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Technology structure of China's export of agricultural products: empirical analysis based on technical complexity

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Abstract

Growing labour costs, increasing resources and environmental constraints and a desire to emphasize high-quality trade have promoted China to prioritize upgrading the agricultural export structure. This brings forth a need for further research on agricultural export technology. We measure the technical complexity and height based on the sample of 178 countries over the 2002–2020 period. The results are then compared with those of the world's major exporters of agricultural products (APs). We find that China's APs export exhibited a pattern of medium-technology products and slowly transitioned towards medium–high and high technology levels. The technology structure of China's APs export was significantly lower than that of the major global AP exporters (except Brazil). The overall technical level of China's APs exports slightly fluctuated near the medium technology grade. The evolutionary trend of the technology structure of China's APs export differs from its export scale, showing a tendency towards a more downmarket in 2002–2012 but some improvement since 2013. There is a widening gap in the technology structure of APs export between China and major developed exporters. China's APs export is losing competitiveness overall, and the upgrading of the technology structure of China's APs export was slower. Therefore, the technology structure of China's APs export can be escalated by raising standards of quality, concentrating on the export of higher technical complexity products, promoting the advances and innovations in agricultural science and technology, and further exploring the trade potential hidden behind the differences between China and other countries in export technology structure.

Keywords Comparative advantage · Economic transition · Trade competitiveness · Technical height

Jingjing Wang and Yujia Deng contributed equally to this work.

Research Design Based on a sample of 178 countries/regions and United Nations Comtrade (COMTRADE) data, this paper uses the technical complexity index to empirically calculate the technology structure, level changes and evolutionary trends of China's APs exports over the 2002–2020 period. These results are also compared with those of world's major exporters of APs.

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Abbreviations

Aps	Agricultural products
WTO	World Trade Organization
COMTRADE	United Nations Comtrade Database
GDP	Gross domestic products
PRODY	Product-relevant income levels
EXPY	Overall export technical level
THI	Technical height index
ETHI	Overall export technical height
RCA	Revealed comparative advantage
RTV	Revealed technology value-added
ETM	Equilibrium technology method
HS	Harmonized Commodity Description and Coding System
WDI	World Development Indicator
TCM	Technical complexity method
SITC	Standard International Trade Classification

1 Introduction

China's foreign trade policy has played an essential role in the APs exports. China has maintained a fast growth of APs export since entering the World Trade Organization (WTO) in 2001. Statistics show that the total Chinese APs export expanded almost four times with an average annual growth rate of 7.99%, from \$23.36 billion to \$87.07 billion during 2002–2020. China has become a significant driving force for developing APs trade globally. Its share (world ranking) of global APs exports grew from 4.90 to 5.32% (5th–4th) over the same period in the world of APs exporters (COMTRADE, 2022).

However, since 2017, China's economy has entered a new paradigm, emphasizing the need for a better quality of development rather than faster growth (Xi, 2017). The quality of exported goods became more important (Li, 2018), especially while the low labour costs advantage of "*made in China*" no longer exists and environmental regulation has been constantly strengthened. Chinese government and manufacturers should prioritize upgrading the quality of export products, and one way to improve the export quality is to gain access to advanced technology (Anwar & Sun, 2018).

In economics, whether a product is of high technology depends on how much technology contributes to its value addition. Hence, *export technology* can be measured as value added by the technology component (Guan, 2002; Lall et al., 2006). This technology value-added refers to the incremental value due to the use of advanced technology during the production process of the exported products. From the perspective of sustainable trade patterns, increases in export volume should bring significant improvements in the share of advanced technology used in export-oriented products (Du & Wang, 2007). For this reason, we need to explore the export technology structure deeply. In the Chinese context, it is particularly important to understand the distribution, overall level, and evolutionary trends of the technology structure of APs export and its performance compared to key global exporting countries. Exploring these issues will help to clarify the relative position of China's agriculture sector and provide evidence for strategy formulation to improve its international competitiveness. This strategy may also provide useful insights about how China can avoid APs export going *down-market* and gain higher benefits in the international markets.

Theoretically, the export technology structure is inseparable from international trade theories. According to Ricardo (1817), production technology differences are the basis of comparative advantage, and countries should export those products where they have a comparative advantage. Neoclassical economic theories further suggest that the comparative advantage does not originate from technology but from different resource endowments (Heckscher, 1919; Ohlin, 1993). New trade theories show that countries with similar endowments have bilateral trade, and countries lacking natural resources can still perform outstanding in global trade. These observations brought serious challenges to the old concept and gave birth to a new concept of competitive advantage, suggesting that competitiveness is based on comparative advantage (Attila & Babu, 2017). Factor endowments do not simply determine national export technology structure but are largely determined by industry innovation and upgrading capacity (Porter, 1990). Based on the cost discovery theory, Hausmann et al. (2007) further proposed a theoretical assumption: the more technical the exported products coming from high-income countries, the higher the sophistication of the products. Overall, the conclusions that comparative advantage is the source of export technology structure and is related to the development level of the national economy have been widely recognized. And previous studies have focused on the change in the export technology structure (Cao & Hanson-Rasmussen, 2018; Deng & Hou, 2017; Duan, 2017) and its international comparison among countries(Schott, 2007; Z. Wang & Wei, 2010). However, few studies(He et al., 2012) pay close attention to the comparison between China and other countries in APs' export structures and evolutionary trends. He et al. (2012) found the competitive advantage complementarity among China, Japan, and South Korea by examining the overall technology structure of APs exports. However, this study compared China's APs export with only two major global economies. It failed to apply the technical height to further study the upgrading trend of export technology structure compared to other economies. To this end, this paper will empirically measure the changes in China's APs export technology with both technical complexity and technical height and compare the results with those of all the world's major exporters of agricultural products.

The existing measures on technology structure consist of two categories, *i.e.* the *technology classification method* and the *index method*. The first is to measure the technology structure based on technology classification standards (Hatzichronoglou, 1996; Lall, 2000; Pavitt, 1984). However, this classification relies on the experts' experience, tends to be subjective, and generates overlaps between categories (Zhu & Chen, 2010). The *index method* (primarily rooted in estimating technology value-added) is the most frequently used way of technology structure analyses. Relevant literature has put various *technology value-added* measures forward and built a generalized consensus. The technology value-added value of a product is closely related to the income level of its producer, and the product produced by high (low) income economies also features higher (lower) technology value-added value (Felipe et al., 2013). Based on this fundamental principle, Lall et al. (2006) proposed a *complexity (sophistication) index* to measure the technology value-added of a product. It took a weighted average of the per-capita gross domestic product (GDP) of the countries exporting a product, where the weights are the world share of each country's exports. However, this assignment of weights may overestimate the role of leading powers and ignore the exports of products with comparative advantages among small countries (Zhu & Fu, 2013). Du and Wang (2007) revised this index by adjusting the weights to each country's world production share in a particular product and constructed a *technical height index (THI)* to map out the upgrading trend of export technology structure in one country compared to other economies. However, the data on world share in production is not available directly. Hausmann et al. (2007) firstly constructed a "*product-relevant income index*"

(PRODY) to embody an associated productivity level for each good, using the *revealed comparative advantage (RCA)* as the weights. Then, the productivity level that corresponds to a country's export basket *(EXPY)* was constructed, by calculating the export-weighted average of the *PRODY* for that country. By contrast, this method (also known as the *technical complexity index*) is more commonly used, which has a clear advantage in data accessibility and can overcome the possible deviations in the calculation process (Fan et al., 2006). Besides, this [index] *method* is like the *revealed technology value-added (RTV)* method, each of which presents its solid theoretical basis to prove the rationality of taking *RCA* as weights. Therefore, this article chooses the *technical complexity index* method to empirically measure the *PRODY* and *EXPY* of China's APs export, and then refers to the practice of Du and Wang (2007) to construct the *technical height index* for further analysing its evolutionary trends.

Although many classification methods for *PRODY* values are available, that leads to distinct conclusions under certain limitations. They mainly include *fixed technical classification* (Zhu et al., 2009), *experience sorting method* (Tang, 2012), *optimal segmentation method* (Wei, 2015), *equal worldwide share method* (Sun & Li, 2016), and *equilibrium technology method* (Cao et al., 2018). In comparison, the *equilibrium technology method (ETM)* can ensure the *PRODY* value differences equal for products of adjacent technology grade (high to low technological levels) and avoid the classification results being limited and influenced by time change and human experiences (Cao & Hanson-Rasmussen, 2018). Thereby, we adapt the *ETM* for APs technical complexity classification.

Previous studies have also explored the technology structure of China's exports mainly at the macro level (Jarreau & Poncet, 2012) or sector level within the economy, *e.g.* industrial manufacturing (Gao et al., 2020; Zhang, 2022), services (Lu & Fu, 2018) and agriculture (Bai, 2020; He et al., 2012; Sun & Li, 2015; Yin & Tian, 2013) levels. However, some studies in the agriculture sector only defined the exported APs with fewer categories based on the *Harmonized Commodity Description and Coding System (HS)* and sample countries (Bai, 2020; He et al., 2012; Yin & Tian, 2013). The studies of (Sun & Li, 2016) and Bai (2020) concluded that the technical structure of China's APs export had upgraded significantly. These results might not be reliable without using a more objective classification method—instead of considering an *equal worldwide share*—and combined analysis of *EXPY* and *THI* together. Therefore, the present paper is designed to revisit the technology structure of China's APs export with (1) extended scope of the traded APs; (2) inclusion of the maximum countries; (3) improved classification method and comprehensive indices. The key novelty is a comparative analysis that scientifically judges the trade pattern and upgrading trend of technology structure of China's APs.

The remainder of this paper is structured as follows. We begin in Sect. 2 with our measure of export technology structure and the dataset used. We then discuss our results in Sect. 3 and the conclusion and policy implications in Sect. 4.

2 Methodology

2.1 Contextualizing APs

There is no universal standard for the definition and classification of APs. We have defined the APs based on HS, a multipurpose international product nomenclature developed by the World Customs Organization. The HS (2002 version) comprises over 1200 items at the 4-digit level and over 5,000 items at the 6-digit level. The system is used worldwide to apply customs tariffs and collect global trade statistics. The present study defines the exported APs by 26 different commodities (HS codes), including HS01-HS24 and HS51-HS52 (see Table 1 for the product description).

2.2 Sample selection and data sources

This study selected the world's 178 APs exporting countries from the developed and developing regions from 2002 to 2020 (please see A1 in Appendix A). During this period, these economies' cumulated APs export volume accounted for over 99.52% of the world's total APs exports. This strong contribution makes a comprehensive and robust representative sample compared to previous studies conducted in agriculture (Bai, 2020; He et al., 2012; Sun & Li, 2016; Yin & Tian, 2013).

The export data were retrieved from the same *HS code system* to ensure data consistency and reduce measurement errors in product classification. We used the HS 2002 for commodity codes and data derived from the COMTRADE database. The annual GDP per capita (in constant 2017 international $) of each exporter was retrieved from the World Development Indicator (WDI) database (The n.d.) of the World Bank (A2 in Appendix B).

2.3 Methods

We need to (1) measure the technical complexity level of each type of APs export and exporting country using the technical complexity method (TCM). There are two steps involved in calculating the technical complexity level. Initially, each year, the annual GDP and export value of different products are used to construct a product-relevant income index PRODY. Then, weighted averages are calculated based on each country's export basket, called the overall technical level (EXPY). (2) Classify APs into five technological levels based on the annual average of PRODY values using the ETM; 3) Calculate the technical height index to further analyse the evolutionary trend of the technology structure of different countries. Each of the steps was explained in detail in respective sections.

2.4 Technical complexity measure

We applied the Hausmann et al. (2007) measure of the technical complexity of a country's export basket. In this measure, each type (HS classification) k that a country can potentially produce and export in year m has an intrinsic level of technical complexity ($PRODY_{mk}$), which is a weighted average of the income level of countries exporting k, where the weights correspond to the RCA of each country j in type k. Exporting more type k product from rich countries, the higher its $PRODY$.

$$PRODY_{mk} = \sum_{j=1}^{n} \frac{x_{mjk}/X_{mj}}{\sum_{j=1}^{n} \left(x_{mjk}/X_{mj}\right)} \times Y_{mj} \tag{1}$$

where n = number of countries, Y_{mj} = GDP per capita of the country j in year m, x_{mjk} =export value of type k APs of the country j in year m, X_{mj}=total APs export of the country j in year m.

Table 1 The technology structure distribution of the world's APs

Classification (n)	Classified standard/$	Products (HS code)
High (3)	$PRODY > 31{,}690$	Edible animal, egg, honey, and dairy products, etc. (**04**). Processed products of grain or milk (**19**). Edible preparations (**21**)
Medium–high (3)	$26{,}155 < PRODY \leq 31{,}690$	Live animals (**01**). Meat and edible meat offal (**02**). Beverages, spirits, and vinegar (**22**)
Medium (8)	$20{,}620 < PRODY \leq 26{,}155$	Fish and crustaceans, molluscs, and other aquatic invertebrates (**03**). Animal-based products, not elsewhere specified or included (**05**). Products of the milling industry include malt, starches, inulin, and wheat gluten (**11**). Meat, fish, crustaceans, molluscs, or other aquatic invertebrates; preparations thereof (**16**). Preparations of vegetables, fruit, nuts, or other parts of plants (**20**). Food industries, residues, and wastes; prepared animal fodder (**23**). Tobacco and manufactured tobacco substitutes (**24**). Wool, fine or coarse animal hair, horsehair yarn, and woven fabric (**51**)
Medium–low (10)	$15{,}085 < PRODY \leq 20{,}620$	Trees and other plants live; bulbs, roots, and the like; cut flowers and ornamental foliage (**6**). Edible vegetables, certain roots, and tubers (**7**). Fruit and nuts, edible; peel of citrus fruit or melons (**8**). Cereals (**10**). Oil seeds and oleaginous fruits; miscellaneous grains, seeds, and fruit; industrial or medicinal plants; straw and fodder (**12**). Lac: gums, resins, and other vegetable saps and extracts (**13**). Animal or vegetable fats and oils and their cleavage products; prepared animal fats; animal or vegetable waxes (**15**). Sugars and their confectionery (**17**). Cocoa and its preparations (**18**). Cotton (**52**)
Low (2)	$PRODY \leq 15{,}085$	Coffee, tea, mate, and spices (**09**). Vegetable plaiting materials: vegetable products not elsewhere specified or included (**14**)

The HS codes come from the UN COMTRADE database; some product descriptions are streamlined. The classification of ETM was based on the average of PRODY values during the period 2002–2020. Source: The authors' calculation is based on the UN COMTRADE and WDI database

The technical complexity level of country j's APs export in year m, denoted by $EXPY_{mj}$, i s then calculated as the average level of the technical complexity of its APs export basket. This level is a weighted average of the $PRODY_{mk}$ for country j, the weights are the value share of the k APs in that country's total APs exports.

$$EXPY_{mj} = \sum_{k=1}^{s} \frac{x_{mjk}}{X_{mj}} \times PRODY_{mk} \tag{2}$$

2.5 Equalization technology classification method

The basic principle of this method is to ensure the equality of the *PRODY* value difference of products from adjacent technological levels. This method provides a relatively objective way to cluster the same level of products into similar categories based on t grades (high to low technological levels), and there is no restriction on the number of products owned by each level. This method consists of three steps. These are,

(1) Sorting the *PRODY* of s-type APs, i.e. $\{PRODY_1, PRODY_2, \cdots, PRODY_n\}$ are arranged in ascending order.
(2) *Orderly n sampled was divided* into the number $q(1, 2, 3, \ldots, t)$ level, denoted by$p(n, q)$. The *PRODY* value grading of APs is$D$. Whereas D is equal to$(a_n - a_1)/t$.
(3) Finally, n-ordered and t-graded levels of *PRODY* values are classified with the help of the following technical classification criteria.

e.g. $if\ a_1 \le a_1 + D,\ a_2 \le a_1 + D,\ \cdots,\ a_k \le a_1 + D,\ a_{k+1} > a_1 + D,\ \cdots,\ a_n > a_1 + D,\ then$ $p(n, 1) = \left\{a_1, a_2, \cdots, a_k\right\}$.

2.6 Technical height measure

The technical complexity of good k may be relatively high or low with the widespread improvement of the world's technological level over time. In other words, whether type k is a high-technology or low-technology product depends on the technical complexity of all products in the same period. Therefore, we first construct an index called *THI* to represent the technical height level of each type of exported APs.

$$THI_{mk} = \left(PRODY_{mk} - PRODY_{mmin}\right) / \left(PRODY_{mmax} - PRODY_{mmin}\right) \tag{3}$$

Here, $PRODY_{mmin}$ and $PRODY_{mmax}$ represent the minimum and maximum technical complexity of all APs in year m, respectively.

The technical height level of country j' APs export in year m, denoted by $ETHI_{mj}$, is the weighted sum of the technical height levels associated with each exported good k. Therefore, THI_{mk} is the weighted value shares of each type of APs in the country's total exports.

$$ETHI_{mj} = \sum_{k=1}^{s} \frac{x_{mjk}}{X_{mj}} \times THI_{mk} \tag{4}$$

Excluding the upgrading of technology structure caused by the world's common technological advancement, the calculated *ETHI* values changing over time represent the evolutionary trend of a country's technology structure of APs export, compared with the other economies in the world.

3 Results and discussion

3.1 Technical complexity structure determination of APs

The technical complexity of various APs worldwide is calculated using Eq. (1). Overall, the export technical complexity of different APs shows an upward trend, with an average increase of 5% from 2002 to 2020 (A3, in Appendix C). Among a variety of APs, HS01-02, HS04, HS19, and HS21-22 show higher technical complexity (the annual average *PRODY* >29,000$), while HS07-09, HS12, HS14, HS17-18, and HS52 are that of lower technical complexity (the annual average *PRODY*<17,000$).

Then, the *equalization technology classification* method was employed to divide the annual average of *PRODY* values of 26-type into five grades, *i.e.* high technical complexity products (*PRODY* > 31,690$), medium–high technical complexity products (26,155$< *PRODY* ≤ 31,690$), medium technical complexity products (20,620$< *PRODY* ≤ 26,155$), medium–low technical complexity products (15,085$< *PRODY* ≤ 20,620$), and low technical complexity products (*PRODY* ≤ 15,085$). The results of APs into five classification categories are reported in Table 1.

The result reveals that all 26 types of commodities are distributed into five different classifications of the technical complexity of products, with the frequency of high and medium–high (3 each), medium (8), medium–low (10), and low (2) in each classification. The classification of 85% APs is like that of He et al. (2012), where HS04, HS06-10, HS13-15, HS17, HS19, and HS21-22 are classified, respectively, in the same groups. These categorization differences are mainly due to the extended scope of APs, and *five-scaled classification* resulted in different *PRODY* values.

3.2 Dynamic distribution of the technology structure

Table 2 shows how China's APs export technology structure varied from 2002–2020. This overall distribution of technology structure characterized by *"big in the middle, small at both ends"* indicates a similar trade pattern with high input resources rather than high technology value-added, to that in He et al. (2012) and Bai (2020). China's APs export is concentrated in the products of low technical content (which require more land or labour input), and high-technology products are far from becoming a dominant role. From 2002 to 2020, the aggregate average export share of medium–low and low technical complexity products was ~ 46.11%, while the yearly average export proportions of high and medium–high technical APs reached 5.62% and 4.40%, respectively. This result is consistent with Du and Wang (2007), who found that China's technology structure of APs export conforms to its resource endowment. A similar message comes from considering the share of specific APs export. Statistics show that China's main exported APs were centred on the following items (HS code), i.e. 52 (cotton), 03 (fish and crustaceans, etc.), 16 (meat, etc.), 07 (edible vegetables, certain roots, and tubers), 20 (preparations of vegetables, fruits, etc.), 08 (edible fruit and nuts, etc.), with an aggregate average export share of 66.33% during 2002–2020, which are of medium or medium–low technical complexity (see Table 1 for the classification of APs).

Table 2 The dynamic distribution in technology structures of China's APs export

Year	Technical complexity ratios (%)				
	High	Medium–high	Medium	Medium–low	Low
2002	4.75	6.87	41.26	44.57	2.55
2003	4.59	5.66	39.94	47.44	2.38
2004	4.87	5.78	45.48	40.92	2.95
2006	5.05	5.28	44.60	42.53	2.54
2007	5.29	4.12	45.52	42.62	2.45
2008	5.53	4.20	45.37	42.23	2.67
2009	5.31	4.12	44.68	42.94	2.96
2010	4.95	3.88	43.55	44.89	2.73
Average (2002–2010)	5.02	4.99	43.87	43.46	2.66
2011	5.20	3.67	44.65	43.75	2.73
2012	5.42	3.76	47.48	40.75	2.59
2013	5.31	3.40	45.42	43.14	2.73
2014	5.52	3.88	45.99	41.71	2.90
2015	5.93	4.23	43.33	43.42	3.08
2016	6.09	4.25	42.62	43.52	3.52
2017	6.06	4.08	42.82	43.66	3.38
2018	6.56	3.96	43.87	42.05	3.57
2019	7.24	3.67	42.13	42.94	4.03
2020	8.21	3.83	40.49	42.66	4.81
Average (2011–2020)	6.15	3.87	43.88	42.76	3.33
±	1.13	− 1.12	0.01	− 0.70	0.67
Overall	5.62	4.40	43.88	43.09	3.02

Source The authors' calculation is based on the UN COMTRADE and WDI database

However, the dynamic change in the technical structure of China's APs export presents a peculiarity of *"decrease in the middle, increase at both ends,"* i.e. the export proportions of high (1.13%) and low (0.67%) technical complexity products, respectively, increased substantially. In comparison, the export share of medium–low (− 0.70%) and medium–high (− 1.12%) technical complexity products reported a reduction in their contribution. This result is the direct opposite of the views of Du and Wang (2007) and He et al. (2012). Possible reasons can be seen from the different classification methods for APs and the study periods. From 2002 to 2020, the export proportion of China's APs of high and low technical complexity jumped from 4.75% and 2.55% to 8.21% and 4.81%, with an increase of 72.84% and 88.63%, respectively. Correspondingly, the export share of medium–low, medium, and medium–high technical complexity products declined from 44.57%, 41.26%, and 6.87% to 42.66%, 40.49%, and 3.83%, with a decrease of 4.29%, 1.87%, and 44.25%, respectively. Note that the export proportions of low and high technical complexity products, although increasing, respectively, are constantly less than 9% and 5% during the study period, demonstrating a limited effect on export structure.

In summary, as a developing country and a large agricultural economy, China has shown a relatively stable export structure dominated by medium-level technology products during the study period. A slow, gradual increase in exports is shifting towards high and low technical complexity products. However, these products have no determining influence on export structure. On the one hand, China's APs export has long been predominant in original processed raw materials and processing trade embedded in the global value chain. Hence, its advantage still falls in the land- and labour-intensive products with relatively low technical content. On the other hand, since trade liberalization in 2001, China's APs export begun to transform, although slower, to exporting products with high technology and good quality, especially reflected in exporting processed products of grain or milk (HS19) and edible preparations (HS21), due to the relative comparative advantage, technology spillover and domestic investment into R&D. Though, China's APs export lacks in implementing stringent international quality standards, especially on meat, egg, honey, and dairy products. This non-compliance was seriously affected by the issues and events concerning food security and animal diseases (such as "Sanlu milk powder" Shuanghui "lean" events) in the previous years (Bradley, 2008; Shao & Cai, 2016).

3.3 Comparison of technology structure of APs export in major economies

This article compares the technology structure of APs export of the world's top ten APs exporters (see A1 for the average annual export value) during 2002–2020.

Table 3 shows how the technology structure of APs export and its change varied across countries in 2002 and 2020. The major exporting countries (apart from China and Brazil), including the USA, the Netherlands, Germany, France, Spain, Italy, Canada, and Belgium, have a relatively higher comparative advantage in exporting technology-intensive products worldwide. Unsurprisingly, compared to these developed countries, the overall technology structure of China's APs export is still at a lower level. From 2002 to 2020, we also found a new leader (higher growth rate) in each technology structure, ranging from higher to lower. For high technology products, Italy shows a ~ 50% growth rate (23% less than China) in the export of APs compared to other international players. While Spain emerges as a leading contributor in medium–high technology APs export with a ~ 51% growth rate. The rest of the top ten exporting countries experienced a declining trend in their growth, where China reported a ~ 44% decline in the growth of medium–high technology APs export. All the international players were experiencing the same declining trend for medium-level technology products except Belgium (0.82% growth rate). China experienced ~ 2%, while Brazil reported the highest ~ 55% decline during this period. Canada (46%) and France (~ 326%), respectively, emerge as the largest contributors to medium–low and low technology APs export growth.

Regarding the changes in technology structure across countries, China's APs export exhibits a transition pattern of "decrease in the middle, increase at both ends" to the dynamic changes of its technical structure, remarkably like the transition pattern in France. In contrast to the "both ends," except for Belgium (only at a low level) and Brazil, the remaining exporters show a significant transition in high and low technical complexity products, which vary between ~ 50% and ~ 8% (high) and ~ 326% and ~ 8% (low), respectively. It is worth noting that the positive change in the technology structure of China's APs export, slowly driven by the rise of high technology products, resulted in a very slight upgrading of the export structure. Additionally, the export growth rate bringing this positive change is the highest among the world's top ten APs exporters. In the further evolutionary trend analysis, we will consider this via a specific vision.

Table 3 The technology structure of APs exports of the world's top-10 APs exporters in 2002 and 2020 (%)

Classification	Year	China	Belgium	Brazil	Canada	France	Germany	Italy	Spain	The Netherlands	USA
I	2002	4.75	20.07	2.66	11.07	17.92	25.56	16.97	7.89	16.86	8.48
	2020	8.21	24.49	1.83	11.88	21.73	28.96	25.4	9.8	20.17	12.11
	±	3.46	4.42	0.83	0.81	3.81	3.4	8.43	1.91	3.31	3.63
	Growth rate	72.84	22.02	− 31.20	7.32	21.26	13.30	49.68	24.21	19.63	42.81
II	2002	6.87	17.57	16.93	27.06	34.45	18.07	20.68	16.71	18.13	14.05
	2020	3.83	20.76	20.12	15.91	33.03	18.18	23.94	25.22	17.7	17.29
	±	3.04	3.19	3.19	11.15	1.42	0.11	3.26	8.51	0.43	3.24
	Growth rate	− 44.25	18.16	18.84	− 41.20	− 4.12	0.61	15.76	50.93	− 2.37	23.06
III	2002	41.26	23.11	30.36	26.42	14.79	26.24	24.38	21.15	26.45	23.38
	2020	40.49	23.3	13.69	20.4	13.52	23.02	20.71	18.3	18.5	15.75
	±	0.77	0.19	16.67	6.02	1.27	3.22	3.67	2.85	7.95	7.63
	Growth rate	− 1.87	0.82	− 54.91	− 22.79	− 8.59	− 12.27	− 15.05	− 13.48	− 30.06	− 32.63
IV	2002	44.57	37.93	42.4	34.78	32.29	27.87	36.46	53.62	38.11	53.45
	2020	42.66	30.26	58.17	50.78	29.38	26.05	26.69	45.55	42.31	54.17
	±	1.91	7.67	15.77	16	2.91	1.82	9.77	8.07	4.2	0.72
	Growth rate	− 4.29	− 20.22	37.19	46.00	− 9.01	− 6.53	− 26.80	− 15.05	11.02	1.35
V	2002	2.55	1.32	7.65	0.66	0.55	2.25	1.5	0.63	0.44	0.64
	2020	4.81	1.19	6.18	1.04	2.34	3.79	3.26	1.13	1.32	0.69
	±	2.26	0.13	1.47	0.38	1.79	1.54	1.76	0.5	0.88	0.05
	Growth rate	88.63	− 9.85	− 19.22	57.58	325.45	68.44	117.33	79.37	200.00	7.81

I = high; II = medium–high; III = medium; IV = medium–low; and V = low. *Source*: The authors' calculation is based on the UN COMTRADE and WDI database

3.4 Overall technical level of China's APs export and its international comparison

Figure 1 shows the *EXPY* of China's APs export basket and its annual growth rate from 2002 to 2020. The bar chart of *EXPY* represents, unsurprisingly, given the technology structure of China's APs export, there was not much fluctuation in value contribution, ranging from 19,000 to 24,100 (US$). However, the annual growth rate showed abrupt changes during the same period. There were robust spillover effects of the global financial crisis during 2007–2009, which down poured the growth of China's APs export (Schmalz & Ebenau, 2012). Another dip in the annual growth rate was visible during 2015–2016 when the Chinese RMB faced the pressure of expected depreciation against US$ due to gradual reforms (Das, 2019). The overall technical level of China's APs export basket declined further, falling into the lower grade from 2009–2017. Still, the differences between China's *EXPY* and medium technical complexity baseline only varied between 396$ (the year 2017) and 1564$ (the year 2012). Since October 2017, China has entered a new era of economic growth, which has induced more rapid technology adoption. Its overall technical level of APs export returned to the grade of medium technical complexity over the 2018–2020 period.

The technical level of China's APs export basket was sensitive to the export policies and the international market. As a result, despite a slump in the first four years, the 2007–2012 period and the 2015–2016 period, China's *EXPY* jumped to 21,844$ in 2006, 19,364$ in 2013, and 20,224$ in 2017, respectively, 4.87%, 1.62% and 3.96% up year-on-year basis. Overall, it indicates that the technical level of China's APs export basket hovered around medium technical complexity grade but showed a slight downtrend. The *EXPY* of China's exported APs dropped by 10.18% between 2002 and 2020, from 24,093$ to 21,640$.

For a comparative analysis of *EXPY*, out of 178 countries, 13 countries from developed and developing regions with a large export volume of APs were selected for further analysis. Figures 2 and 3 show how *EXPY* and its average annual growth rate across sample countries vary between 2002 and 2020. The overall technical level of the sample countries in the developed region rose to varying degrees from 2002 to 2020 (Fig. 2). Over the same

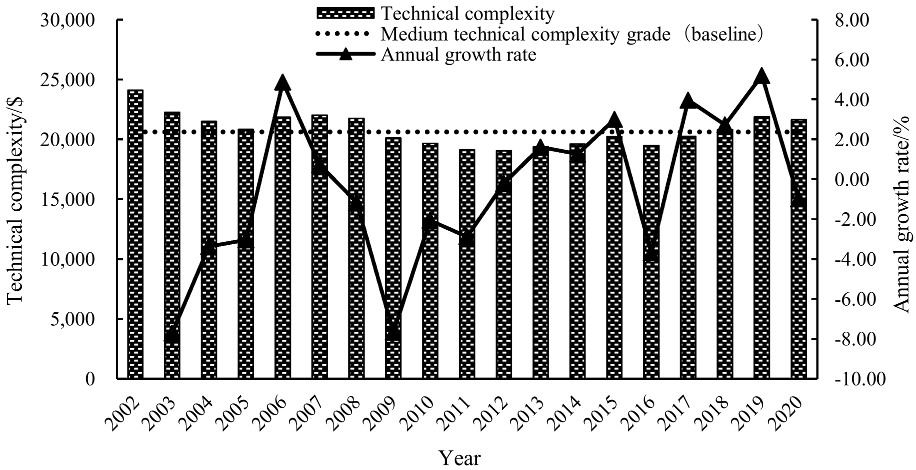

Fig. 1 The overall technical level and annual growth rate of China's APs from 2002 to 2020. *Note(s)* The graphics were drawn according to the *EXPY* and its growth rate. *Source* The authors' calculation is based on the UN COMTRADE and WDI database

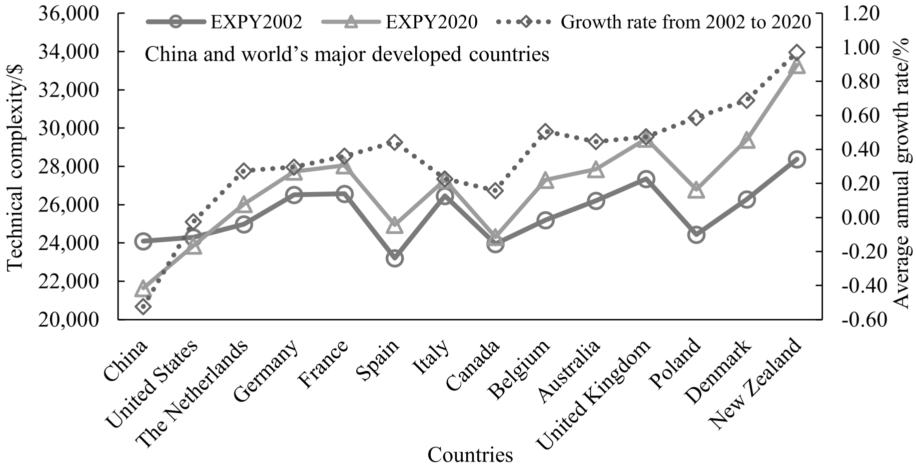

Fig. 2 The comparison of China's EXPY and its growth rate with sample countries in developed countries. *Note(s)* The graphics were drawn according to the *EXPY* and its growth rate. *Source* The authors' calculation is based on the UN COMTRADE and WDI database

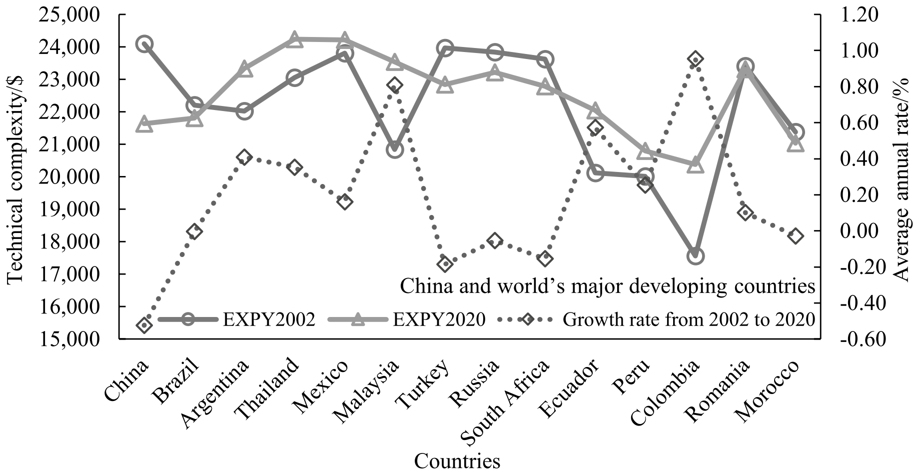

Fig. 3 The comparison of China's EXPY and its growth rate with sample countries in developing countries. *Note(s)* The graphics were drawn according to the *EXPY* and its growth rate. *Source* The authors' calculation is based on the UN COMTRADE and WDI database

period, China fell behind by 0.52% on average, so the gap between China and developed countries' *EXPY* more than tripled from 1590$ to 5769$. All the developed countries in our sample continuously held a leading position in the export technology structure, indicating a significant comparative advantage of developed countries over China.

Figure 3 shows China's leading position as APs export powerhouse in developing regions has diminished between 2002 and 2020. In 2002, China, which had the highest export share in the developing region, exhibited a significant advantage at the overall technical level among our sample countries. By 2020, China, although still ranking first in APs export among developing countries, even up one spot from *2002* in the world, has dropped to the lower middle in terms of *EXPY*, which demonstrates a real difference between the performance of "quantity" and "quality" of China's APs export in the period 2002–2020. Overall, the exported APs in China were losing competitiveness.

These findings bring new insights to the upgrading debate regarding China's APs export structure. Some work has suggested that the overall technical level of APs export in China was significantly improved (Bai, 2020; Sun & Li, 2016) or gradually increased (He et al., 2012). Our results differ from this trend, as shown by the corresponding period observation of line charts on *EXPY* (Fig. 1). Given the weakness of *EXPY* measure which is sensitive to the size of the countries under consideration (Kumakura, 2007) and the choice of product nomenclature (Yao, 2009), possible reasons include: (1) selecting a larger sample size which might reduce the effect of excluding some countries of a small share in APs export on *PRODY* values; (2) taking additional types of Aps, i.e. HS51 and HS52 (average combined export share of 22.59% between 2002 and 2020) into consideration which may generate a significant variation in *EXPY* value. These reasons receive a strong support from a comparison of *EXPY* in the four scenarios ("top 50 exporters and HS01-24", "178 exporters and HS01-24", "178 exporters and HS01-24 + HS5101-5103 + HS5201-5203" versus "178 exporters and HS01-24 + HS51-52") over the study period (Fig. 4). The average *EXPY* values in our current study (scenario 4) are 30.8%, 3.7% and 5.23% lower than that in the scenario 1–3, respectively, during 2002–2020. It is worth noting that the overall upward trends of *EXPY* in scenario 1–2 are fully in line with previous literatures (Bai, 2020; He et al., 2012; Yin & Tian, 2013) provided the same APs scope (HS01-24), which confirms the validity and compatibility of the results using the larger sample. Additionally, except for HS5101-5103 and HS5201-5203, the other types of HS51 and HS52 belong to processing products (R. Wang and Xiao 2021). Hence, the overall downward trend of *EXPY* values in our current study can be further accounted for by taking the processing-trade of HS51-52 into account. In the general case, once considering China's processing-trade regime, Chinese exports look similar to those in other countries with similar level of

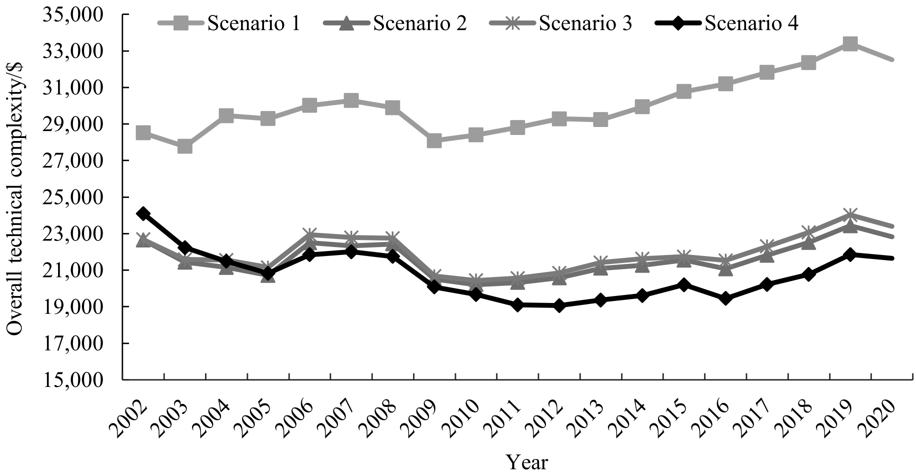

Fig. 4 The EXPY of China's APs export ($) in four scenarios during 2002–2020. *Notes* Scenarios 1–4, respectively, refer to "top 50 exporters and HS01-24", "178 exporters and HS01-24", "178 exporters and HS01-24 + HS5101-5103 + HS5201-5203" and "178 exporters and HS01-24 + HS51-52". *Source*: The authors' calculation is based on the UN COMTRADE and WDI database

development (Wang & Wei, 2010). However, this is not consistent with the reality in terms of China's APs export (see Fig. 3), thereby indirectly indicating that the overall technical level of the above cotton textile processing in China during 2002–2020 somewhat declined, or relatively declined compared to the other international APs exporters.

3.5 Technical height of China's APs export and its international comparison

We further analyse the relative change in the overall technical level of APs export across China and sample countries. These countries exhibit great differences in APs' technological development, which significantly translate into distinction in APs' export structure and overall technical level. One important question for our analysis is how much variation in overall technical level is accounted for by different levels of APs' technological development across countries. The *ETHI* was used to represent the global relative position of a country's overall technical level. This index is a good proxy index to depict the upgradation of technology structure caused by a country's technological advancement.

Figure 5 shows how *ETHI* of China's APs export varies from 2002 to 2020. This line chart of *ETHI* indicates a similar trend to that in *EXPY*, i.e. the overall technical height of China's APs export basket exhibits squiggly patterns—visible with a polynomial trend During 2002–2012, the *ETHI* gradually dropped from 0.582 to 0.371 (36.33% drop reported). This graph trend section is quite similar to the findings of Sun and Li (2016) based on 77 major exporting countries over the 1995–2012 period. The main reason for the drop in China's technical height of APs exports was trade policy adjustment and a substantial increase in imports, resulting in a mammoth trade deficit since 2004, negatively impacting China's agriculture. Later, the *Belt and Road Initiative* gradually improved the quality of economic growth in China (Kong et al., 2021) and enhanced China's APs' technological development level since 2013. This pattern can be seen in the *ETHI* upward trend from 0.34 in 2014 to

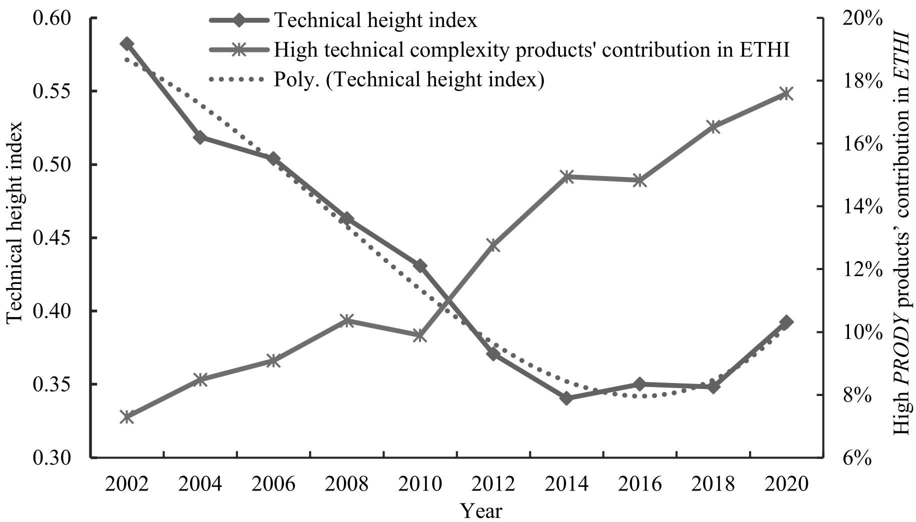

Fig. 5 The dynamic change in the overall technical height index of China's exported Aps. *Note(s)* The graphics were drawn according to the *ETHI*. *Source* The authors' calculation is based on the UN COMTRADE and WDI database

0.393 in 2020, with an average growth rate of 2.84%. Overall, the technology structure of China's APs export appeared a tendency towards a more downmarket trade pattern from 2002 to 2012 compared with other countries but has gradually shown some improvement since 2013. A more obvious message comes from the consideration of the *ETHI* of high technical complexity products as a measure of the evolutionary trend of export technology structure.

The comparison of China's *ETHI* with that of the representative developed and developing countries is summarized in Table 4. The overall technical height index analysis shows a decline in the typical developed (0.06 drop) and developing (~0.08 drop) countries from 2002 to 2020. The average annual index value in developed countries was 0.58 compared to 0.426 in developing countries. By contrast, China's annual average *ETHI* was lower than that of these sample countries in the developed/developing region, except for Brazil, Colombia, Ecuador, Malaysia, Morocco, and Peru (developing), which shows that the upgrading of the technology structure of China's APs export was slower and requires the attention of the policymakers.

4 Conclusions

We have conducted an empirical analysis of China's APs export technology structure based on a sample of 178 countries/districts across the globe during 2002–2020. We have adopted the *equalization technology classification* method to divide all APs into five technological levels. We have found that China's technology structure of APs export exhibits an overall characteristic of *"big in the middle, small at both ends,"* in which the medium-technology products predominate. The change in China's APs export shows a *"decrease in the middle, increase at both ends."* Compared to the other

Table 4 The overall technical height index of exported APs of major sample countries

Developed	2002	2020	Annual average	Developing	2002	2020	Annual average
China	0.582	0.393	0.423	China	0.582	0.393	0.423
Australia	0.664	0.599	0.579	Argentina	0.502	0.449	0.442
Belgium	0.625	0.580	0.566	Brazil	0.509	0.398	0.419
Canada	0.577	0.481	0.490	*Colombia*	*0.329*	*0.351*	*0.298*
Denmark	0.667	0.650	0.644	Ecuador	0.428	0.406	0.384
France	0.679	0.606	0.607	Malaysia	0.456	0.455	0.398
Germany	0.676	0.594	0.601	Mexico	0.571	0.478	0.478
Italy	0.674	0.580	0.570	*Morocco*	*0.477*	*0.372*	*0.413*
New Zealand	0.748	0.779	0.762	*Peru*	*0.424*	*0.364*	*0.373*
Poland	0.596	0.563	0.583	Romania	0.556	0.448	0.471
Spain	0.548	0.502	0.486	Russia	0.572	0.445	0.462
The Netherlands	0.617	0.538	0.544	South Africa	0.564	0.430	0.469
UK	0.709	0.651	0.632	Thailand	0.542	0.479	0.474
USA	0.590	0.466	0.472	Turkey	0.577	0.432	0.452
Average	0.644	0.584	0.580	Average	0.501	0.424	0.426

The annual average was the mean of calculated ETHI during 2002–2020. *Source*: The authors' calculation is based on the UN COMTRADE and WDI database top ten APs exporters (except Brazil), the overall technology structure of China's APs export is significantly lower.

Regarding the overall technical level of China's APs export basket, although there is a slight fluctuation near the medium technical complexity grade, it shows a small decline. We conclude that the evolutionary trend of the technology structure of China's APs export differed from that of its export scale during 2002–2020, i.e. the exporting APs in China were losing competitiveness overall. Compared with other countries, the technology structure of China's APs export tended towards a more downmarket trade pattern from 2002 to 2012 but has gradually improved since 2013. We have also found that upgrading the technology structure of China's APs export falls behind all the sample countries in the developed region but is faster than some sample countries (Brazil, Colombia, Ecuador, Malaysia, Morocco, and Peru) in the developing region.

Therefore, in China, where the APs export is experiencing the transition to medium–high and high technology fields, we suggest that the government should further raise standards for APs quality, concentrate on the export of higher technical complexity products and promote the advances and innovations in agricultural science and technology, to improve the international competitiveness of APs export. Although advantages in land-intensive and labour-intensive products in China's agriculture still exist, the limited natural resources determine the critical role of value increment in the APs processing towards China's APs export. In this respect, long-term policies to promote the domestic APs manufacturers to strengthen investment in talent and technology research would be advisable; for instance, intensifying cooperation in agriculture with developed countries such as New Zealand, Denmark, UK, France, Germany, Australia, Poland, Italy, Belgium, and the Netherlands would help transform China's endangered resource-based competitive advantage into long-term economic saliency. In addition, we suggest that the government adapts to local conditions and further explores the trade potential hidden behind the differences in APs' export technology structure.

However, one should also be aware of the diversity in the scope and classification of APs and the limitations of the export technical complexity index. Currently, the scope of APs mainly includes three standards of WTO, European Union and their extended versions (Wang et al., 2022). These are all defined based on the HS system or Standard International Trade Classification (SITC), which greatly impacts the research conclusion. Researchers must pay close attention to the research objectives and the industry classification of different countries. Moreover, the technical complexity index has been criticized for not considering the processing trade factor, the change in export structure and the implementation of the technology export restriction policy (Cao & Hanson-Rasmussen, 2018). Therefore, future research might explore this method's improvements and application studies, analyse the country/ district with various technical complexity indices or compare the results among different countries/ districts.

Appendix A

See Tables 5, 6 and 7

Table 5 The world's 178 exporters of APs during 2002–2020 (Unit: $100 million)

Country or region	The annual average of export value	Country or region	The annual average of export value	Country or region	The annual average of export value
USA	1215.54	Denmark	189.14	Portugal	62.74
Netherlands	807.63	New Zealand	185.27	United Arab Emirates	61.87
Germany	724.17	Ukraine	157.92	Colombia	60.47
China	653.01	Turkey	151.74	Greece	60.13
France	637.43	Chile	133.03	Japan	58.60
Brazil	614.85	Russia	130.21	Egypt	52.39
Spain	425.19	Ireland	120.32	Philippines	51.12
Italy	421.47	Austria	108.83	Côte d'Ivoire	51.09
Canada	398.88	China Hong Kong	107.87	Iran	46.54
Belgium	334.86	Norway	90.32	Romania	45.84
Indonesia	332.98	Singapore	79.96	Lithuania	40.97
India	313.36	Hungary	77.38	Uruguay	40.53
Argentina	312.41	Sweden	76.34	Paraguay	40.34
Australia	280.81	South Africa	76.23	Morocco	40.18
UK	274.69	Pakistan	76.14	Guatemala	38.02
Thailand	260.12	Switzerland	73.94	Costa Rica	36.32
Mexico	218.79	Ecuador	70.04	Myanmar	35.89
Poland	203.04	Czechia	66.91	Bulgaria	35.17
Viet Nam	190.66	Rep. of Korea	65.14	Belarus	33.98
Malaysia	189.82	Peru	63.67	Slovakia	28.20

Data source Authors' calculation based on the UN COMTRADE database

Table 6 The world's 178 exporters of APs during 2002–2020 (Unit: $100 million)

Country or region	The annual average of export value	Country or region	The annual average of export value	Country or region	The annual average of export value
Saudi Arabia	27.18	Bolivia	11.68	Azerbaijan	6.63
Serbia	26.96	Luxembourg	11.38	Madagascar	6.11
Ghana	26.21	Namibia	11.32	Zambia	5.88
Kenya	25.24	Slovenia	11.14	Georgia	5.67
Uzbekistan	24.56	Uganda	10.96	Burkina Faso	5.58
Kazakhstan	23.69	Jordan	10.57	Eswatini	5.49
Nigeria	22.06	Fmr Sudan	10.44	North Macedonia	5.32
Sri Lanka	21.93	Zimbabwe	10.36	Lebanon	5.22
Iceland	20.63	Oman	10.14	Mozambique	5.13
Dominican Rep	20.18	El Salvador	9.99	Mali	4.46
Israel	20.11	Cameroon	8.88	Afghanistan	4.20
Honduras	18.66	Bangladesh	8.56	Benin	4.18
Latvia	17.94	Panama	8.48	Guyana	4.05
Finland	16.83	Rep. of Moldova	8.47	Bahrain	3.96
Nicaragua	15.92	Papua New Guinea	7.98	Fiji	3.94
Croatia	15.64	Senegal	7.87	Cyprus	3.86
Tunisia	14.95	Malawi	7.87	Jamaica	3.78
Tanzania	14.26	Mauritius	7.60	Kuwait ara>	3.73
Estonia	13.35	Lao People's Dem. Rep	7.56	Trinidad and Tobago	3.71
Ethiopia	12.50	Mauritania	7.05	Bosnia Herzegovina	3.61

Data source Authors' calculation based on the UN COMTRADE database

Table 7 The world's 178 exporters of APs during 2002–2020 (unit: $100 million)

Country or region	The annual average of export value	Country or region	The annual average of export value
Armenia	3.42	Montenegro	0.64
Seychelles	3.07	Guinea	0.62
Cambodia	3.06	Cabo Verde	0.54
Mongolia	2.92	Gabon	0.44
Niger	2.77	Qatar	0.44
Malta	2.39	Saint Lucia	0.40
Nepal	2.29	Vanuatu	0.35
Togo	2.21	Saint Vincent and the Grenadines	0.32
Kyrgyzstan	2.19	Grenada	0.24
Rwanda	2.08	Congo	0.24
Algeria	2.07	Libya	0.23
State of Palestine	2.04	FS Micronesia	0.20
Tajikistan	2.03	Samoa	0.20
Belize	1.93	Gambia	0.18
Albania	1.36	Comoros	0.17
Botswana	1.35	Timor-Leste	0.12
Sierra Leone	1.33	Iraq	0.12
Maldives	1.28	Dominica	0.12
Suriname	1.17	Tonga	0.10
Lesotho	1.07	Brunei Darussalam	0.10
Barbados	0.97	Sao Tome and Principe	0.08
China Macao	0.97	Kiribati	0.07
Dem. Rep. of the Congo	0.96	Saint Kitts and Nevis	0.04
Bahamas	0.95	Central African Rep	0.04
Aruba	0.83	Palau	0.04
Angola	0.77	Bermuda	0.04
Solomon Islands	0.75	Antigua and Barbuda	0.03
Burundi	0.74	Turks and Caicos Islands	0.02
Bhutan	0.68	Cayman Islands	0.00

Data source Authors' calculation based on the UN COMTRADE database

Appendix B

See Tables 8, 9 and 10.

Table 8 Annual GDP[1] per capita of 178 exporters[2] based on PPP[3] during 2002–2020 (unit: $)

Country (or region)	The annual average of GDP per capita	Country (or region)	The annual average of GDP per capita	Country (or region)	The annual average of GDP per capita
Luxembourg	112,796	Belgium	48,110	Slovenia	33,622
China Macao	107,637	Bahrain	46,634	Portugal	31,646
Qatar	93,035	Finland	45,909	Greece	31,578
Singapore	79,733	Saudi Arabia	45,390	Estonia	29,145
Bermuda	79,614	Australia	45,338	Trinidad and Tobago	27,307
United Arab Emirates	70,276	Canada	45,136	Lithuania	27,086
Cayman Isds	67,871	UK	43,596	Hungary	26,232
Brunei Darussalam	66,003	France	42,772	Slovakia	25,416
Switzerland	65,788	Italy	42,461	Croatia	25,036
Ireland	62,897	New Zealand	39,185	Poland	24,705
Norway	62,273	Japan	39,122	Seychelles	24,572
Kuwait	59,188	Spain	37,754	Latvia	24,179
USA	56,279	Bahamas	37,747	Saint Kitts and Nevis	24,037
Denmark	52,571	Aruba	37,624	Russia	23,720
Netherlands	52,246	Cyprus	37,339	Panama	23,691
Austria	52,014	Oman	36,050	Turks and Caicos Isds	23,553
China Hong Kong	51,319	Rep. of Korea	34,826	Turkey	22,243
Iceland	50,398	Malta	34,696	Kazakhstan	21,933
Germany	48,521	Israel	34,634	Malaysia	21,926
Sweden	48,250	Czechia	34,041	Romania	21,746

[1]The data are from the WDI database; [2]Missing values are imputed using the compound annual growth rate of the dataset during the years with data; [3]The PPP uses the "Constant 2017 international $" standard

Table 9 Annual GDP[1] per capita of 178 exporters[2] based on PPP[3] during 2002–2020 (unit: $)

Country (or region)	The annual average of GDP per capita	Country (or region)	The annual average of GDP per capita	Country (or region)	The annual average of GDP per capita
Argentina	21,737	Thailand	14,717	Ecuador	10,568
Chile	21,708	Saint Lucia	14,636	Jordan	10,481
Antigua and Barbuda	19,496	Dominican Rep	14,357	Tunisia	10,290
Uruguay	18,998	Brazil	14,095	Peru	10,153
Suriname	18,987	North Macedonia	13,573	Indonesia	10,141
Mexico	18,433	South Africa	13,315	Armenia	10,125
Bulgaria	18,220	Iran	13,001	China	9,811
Libya	18,151	Azerbaijan	12,778	Iraq	9,758
Montenegro	17,890	Ukraine	12,392	Jamaica	9,654
Palau	17,754	Colombia	12,209	Rep. of Moldova	9,602
Costa Rica	17,492	Saint Vincent and the Grenadines	11,921	Sri Lanka	9,575
Mauritius	17,351	Bosnia Herzegovina	11,636	Namibia	9,354
Maldives	16,644	Dominica	11,622	Mongolia	8,953
Belarus	16,060	Fiji	11,510	Eswatini	8,028
Lebanon	15,961	Georgia	11,304	El Salvador	7,626
Barbados	15,601	Guyana	11,014	Angola	7,608
Serbia	15,546	Algeria	10,860	Guatemala	7,567
Botswana	15,050	Albania	10,767	Bhutan	7,296
Gabon	15,012	Egypt	10,680	Belize	7,229
Grenada	14,815	Paraguay	10,641	Uzbekistan	7,151

[1]The data are from the WDI database; [2]missing values are imputed using the compound annual growth rate of the dataset during the years with data; [3]the PPP uses the "Constant 2017 international $" standard

Table 10 Annual GDP[1] per capita of 178 exporters[2] based on PPP[3] during 2002–2020 (Unit: $)

Country (or region)	The annual average of GDP per capita	Country (or region)	The annual average of GDP per capita
Bolivia	6981	Vanuatu	3084
Philippines	6940	Papua New Guinea	3017
Lao People's Dem. Rep	6502	Zambia	2991
Cabo Verde	6400	Comoros	2962
Morocco	6317	Senegal	2912
Samoa	6156	Benin	2900
State of Palestine	5791	Timor-Leste	2723
Viet Nam	5752	Bangladesh	2700
Tonga	5496	Lesotho	2595
Honduras	5022	Solomon Isds	2366
Nigeria	4982	Tanzania	2196
Mauritania	4970	Gambia	2111
Nicaragua	4943	Kiribati	2092
Congo	4685	Mali	2089
Fmr Sudan	4673	Afghanistan	1973
India	4668	Guinea	1969
Kyrgyzstan	4345	Uganda	1851
Ghana	4242	Burkina Faso	1819
Pakistan	4088	Togo	1801
Côte d'Ivoire	4000	Sierra Leone	1688
Myanmar	3791	Rwanda	1684
Sao Tome and Principe	3784	Madagascar	1558
Kenya	3752	Ethiopia	1495
FS Micronesia	3586	Malawi	1342
Tajikistan	3404	Dem. Rep. of the Congo	1074
Cameroon	3370	Niger	1065
Zimbabwe	3256	Mozambique	1056
Cambodia	3129	Central African Rep	1028
Nepal	3114	Burundi	817

[1]The data are from the WDI database

[2]missing values are imputed using the compound annual growth rate of the dataset during the years with data

[3]the PPP uses the "Constant 2017 international $" standard

Appendix C

See Tables 11 and 12.

Table 11 Technical complexity (PRODY) for various kinds of APs during 2002–2020 (unit: $)

Year	HS09	HS14	HS52	HS18	HS17	HS12	HS08	HS07	HS15	HS13	HS06	HS10	HS16	HS23
2002	9050	15,464	29,757	20,901	17,650	21,231	19,050	19,260	18,705	31,774	18,105	23,384	21,476	20,248
2003	9777	13,099	24,141	18,420	17,416	16,451	18,534	18,040	17,313	27,484	17,700	22,986	19,956	19,426
2004	7806	7492	21,850	17,740	17,737	15,366	17,433	19,593	17,349	27,448	17,885	20,875	19,952	20,667
2005	7407	7000	19,742	15,656	17,368	14,658	17,181	17,040	17,759	27,677	16,883	20,202	21,160	21,462
2006	7345	6140	18,404	16,882	18,877	16,372	17,051	18,235	18,869	9,772	14,897	21,463	21,910	22,040
2007	7920	12,284	19,558	15,559	15,671	13,950	17,826	17,462	16,742	16,322	16,495	21,713	22,000	22,266
2008	8238	12,734	17,653	14,673	15,271	15,533	16,241	17,137	18,490	15,650	15,641	22,708	21,556	22,640
2009	7978	8811	16,639	13,959	14,676	14,252	15,897	15,910	17,512	15,147	15,054	19,920	20,131	21,374
2010	8629	6995	15,846	14,920	14,660	15,115	15,981	15,404	15,885	13,141	19,518	18,558	20,781	21,016
2011	8913	7461	12,107	13,974	14,680	14,909	16,262	15,304	16,310	11,130	22,379	19,242	20,772	21,412
2012	8941	14,346	10,869	14,363	15,126	16,296	15,548	15,715	15,562	13,936	22,361	18,673	20,082	20,671
2013	9043	8205	11,742	14,730	14,636	14,887	15,047	16,336	17,247	15,971	19,647	18,845	21,460	22,127
2014	10,588	9794	11,130	13,765	15,141	15,748	15,453	16,231	17,568	19,287	23,475	18,908	21,195	21,606
2015	10,444	11,299	13,788	12,532	16,408	15,651	16,821	15,644	15,808	14,717	21,398	18,152	22,834	21,512
2016	10,136	10,347	9,789	14,383	16,522	16,195	16,905	17,111	17,087	14,145	21,840	19,106	21,635	21,546
2017	10,054	10,147	10,059	14,270	15,485	16,846	16,793	17,393	17,597	13,678	21,801	19,662	22,493	21,426
2018	10,967	9,386	8,739	14,361	14,724	17,765	17,655	17,244	18,249	15,953	21,947	20,390	21,865	21,707
2019	11,318	11,908	9,938	16,358	15,458	18,551	17,604	16,528	19,198	16,253	20,657	21,194	23,671	23,119
2020	16,897	14,524	9,804	19,642	15,291	18,061	18,190	16,379	21,231	21,550	20,369	21,226	23,282	22,208
Average	9,550	10,391	15,345	15,636	15,937	16,202	16,920	16,945	17,604	17,949	19,371	20,379	21,485	21,499
Change	7848	−941	−19,953	−1,259	−2,359	−3,170	−860	−2,881	2,526	−10,224	2,264	−2,159	1,806	1,960
Increase/%	87	−6	−67	−6	−13	−15	−5	−15	14	−32	13	−9	8	10
Year	HS03	HS51	HS24	HS11	HS05	HS20	HS01	HS22	HS02	HS21	HS19	HS04	Average	
2002	19,961	25,138	30,056	24,553	17,492	26,020	19,912	31,128	29,376	30,516	32,753	34,879	23,378	
2003	20,007	23,925	24,672	24,467	18,388	26,055	21,301	28,595	29,275	30,649	30,804	33,687	22,022	
2004	21,241	22,967	23,954	23,300	17,966	25,408	18,961	26,617	29,076	31,358	31,333	34,477	21,379	

Table 11 (continued)

Year	HS03	HS51	HS24	HS11	HS05	HS20	HS01	HS22	HS02	HS21	HS19	HS04	Average
2005	20,128	22,384	24,164	22,902	20,783	24,342	31,904	24,776	30,826	31,872	32,157	34,013	21,594
2006	24,608	21,171	22,500	24,737	24,011	27,513	29,478	26,833	32,193	33,557	34,283	37,302	21,786
2007	22,926	22,478	24,114	22,847	25,812	27,400	33,332	26,786	31,062	32,119	34,879	37,350	22,188
2008	23,981	27,387	23,119	26,950	23,336	28,163	26,474	26,311	33,600	30,997	34,320	37,405	22,162
2009	20,123	28,145	23,785	20,878	27,603	25,923	30,093	25,045	27,357	30,250	31,964	36,296	20,951
2010	19,931	27,105	18,800	20,066	24,402	25,928	29,723	29,300	29,079	30,830	32,848	36,403	20,802
2011	20,633	26,317	31,096	30,778	23,442	24,447	19,941	27,333	29,241	32,695	31,475	36,547	21,108
2012	20,916	23,584	29,664	20,317	21,374	24,077	36,219	29,913	30,298	31,437	33,767	35,517	21,522
2013	20,650	18,374	29,588	35,924	21,499	27,503	22,694	27,399	32,362	33,936	34,545	37,735	21,621
2014	21,115	17,895	29,142	30,229	27,958	25,275	24,220	29,478	28,111	36,195	35,786	38,616	22,073
2015	23,609	17,569	20,479	21,156	20,136	24,806	43,362	30,384	30,208	32,366	38,065	38,360	21,827
2016	22,740	16,694	21,422	22,812	17,836	25,743	32,411	34,047	30,876	32,826	32,812	37,392	21,321
2017	24,108	17,225	26,664	23,083	29,107	26,822	31,570	33,267	31,174	31,700	33,635	38,596	22,102
2018	24,196	19,113	25,971	19,771	37,389	26,629	32,128	31,430	32,049	36,541	43,292	40,681	23,082
2019	27,216	18,017	25,458	20,204	39,552	27,719	34,628	34,142	33,163	37,903	40,611	42,067	23,940
2020	26,083	14,941	21,953	20,607	35,797	26,720	33,000	32,119	33,280	34,608	35,078	39,959	23,569
Average	22,325	21,602	25,084	23,978	24,941	26,131	29,018	29,205	30,663	32,756	34,442	37,225	
Change	6,122	−10,197	−8,102	−3,946	18,305	699	13,089	991	3,904	4,093	2,325	5,079	191
Increase/%	31	−41	−27	−16	105	3	66	3	13	13	7	15	5

The results were obtained from the sample of 178 countries. *Source* Authors' calculation based on the UN COMTRADE and WDI database

Table 12 Technical complexity (*PRODY*) for various kinds of APs during 2002–2020 (unit: $)

Year	HS09	HS14	HS52	HS18	HS17	HS12	HS08	HS07	HS15	HS13	HS06	HS10	HS16
2002	21,176	25,443	30,968	36,628	24,981	26,739	21,844	25,172	25,478	39,177	19,780	25,634	25,447
2003	21,317	19,965	24,786	23,398	28,303	25,772	21,896	23,744	22,368	32,998	20,239	25,802	25,677
2004	19,893	25,049	25,695	24,588	30,412	28,411	21,255	32,153	27,103	34,814	21,814	25,802	26,509
2005	20,998	26,439	26,716	25,500	33,831	29,920	22,404	25,682	28,007	33,943	21,197	24,586	26,714
2006	20,777	26,378	26,747	26,821	31,959	29,957	23,501	27,046	29,427	34,203	22,046	26,578	26,310
2007	22,255	27,664	26,798	27,615	32,610	31,160	24,657	28,208	27,560	33,476	22,988	27,558	26,577
2008	23,146	25,983	25,863	26,094	30,209	29,360	23,407	26,629	26,764	29,609	22,795	26,222	25,836
2009	20,634	9852	24,154	24,523	28,219	28,186	22,292	21,766	25,101	25,957	22,904	23,619	25,893
2010	20,350	7672	23,770	24,788	27,841	28,537	21,779	22,142	22,003	23,418	21,789	24,823	27,341
2011	21,948	8881	24,580	24,889	26,132	28,246	22,399	23,583	22,958	20,650	23,626	26,259	27,814
2012	21,887	11,452	23,767	26,326	27,039	30,399	23,571	23,906	22,961	17,591	22,943	25,416	26,972
2013	24,583	12,025	23,874	26,285	27,392	29,661	22,630	24,695	23,826	22,228	22,812	25,454	26,679
2014	24,944	12,152	23,169	26,783	27,661	29,424	22,530	24,489	23,750	23,582	22,953	25,875	28,202
2015	24,044	12,015	22,553	27,174	29,400	29,739	23,243	25,860	24,059	25,196	23,227	26,584	30,316
2016	23,488	11,841	22,120	27,758	29,272	30,310	23,440	26,900	24,553	28,277	23,536	26,643	30,881
2017	25,113	10,841	22,501	28,626	30,612	30,614	23,341	27,925	25,057	31,787	24,230	26,801	31,449
2018	25,714	10,673	22,129	28,905	29,426	29,767	23,392	27,055	25,105	32,361	24,305	26,457	32,110
2019	29,259	13,447	22,125	28,978	29,568	30,808	24,689	29,501	23,161	32,936	24,807	25,985	32,741
2020	31,762	21,372	20,722	41,556	29,502	31,114	23,911	28,445	25,386	32,449	24,169	25,168	30,834
Year	HS23	HS03	HS51	HS24	HS11	HS05	HS20	HS01	HS22	HS02	HS21	HS19	HS04
2002	23,187	33,642	30,462	35,757	30,634	28,148	26,572	27,180	34,464	35,396	36,885	37,077	37,974
2003	22,758	33,447	30,072	43,952	34,543	27,386	27,074	27,451	35,739	35,580	38,017	36,599	38,636
2004	24,059	32,247	30,861	41,071	35,467	28,152	28,197	27,867	36,800	36,513	38,824	38,558	39,392
2005	24,975	33,362	32,200	42,181	32,917	29,470	29,185	28,846	37,900	37,203	39,621	39,340	40,057
2006	26,897	34,268	32,675	40,356	33,623	29,997	30,011	31,999	39,829	38,475	40,059	40,382	41,391
2007	27,882	34,594	33,821	38,056	32,794	33,068	29,522	34,415	41,452	38,884	40,180	41,536	41,999

Table 12 (continued)

Year	HS23	HS03	HS51	HS24	HS11	HS05	HS20	HS01	HS22	HS02	HS21	HS19	HS04
2008	27,270	35,166	34,638	36,908	33,706	32,012	29,510	36,708	40,958	38,431	38,920	40,333	39,252
2009	25,447	33,681	33,022	33,727	29,473	32,266	26,442	35,216	39,347	37,000	36,634	38,432	38,366
2010	26,708	34,215	33,976	34,413	29,175	32,451	27,414	35,631	39,589	38,405	37,432	38,666	38,298
2011	27,726	34,696	34,860	35,438	27,481	32,243	25,966	35,721	41,990	38,641	38,192	38,839	38,942
2012	27,810	35,469	34,936	38,483	28,497	33,875	25,790	33,568	42,541	38,300	37,816	40,545	39,890
2013	28,686	35,332	34,704	35,733	29,096	32,681	25,204	35,140	42,289	38,198	38,817	39,218	39,361
2014	29,365	35,283	35,175	36,144	29,856	33,373	26,396	39,111	42,827	39,090	40,640	40,683	40,183
2015	30,475	36,427	35,890	37,305	29,107	34,693	26,099	37,689	44,249	40,423	41,446	42,534	41,659
2016	30,338	36,455	35,760	40,076	30,837	34,736	26,875	38,170	45,109	41,260	42,166	42,914	42,268
2017	30,611	36,890	36,180	40,325	32,065	35,457	27,666	41,406	45,958	42,696	43,747	44,357	44,193
2018	30,914	37,438	37,069	44,188	31,872	36,429	28,421	42,144	45,960	43,863	48,342	44,357	45,506
2019	32,863	37,540	37,807	44,393	32,082	37,514	30,749	44,449	47,021	43,805	49,185	45,560	48,213
2020	33,101	36,751	36,625	40,490	31,883	37,296	29,948	41,495	43,852	42,206	48,106	43,971	46,769

The results were obtained from the sample of top 50 countries. *Source* Authors' calculation based on the UN COMTRADE and WDI database

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Data availability statement Publicly available datasets were analysed in this study. This data can be found here: [https://comtrade.un.org; https://data.worldbank.org.cn].

Declarations

Competing interests The authors report there are no competing interests to declare.

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