	*Health protection and recovery products*	*Dental equipment and materials*
2007	5.55	3.15	0.39	3.00	0.25
2008	6.10	3.55	0.45	3.65	0.27
2009	8.05	3.46	0.41	3.33	0.34
2010	7.86	3.09	0.40	3.16	0.35
2011	3.73	3.65	0.55	4.10	0.48
2012	3.41	4.07	0.57	4.17	0.49
2013	3.08	3.93	0.57	4.12	0.53
2014	3.10	3.06	0.54	3.92	0.52
2015	2.85	3.00	0.55	3.59	0.53
2016	2.60	3.05	0.52	3.74	0.55
2017	2.62	3.29	0.53	3.65	6.00
2018	2.63	3.40	0.57	3.70	0.67
2019	2.60	4.35	0.61	3.77	0.84