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Technological innovation and the complexity of imported technology: Moderating effects based on environmental regulation

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The complexity of imported technology is an essential expression of structural optimization of import trade. Achieving high-quality import opening through import technology complexity under stricter environmental regulations and the increasing urgency of technological innovation has essential theoretical and practical significance. Given this, based on multiple database matching, this paper studies the effect of technological innovation on the complexity of imported technology and the mechanism of environmental regulation on this effect from the dimension of provincial-import source-manufacturing products (HS6). The results show that technological innovation has a positive impact on the complexity of imported technology, and environmental regulation can strengthen the positive impact of technological innovation. The moderating effect of environmental regulation is significant and differentiated at the regional and industry levels. The strengthening effects are more critical in eastern China and high pollution industries. These conclusions provide a theoretical and empirical basis for encouraging technological innovation and introducing differentiated environmental policies.

KEYWORDS

technological innovation, environmental regulation, complexity of imported technology, manufacturing industry, moderating effects

1 Introduction

In the face of the world's unprecedented changes in a century, General Secretary Xi Jinping has stressed on many occasions that "China's door of opening-up will not be closed, but will only open even wider," he also said, "We will continue to promote reform, development, and innovation through opening-up, and continue to open up to a higher level." Actively expanding imports is an inevitable choice for China to unleash the vitality of domestic demand and accelerate the building of a "dual cycle" pattern. It is also a strategic choice for China to achieve high-quality development and contribute to building a trading power. China's import trade volume was 809.98 billion dollars in 2007 and reached 1659.78 billion dollars in 2021, with China's import trade scale achieving continuous rapid growth. At the same time, "the Implementation Opinions on Promoting Innovative Development of Foreign Trade" emphasizes the urgency of optimizing China's foreign trade structure under the demand for high-quality development. Driven by the self-selection effect and import-promoting competition effect, it will be essential to improve the technological level of imported trade products (especially manufacturing industry) through adjustment of access threshold and scientific and technological innovation (Wei et al., 2020). This means that the increasingly strict environmental regulation policies under the "dual carbon target,"[1]and the urgent need for technological innovation to cope with the "technology lock-in"[2] and "technology decoupling"[3] of European and American countries will have a significant impact on the development trend of China's imported technology complexity.

Product technical complexity is the expression form of technical product structure. It is the mainstream approach to describing product and trade systems and high-quality degrees in existing theoretical and empirical research. Unlike the mature research on export technology complexity, the research on import technology complexity is still in its infancy. Based on the firm level, some scholars have studied the impact of trade policy uncertainty (Shepotylo and Stuckatz, 2017; Imbruno, 2019), intellectual property protection (Foster, 2014), and internet development (Yadav, 2014) on the structure of imported products but have not focused on the complexity of imported technology. At the industry level, the rapid development of productive services has pushed research on the technical complexity of imports of productive services to heights (Amiti and Khandelwal, 2013; Antoniades, 2015; Yang and Zhao, 2022). However, these studies ignore the effect of technological innovation on the complexity of imported technology, and do not pay attention to the impact of environmental regulation on the above mechanism. In particular, the "Porter effect" and "pollution haven effect" on technological innovation have clarified the impact of environmental regulation on technological innovation. While the "Porter effect" caused by compliance with environmental regulations can improve the competitiveness of domestic products through compensation for technological innovation, thus optimizing the structure of import trade and increasing the complexity of imported technology (Horváthová, 2012; Xie et al., 2017), as trade liberalization progresses, scholars have found that The "pollution haven effect" caused by stronger environmental regulations does not lead to technological innovation nor does it increase the complexity of imported technology (Solarin et al., 2017). Given this, it is of theoretical significance and practical value to explore the impact mechanism of technological innovation on the complexity of imported technology from the perspective of environmental regulation.

The marginal contribution of this paper is mainly manifested in three aspects: The first is the theoretical mechanism has been improved. Based on environmental regulation, we will expand and supplement the influence mechanism of technological innovation on the complexity of imported technology; The second is the extension of the research perspective will be a useful supplement to the existing research. The existing related studies mainly focus on the complexity of exported technology, and a small amount of attention is paid to the complexity of imported technology at the level of enterprises or industries. Based on the provincial level, We will improve the impact mechanism of the complexity of imported technology, and conduct theoretical and empirical research on the heterogeneity of different dimensions. The third is more detailed data. We will match the CEPII-BACI database, China Customs database, and China Environmental Statistics Yearbook. We also construct a total of 66,170 observations[4]from 29 provinces and 39 import source countries (regions)[5], and 26 manufacturing industries in China from 2007 to 2019. It is beneficial for this paper to discuss more

1 "The "double carbon" target is a formal commitment made by General Secretary Xi Jinping in 2020 to "strive to achieve carbon peak by 2030 and carbon neutrality by 2060". The carbon peak means that China is committed to stopping the growth of CO_2 emissions by 2030 and gradually reducing them after reaching the peak. The carbon neutrality means that Chinese enterprises, groups or individuals will measure the total amount of greenhouse gas emissions they produce directly or indirectly within a certain period, and then offset their CO_2 emissions through planting trees and forestation, energy saving, and emission reduction, to achieve "zero" CO_2 emissions.

2 The term "technology lock-in" was first introduced by David Paul A (1985) and Arthur W Brian (1989). Arthur argues that technology lock-in is an equilibrium in an economic system that lasts for a long time if external incentives are not strong enough and that breaking this equilibrium is costly. if the actor cannot afford this cost, the technology used will continue to develop in the same way as before, i.e., technological dependence over time leads to technology lock-in.

3 "Technology decoupling" refers to the use of core technology sanctions by the United States to curb the development of other countries to accelerate the decoupling of high technology. One of the Chinese companies, Huawei, has been severely affected by this, with the US imposing blanket restrictions on Huawei's purchase of semiconductors produced using US software and technology, including those production facilities that are outside the US but are on the US Commerce Control List and require a license from the US government before they can be manufactured on behalf of Huawei.

4 The 66,170 observations in the paper are unbalanced panel data with full-time and province dimensions but with differences in import sources and manufacturing industries, retained after data processing. In contrast, the overall sample size is a balanced panel of 382,278 valid data and some missing values for 13 years, 26 industries, 39 countries (regions), and 29 provinces.

5 The main source of imports we choose includes Hong Kong, China. Hong Kong, China is an administrative unit below the state level, so it is expressed as a region rather than an intercontinental region.

practical problems around robustness, heterogeneity, endogeneity, and further test.

The remainder of this paper is arranged as follows: the first part sorts out the influencing factors of technical complexity and the two kinds of literature on environmental regulation and technological innovation. On this basis, the second part proposes some hypotheses about the effect of technological innovation on the complexity of imported technology, the impact of environmental regulation on the above effect, and the heterogeneity of different regions. The third part is the empirical model, index selection, and data explanation. The fourth part presents the empirical analysis of benchmark tests, robustness tests, endogeneity tests, and heterogeneity tests. Further, relevant conclusions and policy recommendations are presented.

2 Literature review

The research results related to this paper fall into two main categories: firstly, studies on technological complexity, including the complexity of exported technology and the complexity of imported technology, and studies related to the complexity of exported technology at the enterprise and industry levels; secondly, studies related to environmental regulation and technological innovation and import trade.

2.1 Research on technology complexity

High-quality and sustainable economic development should not only focus on the expansion of trade scale but also the optimization of trade structures (Kuznets and Yi, 1989). Whether it is export or import trade, the optimization of trade structure, on the one hand, means the improvement of the technical complexity of products. However, product technical complexity is derived from economic complexity, and Hidalgo and Horvathova. (2009) propose the Economic Complexity Indicator (ECI), which separates economic complexity from country income information and is constructed entirely from export information. Specifically, the ECI constructs 2 interactive indicators at the product and country levels - product universality and country diversity. Product universality is the number of countries that can produce or export the product; if the product has low universality, its technical complexity is high; country diversity is the number of types of products that countries can produce or export; countries with more capabilities will be able to produce products that require more specialized knowledge and have higher national economic complexity. The approach combines these two dimensions and considers countries that can produce more products with low universality to be countries with high economic complexity, and products that can only be produced by countries with high economic complexity to be products with high technical complexity.

The existing literature on technology complexity mainly focuses on the influencing factors of export technology complexity. However, worldwide exports and imports have a correspondence, and an increase in the complexity of exported technology from exporting countries implies an increase in the complexity of imported technology from importing countries. The research perspective mainly includes the effects of trade liberalization (Amiti and Freund, 2016), human capital (Wang et al., 2010), digital economy (Acemoglu and Restrepo, 2020; Du and Guan, 2021), technological innovation (Humphrey and Schmitz, 2000), etc. This effect is mainly reflected in an increase in the technical content of export products and the improvement of the productivity of export enterprises (Kaufmann et al., 2003; Saadi, 2020). However, there is still a lack of systematic research on the complexity of imported technology in the context of trade liberalization. Based on Hausmann et al.'s (2007) method of measuring the complexity of exported technology and China's import data from 1996 to 2006, Marvasi (2012) measured the complexity of imported technology of Chinese products. The results showed that the complexity of imported technology of Chinese products is higher than that of exports and that imports are pretty "complex. " The increase in national income is one of the main reasons for the rise in the complexity of imported technology. The increase in national income implies an increase in consumer spending power, and consumers are willing to buy more technical products. To meet consumer demand, product imports will tend to be medium to high technology, and thus the complexity of imported technology will increase (Zhang and Yin, 2019). Based on this, scholars began to focus on the analysis of the technological structure of China's imported products, including the transformation of the type of imported products' technical structure from resource and low technology to medium and high technology (Wong et al., 2013; Wei et al., 2020). With the continuous enrichment of micro-data, some scholars extend the research perspective to the level of enterprises and industries. Yue et al. (2016) and Liu et al. (2020) studied the impact of Internet development and trade policy uncertainty on firms' import technology complexity at the firm level, respectively, the research on the technological complexity of producer services imports is widespread (Amiti and Khandelwal, 2013; Antoniades, 2015; Yang and Zhao, 2022). Although the research perspective has been expanded from the product level to the enterprise and industry level, such research lacks expansion at the provincial level. It does not link technological innovation with the complexity of imported technology.

2.2 The relationship between environmental regulation, technological innovation, and import trade

Environmental regulation mainly refers to a series of laws and regulations promulgated by the government to protect the environment, which in turn restrains the emission behavior of economic agents and makes enterprises discharge to meet the requirements of environmental protection. Existing literature on environmental regulation has been relatively mature. Its research perspective mainly focuses on industrial structure upgrading (Acemoglu et al., 2012), Green technology innovation of enterprises (Steinhorst and Matthies, 2016), Green total factor productivity (Albrizio et al., 2017), et al. The research on environmental regulation, technological innovation, and import trade are mainly based on the "Porter effect" and the "Pollution haven effect" caused by environmental regulation.

In studying the relationship between environmental regulation and technological innovation and import trade, ecological factors are often considered as factors of production, and their impact on the comparative advantage of countries is studied, and a correlation is found between the strength of environmental regulation and import trade (Mihov and Sibert, 2006). The "Porter effect" caused by environmental regulation compliance will have a positive impact on the scale of import trade (Ederington and Minier, 2003), and this positive effect is mainly through the innovation compensation effect. Lovely and Popp (2011) find that large countries respond to the cost effects of environmental regulation through green technological innovation, allowing consumers in other countries to bear the costs of environmental regulation in large countries through import and export trade, based on the innovation compensation effect. Dussaux et al. (2017) argue that compliance with environmental regulations will bring innovation compensation effects to firms, which can stimulate them to engage in technological innovation and improve their competitiveness through green technological innovation, which in turn has an impact on the structure of import trade. In the context of Chinese data, Du et al. (2019) investigate the relationship between environmental regulation, technological transformation, and firm productivity to verify the existence of the "Porter effect," which states that environmental regulation has a cost effect as well as a compensatory effect on innovation. However, as trade liberalization continues, some scholars argue that the "Pollution haven effect" caused by strict environmental regulations can hurt import trade (Cole and Elliott, 2003). This negative effect is mainly based on the cost effect. In order to meet the environmental standards set by the government, enterprises will use clean production methods, which requires a large amount of capital investment, easily squeezing the production costs of enterprises, discouraging the production enthusiasm of enterprises, and negatively affecting import trade (Busse, 2004). At the same time, the environmental costs incurred by environmental regulations can crowd out firms' profit funds while increasing their pollution control costs, which in turn can hurts their import trade (Hu, 2019). Due to the heterogeneity of economic development, environmental systems, and industrial structures between different countries (regions), the "Porter effect" and "Pollution haven effect" cannot explain the relationship between environmental regulations, technological innovation and import trade in all regions and industries.

The research on environmental regulation has been relatively mature, but there are few studies on the combination of environmental regulation and import technology complexity, and the research has not been extended to the provincial level. Based on this, this paper builds on previous work by linking "technological innovation - environmental regulation - import technology complexity" to further broaden the perspective of this area of research.

3 Theoretical hypothesis

Hausmann et al. (2007) proposed a prody indicator to measure the technological structure of a country's export products. They constructed a complexity of exported technology using the apparent comparative advantage of each country's export products as the weight, while many studies at home and abroad have built a complexity of imported technology based on the calculation method of the complexity of exported technology due to the correspondence between exports and imports in the world, and This index is used to measure the technological content of imported products. However, the method proposed by Hausmann et al. considers the national level and the product level. At the same time, we further combine the measure of enterprise imported technological complexity submitted by Yue et al. (2016) to measure the complexity of imported technology at the inter-provincial level in China, extending the measurement perspective to the inter-provincial level.

First, we calculated the technical complexity of China's manufacturing product imports based on export data.

$$Prody_{nkt} = \frac{X_{nkt}/X_{nt}}{\sum_n X_{nkt}/X_{nt}} \times pergdp_{nt}$$

Where $Prody_{nkt}$ denotes the technological complexity of product k imported from country n in year t; the numerator X_{nkt}/X_{nt} denotes the share of product k exports of country (region) n in all product exports in year t; $pergdp_{nt}$ denotes the per capita income level of country (region) n in year t, as GDP per capita in 2007–2019.

Second, the technical complexity of China's imports of manufacturing products from various countries was merged with the China Customs trade database for 2007–2019 to measure the technical complexity of imports at the inter-provincial level using data on Chinese imports:

$$So_{fnkt} = \frac{X_{fkt}}{X_{ft}} \times Prody_{nkt}$$

Where So_{fnkt} denotes the technical complexity of product k imported by province f from country n in year t, X_{fkt} denotes the amount of product k imported by province f in year t, and X_{ft} indicates the total amount of imports by province f in year t.

And we argue that there is a positive effect of technological innovation on the complexity of imported technology and we also believe technological innovation affects the complexity of imported technology mainly through the competitive impact of the product, the economic growth effect, and the income effect.

First, based on the competitive effects. Enterprises use new technologies and produce new products to increase the technological content of domestic products to improve product competitiveness (Coe and Helpman, 1993; Melitz and Ottaviano, 2008). On the one hand, fierce competition increases the market access threshold of imported products, and the import of medium and high-tech products expands, thus improving the complexity of imported technology. On the other hand, the improvement of product competitiveness increases the market profit sharing of enterprises, enterprises expand production with additional profit sharing, thus forming the scale effect of the application of new technology and the production of new products, improving the overall technological content of products of enterprises, and further intensifying the competition effect. Therefore, improving the technical range of domestic products under the influence of competition will eventually lead to the progress of the complexity of imported technology.

Secondly, based on the effect of economic growth. Technological innovation not only promotes the economic development of a country but also strengthens its investment capacity. Economic development to a particular stage, the quantity of expansion cannot meet the high level, high-quality development goals. In order to achieve a qualitative leap, governments tend to invest more in technology-intensive industries to upgrade the industrial structure and improve product quality. The such technology-oriented investment will improve the technical content of domestic products and ultimately increase the complexity of imported technology.

Finally, based on the income effect. One of the ultimate goals of high-level and high-quality economic development is to raise national income and achieve shared prosperity. The increase in national income means improving consumers' consumption power and that consumers are willing to buy more technically advanced products. To meet consumer demand, enterprises tend to produce technology-oriented products and import medium-high technology products, thus increasing the complexity of imported technology.

Hypothesis 1: Technological innovation can improve the technological complexity of product import.

This paper argues that there is a positive effect between environmental regulation and technological innovation, which follows the "Porter hypothesis" mainly for two reasons. On the one hand, compared with developed countries, China's environmental regulation policies are implemented late and still in the initial stage. On the other hand, as a developing country, China mainly relies on industrial development, and the high environmental costs caused by environmental solid regulations will restrict industrial development. Therefore, various development constraints lead to a moderate or even low environmental regulation intensity in China. Compliance with environmental regulation has a positive effect on technological innovation. This positive effect not only strengthens the positive impact of technological innovation on the complexity of imported technology but also has regional differences. Reviewing the existing literature, the positive moderating effect of environmental regulation is mainly based on the following two aspects.

On the one hand, following the cost effect, environmental regulation will lead to short-term cost increases for enterprises (Brandt, 2007). Firstly, the environmental regulation policy requires enterprises to strictly comply with the policy conditions for the emission of pollutants such as waste gas and wastewater, which increases the constraints on production. Secondly, under strict pollution emission restrictions, enterprises may also seek pollution treatment, purchase advanced machinery and equipment, change production methods, and develop green technology and other methods to reduce enterprise pollution emissions from the root, either way will increase the environmental costs of enterprises and raise the market access threshold for the products they produce. The "cost effect" suggests that the ecological costs of environmental regulation are eventually added to the cost of production. This additional cost is a drain on firms' R&D capital (Popp et al., 2010), forcing them to rely on imports to meet the demand for medium- and high-tech intermediate goods in the upgrading of their product mix. Finally, the short-term increase in production costs will not give enterprises an incentive to innovate, and they will not be able to achieve technological breakthroughs in a relatively short period. They will have to rely on imports to ease the pressure to upgrade their product mix. Therefore, the rise in demand for intermediate technical goods in the production process of enterprises in the short term has increased the technical complexity of intermediate goods imports.

On the other hand, based on the innovation compensation effect, environmental regulation reduces the long-term costs of enterprises (Horváthová, 2012; Xie et al., 2017). While in the short term, firms' R&D capital will be crowded out by additional cost mark-ups, in the long term, the increased costs associated with reasonable environmental regulation will stimulate technological transformation and productivity improvements (Porter and Linde, 1995). The economic benefits of increased productivity are partially used to offset environmental costs and partly to improve the technological content of the products produced by enterprises. Based on the competitive effect of technological innovation, the increased competitiveness of domestic products will raise the market entry barrier for imported products. This leads to a bias in product imports towards medium and high technology categories, which ultimately allows for an increase in the complexity of imported technology.

Hypothesis 2: Environmental regulation can strengthen the positive promoting effect of technological innovation on the complexity of imported technology.

Focus on China, there is regional heterogeneity in the positive regulatory effects of environmental regulation, dividing the region into East, Central, and West. The study found that only environmental regulations in the eastern area had a significant effect on the complexity of imported technology and that only environmental regulations in the east of area had a positive moderating effect on technological innovation. Many heavy industries with heavy polluting emissions are concentrated in the north of east, such as Liaoning's steel industry, Jilin's petrochemical industry, and Heilongjiang's oil and coal industry.

The production processes of these enterprises are often accompanied by serious pollution emissions and therefore the environmental regulation requirements for these areas are relatively strict (Yang et al., 2016). Strict environmental regulations force enterprises to innovate and invest a lot of money to develop green production technology. Therefore, the environmental regulation in eastern China not only significantly promotes the complexity of imported technology but also has a significant positive moderating effect.

Hypothesis 3: Environmental regulation has a more significant positive effect on eastern China.

4 Research designing

4.1 Model setting

To further explore the impact of technological innovation on import technology complexity and the moderating effect of environmental regulation, based on panel data of 29[6] provinces in China, the interaction term of the environmental regulation composite index and technological innovation is introduced to reflect the moderating effect of regional environmental regulation on technological innovation and the complexity of imported technology. And the econometric model Eq. 1 is obtained:

$$ln\,So_{ihjt} = \alpha_0 + \alpha_1 lnRd_{ijt} + \alpha_2 lnEnv_{it} + \alpha_3 Rd \times Env_{it} + \theta X_{ijt} + \beta_i + \gamma_j + \varphi_h + \delta_t + \varepsilon_{ihjt} \tag{1}$$

In Eq. 1, i is the 29 provinces; h is the manufacturing import source country (region); j is the manufacturing subdivision industry; t is the years; So is the complexity of imported technology; Rd is the technological innovation; Env is the environmental regulation; $Rd \times En$ is the interaction term of technological innovation and environmental regulation; X is the control variable, β_i, γ_j, φ_h, δ_t and ε_{ijt} respectively represent province fixed effect, individual fixed effect, country fixed effect, year fixed effect. The random error term, α_1, α_2, α_3 and θ are parameters to be estimated.

6 Excluding Qinghai Province, The Tibet Autonomous Region is negligible mainly because of its low manufacturing imports.

4.2 Index selection and data processing

4.2.1. Year-industry-province dimension technological innovation (*Rd*)

We use the product of R&D investment, i.e., industry-level R&D expenditure, and each province's GDP share in 26 manufacturing industries from the China Statistical Yearbook as a measure of technological innovation at the industry and provincial levels. In the robustness analysis, industry-level R&D expenditure is multiplied by the share of R&D expenditure by province as a replacement variable for technological innovation (Ino), Designed to test the reliability of the model regression results.

4.2.2. National-year-industry-province dimension complexity of imported technology (*S* o)

Based on the calculation method of export technology complexity proposed by Hausmann et al. (2007), we combined export data of 39[7]countries (regions) in the CEPII-BACI database to calculate the technology complexity of HS6 bit code manufacturing products. The calculation formula is as follows:

$$Prody_{nkt} = \frac{X_{nkt}/X_{nt}}{\sum_n X_{nkt}/X_{nt}} \times pergdp_{nt}$$

Where, $Prody_{nkt}$ represents the technical complexity of k products imported from n country in year t, X_{nkt}/X_{nt} represents the proportion of k product exports in all product exports in country n (region) in year t; $pergdp_{nt}$ refers to the per capita income level of n country (region) in year t, and is the per capita GDP from 2007 to 2019, with data from the World Bank. Secondly, the product technology complexity data is combined with the China Customs Trade database from 2007 to 2019, and the imported technology complexity data of China is used to measure the import technology complexity at the provincial level:

$$So_{fnkt} = \frac{X_{fkt}}{X_{ft}} \times Prody_{nkt}$$

Where, So_{fnkt} represents the technical complexity of product k imported by province f from country n in t, X_{fkt} represents the amount of product k imported by province f in year t. X_{ft} represents the total import amount of province f in year t.

4.2.3. Environmental regulation composite index (*Env*)

The environmental regulation comprehensive index calculated by Ren et al. (2020) measures the implementation degree of environmental regulations. The index is mainly calculated from the data of industrial wastewater discharge, industrial discharge, and industrial smoke discharge obtained from the China Environmental Statistics Yearbook. The value ranges from 0 to 1, the stricter the environmental regulation, the smaller the value. In the robustness analysis, the variable of environmental regulation lagging one period was used as a substitute variable (Env_1).

4.2.4. Control variable selection

The economic scale of exporting country (Gdp): The larger the exporting country's economy, the higher the technical complexity of the exporting country's products, and then the relatively higher the technical complexity of China's imports from that country is likely to be. Thus, there is a positive correlation between the size of the exporting country's economy and the technical complexity of China's imported technology.

Economic freedom index ($Free$): in this paper, the property rights of legal effect, the government integrity, tax burden, government expenditure, fiscal health, freedom of business, labor, currency freedom, freedom of trade, investment, finance said eleven aspects such as economic freedom index to measure the degree of economic openness of exporters. For exporting countries, the less open their economies are, the higher the fixed trade costs of shipping. Faced with high fixed trade costs, exporting countries will reduce their exports, which in turn will affect the size of imports and the complexity of imported technology in importing countries.

Fixed asset investment in manufacturing (Inv): fixed asset investment tends to have a low demand for high technology-intensive products, which to some extent reduces the share of imports of high technology-intensive products, which in turn reduces the complexity of imported technology. Thus, there is a negative correlation between investment in manufacturing fixed assets and the complexity of imported technology (Lei, 2016).

Foreign investment level (FDI): Du and Guan (2021) use the product[7] of the amount of outward investment and each province's GDP share to measure the level of external investment. Foreign investors introduce many advanced technologies and equipment through direct investment, which affects the complexity of imported technology by optimizing the industrial structure. Therefore, there is a positive correlation between foreign investment and the complexity of imported technology (Lei, 2016).

4.2.5. Related data processing

To make the importing country (region) involved in China's manufacturing industry more representative, in this paper, the choice of 39 countries' (regions') economic development levels has specific heterogeneity, so China's imports from these countries (regions) of manufacturing are different, this leads to the provinces manufacturing year, industry, source of imports, imported technology complexity to zero value or missing value. Table 1 reports the selection of all indicators and data sources. Based on this, we make the following processing:1) the provinces, industries, and countries (regions) are numbered, and only the numbers with 13 total years are retained. Because Qinghai and Tibet do not have complete years, and the final complexity of imported technology at the inter-provincial level included only 29 provinces; 2) These numbers have a complete-time dimension and province dimension, but there are differences in import origin and manufacturing industry[8].3) As the index of economic freedom is an index type of data and the model is logarithmic for all variables except the index of financial freedom to minimize the possible impact of heteroskedasticity on the model estimation results.

4.2.6. Descriptive statistics

Table 2 reports the sample size, mean, standard deviation, minimum and maximum values of the selected variables. The standard deviations of all variables are minor, indicating that the data are relatively concentrated and there is no interference from extreme outliers.

5 Empirical analysis

5.1 Baseline regression

This paper examines the relationship between technological innovation and the complexity of imported technology by matching data on the technical complexity of product imports and the level of technological innovation in China at the inter-provincial level obtained by the measure. To maintain the stability of the model and reduce the error in parameter estimation, we control for province fixed effects, industry fixed effects, country fixed effects, and time fixed effects in the model based on the Hausman test. The estimation results are shown in Table 3: columns (1) and (4) indicate that the coefficient on technological innovation is significantly positive at the 1% level of significance, regardless of whether or not the control variables are considered, meaning that there is a significant positive effect of technological innovation on the complexity of imported technology. (2) After considering the environmental regulation, the stricter the environmental regulation, the smaller the index and the greater the intensity of

7 The 39 countries (regions) refer to including Burma, Cambodia, Hong Kong, India, Indonesia, Japan, Malaysia, the Philippines, Singapore, South Korea, Thailand, Vietnam, South Africa, Belgium, Denmark, Britain, Germany, France, Ireland, Italy, the Netherlands, Greece, Portugal, Spain, Austria, Finland, Hungary, Poland, Sweden, Switzerland, Russia, the Czech Republic, Brazil, Chile, Mexico Columbia, Canada, the United States, Australia, New Zealand.

8 Example: Shanghai imports textile products from Australia, but Jiangsu does not import textile products from Australia.

TABLE 1 Index selection and data sources.

Owning variable	Variable name	Meaning	Data source
Explained variable	So	The complexity of imported technology	CEPII-BACI database, China Customs database
Explanatory variable	*Rd*	R&D expenditure	China Statistical Yearbook
	Ino	R&D expenditure proxy variables	China Statistical Yearbook
Adjust the variable	*Env*	Environmental Regulation Composite Index	China Environmental Statistics Yearbook
	Env_1	Environmental regulation lags behind	Data processing acquisition
Control variables	*Gdp*	The economic scale of exporting country	the World Bank database
	Inv	Fixed asset investment in manufacturing	China Statistical Yearbook
	Free	Economic freedom index	the World Bank database
	FDI	Foreign investment level	China Statistical Yearbook

TABLE 2 Descriptive statistics of variables.

Variable	Obs	Mean	Std. Dev	Min	Max
So	66170	2.819	2.635	−13.325	9.048
Rd	66170	5.783	1.374	0.443	9.205
Ino	66170	11.407	1.517	3.368	15.216
Env	66170	0.448	0.368	0	1.277
Env_1	61080	0.444	0.366	0	1.277
Inv	66170	8.123	1.242	3.907	10.255
Free	66170	70.836	8.691	37.674	90.2
Gdp	66170	20.479	1.263	15.923	23.348
FDI	66170	−5.549	1.166	−12.231	−2.708

TABLE 3 Technological innovation, environmental regulation, and complexity of imported technology.

	(1)	(2)	(3)	(4)
	So	*So*	*So*	*So*
Rd	0.098***		0.103***	0.085***
	(0.011)		(0.011)	(0.013)
Env		−0.474***		−0.328***
		(0.084)		(0.096)
Rd × Env		0.068***		0.043***
		(0.011)		(0.013)
Inv			−0.029***	−0.040***
			(0.010)	(0.011)
Free			0.016***	0.016***
			(0.002)	(0.002)
Gdp			0.924***	0.914***
			(0.067)	(0.067)
FDI			0.008	0.012
			(0.007)	(0.007)
_Cons	2.251***	2.846***	−17.572***	−17.126***
	(0.066)	(0.020)	(1.317)	(1.327)
Industry fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Country fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Province fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Year fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
N	66,170	66,170	66,170	66,170
F	74.700	20.228	92.549	67.972
R^2	0.902	0.902	0.903	0.903

Note (1) *, **, and *** are significance levels of 10%, 5%, and 1% respectively; (2) Robust standard error in parentheses; The following table with.

environmental regulation. Therefore, at the significance level of 1%, the coefficient of environmental regulation is significantly negative, indicating that environmental regulation has a significant positive effect on the complexity of imported technology. At the same time, the interaction term between environmental regulation and technological innovation is significantly positive at the significance level of 1%, indicating that environmental regulation can strengthen the positive effect of technological innovation on the technical complexity of product imports.

After taking control variables into account, the results in column (4) show that the financial degree of freedom index is significantly positive at the significance level of 1%, indicating a positive relationship between the economic degree of freedom and the complexity of imported technology. Fixed asset investment in manufacturing is significantly negative at the significance level of 1%. The results show a negative relationship between fixed asset investment and the complexity of imported technology. The market size of exporting country is significantly positive at the significance level of 1%, indicating that the market size of exporting country is also positively correlated with its export desire. The larger the market size of exporting countries is, the more likely they will obtain additional benefits through trade surplus, thus increasing the complexity of exported technology. The level of foreign investment is significantly positive at the significance level of 10%. Foreign investors introduce many advanced technologies and equipment through direct investment, which

TABLE 4 Robustness analysis.

	(1)	(2)	(3)
	Env_1	*Ino*	*Winsor*
Rd	0.066***	0.096***	0.087***
	(0.014)	(0.013)	(0.013)
Env	−0.243**	−0.326**	−0.297***
	(0.108)	(0.164)	(0.094)
Rd × Env	0.046***	0.023*	0.038***
	(0.015)	(0.013)	(0.012)
Inv	0.013***	0.016***	0.016***
	(0.003)	(0.002)	(0.002)
Free	−0.023*	−0.053***	−0.038***
	(0.012)	(0.011)	(0.011)
Gdp	0.826***	0.917***	0.885***
	(0.074)	(0.067)	(0.065)
FDI	0.015*	0.008	0.012
	(0.008)	(0.007)	(0.007)
_Cons	−15.126***	−17.725***	−16.500***
	(1.477)	(1.335)	(1.296)
Industry fixed effect	*Yes*	*Yes*	*Yes*
Country fixed effect	*Yes*	*Yes*	*Yes*
Province fixed effect	*Yes*	*Yes*	*Yes*
Year fixed effect	*Yes*	*Yes*	*Yes*
N	61,080	66,170	66,170
F	42.111	67.692	67.009
R^2	0.908	0.903	0.903

improves the complexity of imported technology by optimizing the industrial structure. In summary, the economic meanings of the core explanatory and control variables are all consistent with the intended economic purposes, and the results of the empirical tests are generally consistent with the results of the theoretical analysis.

5.2. Robustness test

We replaced the explanatory variables, moderating variables and regression methods on the basis of the baseline regression to verify the robustness of the above findings, and therefore did the following robustness tests: Firstly, a one-period lag of environmental regulation was used as a replacement variable for the moderating variable, as there is often a lag in the impact of the implementation of policies such as environmental regulation on the complexity of imported technology. Second, industry-level R&D expenditure is multiplied by the share of R&D expenditure by province as a replacement variable for technological innovation. Third, tailoring of the explanatory variables to eliminate the influence of extreme, outliers on the study. Compared with the results in Table 3, the regression results in Table 4 show that the direction and significance between the variables are basically the same, except for slight fluctuations in the regression coefficients, with the level of technological innovation and environmental regulation still having an elevating effect on the technological complexity of imports, and environmental regulation still has a positive impact on technological innovation.

5.3 Endogenous problems

Appropriate variables are controlled in the benchmark regression model. The regression results also verify the impact of technological innovation on the complexity of imported technology and the moderating effect of environmental regulation. However, measurement error, omitted variables, and bi-directional causality in the model set can lead to biased estimates. Based on this, the issue of endogeneity needs to be discussed. First of all, although the measurement of the complexity of imported technology in this paper is based on the method established by authoritative scholars widely recognized in the academic world, there will be measurement errors in measuring the complexity of imported technology at the provincial level in China. Secondly, this paper cannot control all the factors that affect the complexity of imported technology. These omitted variables will enter the perturbation term, which leads to the correlation between the perturbation term and the explanatory variable, and then a biased estimate is obtained. Finally, technological innovation affects the complexity of imported technology through competitive effects, economic growth effects and income effects. Likewise, the complexity of imported technology through the technology spillover effect will also impact technological innovation. Therefore, there is an associative causal relationship between the two, which in turn biases the estimates. Based on this, to eliminate the error of the estimation results, this paper uses instrumental variables to estimate, selects the number of road miles by the province in 2000 as the instrumental variable of technological innovation, and uses the two-stage least square method (2SLS) to identify the causal relationship between technological innovation and the complexity of imported technology. The number of road miles, as a kind of infrastructure construction, is correlated with the technological innovation of enterprises, which satisfies the correlation hypothesis. In addition, there is no direct relationship between the number of road miles in 2000 and the complexity of imported technology in 2007 and later, satisfies the exogenous hypothesis.

Table 5 reports the estimation results using the number of road miles by the province in 2000 as the instrumental variable. Columns (1), (2), (3), and (4), respectively consider the estimated results without and with control variables. The

TABLE 5 Estimates of instrumental variable.

	(1)	(2)	(3)	(4)
	Stage I	**Stage 2**	**Stage 1**	**Stage 2**
IV Rd	0.296***		0.091***	
Rd		0.818***		2.741***
Control	*No*	*No*	*Yes*	*Yes*
Industry fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Country fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Province fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Year fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
N	66,170	66,170	66,170	66,170
Anderson canon. corr. LM statistic	4133.90		212.37	
Cragg-Donald Wald F statistic	4408.44		212.99	

results show that: firstly, a significant positive correlation between the number of road miles as an instrumental variable and technological innovation in each province in 2000; Secondly, the F-statistic for the first stage is much more significant than 10, indicating that there is no weak instrumental variable problem; Finally, according to the estimation results of instrumental variables, we can see that the core conclusion of this paper is consistent with the benchmark regression after accounting for endogeneity.

5.4 Heterogeneity test

5.4.1. Regional heterogeneity

In the analysis of regional heterogeneity, we divide China into eastern, central, and western regions[9]. According to the results in Table 6, in the case of regional heterogeneity, the effect of technological innovation on the complexity of imported technology is significantly positive at the 1% significance level, with only a weak difference in coefficient size. At the same time, the table shows that only the environmental regulations in the eastern region significantly improve the complexity of imported technology, and only the environmental regulations in the eastern region have a significant positive moderating effect on technological innovation. This important regional variability is mainly reflected in: on the one hand, the eastern coastal region is home to most of the large enterprises, which have a higher level of production capacity, efficiency and technology, and the room for technological innovation is more limited, so the impact factor of technological innovation in the eastern region is more minor; on the other hand, the eastern and northern regions are home to many heavily polluting industries, such as Liaoning's steel industry, Jilin's petrochemical industry and Heilongjiang's oil and coal industry. The production processes of these enterprises are often accompanied by serious polluting emissions and therefore the requirements for environmental regulation in these areas are more stringent.

TABLE 6 Heterogeneity of eastern, central, and western regions.

	(1)	(2)	(3)
	East	**Central**	**West**
Rd	0.050***	0.270***	0.271***
	(0.014)	(0.054)	(0.052)
Env	−0.496***	−0.142	0.318
	(0.108)	(0.496)	(0.423)
Rd × Env	0.047***	0.065	−0.048
	(0.014)	(0.084)	(0.084)
Control	*Yes*	*Yes*	*Yes*
_Cons	−18.717***	0.940	−9.924
	(1.387)	(5.547)	(6.179)
Industry fixed effect	*Yes*	*Yes*	*Yes*
Country fixed effect	*Yes*	*Yes*	*Yes*
Province fixed effect	*Yes*	*Yes*	*Yes*
Year fixed effect	*Yes*	*Yes*	*Yes*
N	52,871	7163	6136
F	62.303	10.070	9.344
R^2	0.910	0.849	0.815

9 The eastern region includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, Liaoning, Jilin, and Heilongjiang. The central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan, and the rest is the western region.

TABLE 7 Heterogeneity of environmental constraints.

	(1)	(2)	(3)	(4)
	High pollution industry	**Low pollution industry**	**Strict environmental regulations**	**Lax environmental regulation**
Rd	0.144***	0.023	0.084***	0.005
	(0.016)	(0.021)	(0.018)	(0.031)
Env	−0.444***	−0.284*	−1.193***	−0.721***
	(0.123)	(0.156)	(0.390)	(0.234)
Rd × *Env*	0.061***	0.037*	0.200***	0.092***
	(0.016)	(0.021)	(0.064)	(0.033)
Control	Yes	Yes	Yes	Yes
_Cons	−18.231***	−15.958***	−19.892***	−14.442***
	(1.775)	(2.001)	(2.026)	(1.800)
Industry fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Country fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Province fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
Year fixed effect	*Yes*	*Yes*	*Yes*	*Yes*
N	35,594	30,576	33,786	32,355
F	53.589	29.256	40.197	27.421
R^2	0.891	0.909	0.896	0.915

In the context of strict environmental regulations, enterprises have to innovate and invest heavily in green production technologies to survive. Thus, there is not only a significant elevating effect of environmental regulation on imported technological sophistication in the east but also a significant positive moderating effect on technological innovation.

5.4.2. Heterogeneity of environmental constraints

Based on the analysis of the pollution degree and intensity of environmental regulation implement heterogeneity, according to the relevant heavy polluting industries by the applicable provisions of Chapter IV of the Environmental Protection Law of the People's Republic of China on pollution prevention and control, the 26 manufacturing industries are divided into high and low polluting industries[10]. The region was divided into strict environmental regulations and lax environmental regulations. The region with a composite index of environmental regulations of less than 0.55 was the region with strict environmental regulations. According to the results in Table 7, only in high-pollution industries and areas with strict environmental regulations and the impact of technological innovation on the complexity of imported technology is significantly positive at the significance level of 1%. The reason is that high-pollution industries are often subject to stricter environmental control by the state, and enterprises can only alleviate ecological management by developing green technologies. Therefore, the increase in R&D investment will lead to extensive technological innovation, which will indirectly increase the complexity of imported technology by improving the technical content of domestic products. Similarly, areas with stringent environmental regulations tend to be highly polluting industries, where enterprises have to mitigate environmental controls through technological innovation to reduce their environmental costs. Hence the ultimate impact effect is consistent with that of highly polluting industries.

At the same time, there is a significant positive effect of environmental regulation on the complexity of imported technology, both in industries with different levels of pollution and in regions with varying intensities of environmental regulation, and a significant positive moderating effect on technological innovation, with only minor differences in the magnitude of the coefficients.

10 High pollution industries including clothing and other fiber products manufacturing, textile industry, nonmetal mineral products industry, chemical fiber, chemical raw materials, and chemical products manufacturing, fabricated metal products, beverage manufacturing industry, leather, fur, feather and its products, oil processing and coking, rubber products, plastic products, pharmaceutical manufacturing, non-ferrous metal smelting, and rolling processing industry, Paper and paper products industry, others are low pollution industries.

6 Conclusion and policy recommendations

We use China's manufacturing imports at the inter-provincial level from 2007 to 2019 as a research sample and measures the technical complexity of China's product imports at the inter-provincial level through the export value of 39 countries (regions), GDP per capita, and the import value of manufacturing industries in 29 Chinese provinces. In combination with technological innovation measurement data and environmental regulation composite index, this paper studies the impact of technological innovation on the complexity of imported technology at the inter-provincial level in China. In contrast, the moderating effect of environmental regulation on the relationship is considered. Based on a benchmark regression, regional heterogeneity and environmental constraint heterogeneity were tested. The results of the study show that: firstly, technological innovation can contribute to the complexity of imported technology. However, there is no regional heterogeneity in the significance of this positive effect, and only a slight difference in coefficient size exists. The positive impact of technological innovation is more significant for heavily polluting industries and areas with strict environmental regulations. Secondly, environmental regulation can strengthen the positive effects of technological innovation on the complexity of imported technology. However, there is regional heterogeneity in the positive strengthening impact. It is found that only in the eastern region will environmental regulation strengthen the positive effects of technological innovation on the complexity of imported technology.

Based on the above research results and conclusion, we put forward the following policy recommendations: First, enterprises, as the main body of innovative behavior, should promote the standardization and specialization of technological innovation and then encourage the international standardization of technological innovation. Only with international standards, most of which are China's dominance, can it compete for dominance in international trade. At present, some of China's advanced research laboratories have achieved remarkable results in technology development. But they lack a standardized production system and cannot realize the standardization, specialization, and scale of product production, which leads to a lack of international standards led by China.

Second, in addition to advanced production methods and high-end machines and equipment, technological innovation should also include the cultivation of innovative talents, which is an essential support for the innovation-driven development strategy. On the one hand, the government should build a talent training system with socialist characteristics of Chinese characteristics based on long-term development goals, give full play to the advantages of the system, integrate innovative and entrepreneurial thinking into the construction of undergraduate teaching, and cultivate Chinese youths with creative thinking and innovative abilities. On the other hand, governments at all levels also need to strengthen the construction of innovation and entrepreneurship platforms for young people in various localities from the bottom practical point of view, and improve the mechanism for transforming innovation results, to encourage young people to engage in practice and join the army of innovation and entrepreneurship.

Third, environmental regulation plays a vital safeguard role in the promotion of technological innovation on the complexity of imported technology, and the government should strengthen the intensity of environmental regulation while taking full account of its regional and industrial heterogeneity. On the one hand, while the government emphasizes the strengthening of environmental regulations in industrial areas and heavily polluting industries, it should not neglect environmental regulations in other areas to avoid the formation of "pollution havens" by enterprises to reduce environmental costs. On the other hand, the government needs to help enterprises' technological innovation by improving and strengthening environmental regulations. The government should take the initiative to share the risks of enterprise innovation, incentivize enterprises to innovate on their own, and protect their incentives to invest in the field of technological innovation.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Acemoglu, D., Aghion, P., Bursztyn, L., and Hemous, D. (2012). The environment and directed technical change. *Am. Econ. Rev.* 102 (1), 131–166. doi:10.1257/aer.102.1.131

Acemoglu, D., and Restrepo, P. (2020). Robots and jobs: Evidence from US labor markets. *J. Political Econ.* 128 (6), 2188–2244. doi:10.1086/705716

Albrizio, S., Kozluk, T., and Zipperer, V. (2017). Environmental policies and productivity growth: Evidence across industries and firms. *J. Environ. Econ. Manag.* 81 (81), 209–226. doi:10.1016/j.jeem.2016.06.002

Amiti, M., and Freund, C. (2016). The anatomy of China's export growth. *Soc. Sci. Electron. Publ.* 199 (5), 1–29. doi:10.1596/1813-9450-4628

Amiti, M., and Khandelwal, A. K. (2013). Import competition and quality upgrading. *Rev. Econ. Stat.* 95 (2), 476–490. doi:10.1162/rest_a_00271

Antoniades, A. (2015). Heterogeneous firms, quality, and trade, quality, and trade. *J. Int. Econ.* 95 (2), 263–273. doi:10.1016/j.jinteco.2014.10.002

Brandt, N. (2007). Mark-ups, economies of scale and the role of knowledge spillovers in OECD industries. *Eur. Econ. Rev.* 51 (7), 1708–1732. doi:10.1016/j.euroecorev.2006.12.001

Busse, M. (2004). Trade, environmental regulations and the world trade organization: New empirical evidence. *J. world trade* 38 (2), 285–306. doi:10.54648/trad2004012

Coe, D. T., and Helpman, E. (1993). International R&D spillovers. *Eur. Econ. Rev.* 39 (5), 859–887. doi:10.1016/0014-2921(94)00100-e

Cole, M. A., and Elliott, R. J. R. (2003). Do environmental regulations influence trade patterns? Testing old and new trade theories. *World Econ.* 26 (8), 1163–1186. doi:10.1111/1467-9701.00567

Du, C. Z., and Guan, H. F. (2021). Digital economy and technological complexity of China's manufacturing exports: A test based on mediating effect and threshold effect. *J. South. Econ.* (12), 1–20. doi:10.19592/j.cnki.scje.390516

Du, L. Z., Zhao, Y. H., Tao, K. T., and Lin, W. F. (2019). The compound effect of environmental regulation, governance transition on green competitiveness enhancement-empirical evidence based on Chinese industry. *Econ. Res.* 54 (10), 106

Dussaux, D., Dechezleprêtre, A., and Glachant, M. (2017). Intellectual property rights protection and the international transfer of low-carbon technologies. *Work. Pap.*

Ederington, J., and Minier, J. (2003). Is environmental policy a secondary trade barrier? An empirical analysis. *Can. J. Econ.* 36 (1), 137–154. doi:10.1111/1540-5982.00007

Foster, N. (2014). Intellectual property rights and the margins of international trade. *J. Int. Trade Econ. Dev.* 23 (1), 1–30. doi:10.1080/09638199.2012.664556

Hausmann, R., Hwang, J., and Rodrik, D. (2007). What you export matters. *J. Econ. GrowthBost.* 12, 1–25. doi:10.1007/s10887-006-9009-4

Hidalgo, C. A., and Horváthová, E. (2009). Hausmann R. The building blocks of economic complexityThe impact of environmental performance on firm performance: Short-term costs and long-term benefits? *PNASEcological Econ.* 10684 (2612), 1057091–1057597. doi:10.1016/j.ecolecon.2012.10.001

Hu, H. R. (2019). Can environmental regulations for cleaner production improve product quality? *Econ. Sci.* (03), 93–105. doi:10.12088/PKU.jjkx.2019.03.09

Humphrey, J., and Schmitz, H. (2000). *Governance and upgrading: Linking industrial cluster and global value chain research*. Brighton: Institute of Development Studies. Working Paper No. 120.

Imbruno, M. (2019). Importing under trade policy uncertainty: Evidence from China. *J. Comp. Econ.* 47 (4), 806–826. doi:10.1016/j.jce.2019.06.004

Kaufmann, A., Lehner, P., and Todtling, F. (2003). Effects of the Internet on the spatial structure of innovation networks. *Inf. Econ. Policy* 15 (3), 402–424. doi:10.1016/s0167-6245(03)00005-2

Kuznets, R., and Yi, C. (1989). *Modern economic growth*. Beijing: Beijing : University of Economics Press.

Lei, H. M. (2016). *Characteristics and influencing factors of imported technology complexity in China*. [Tianjin] :Tianjin University of Finance and Economics. [Master's Thesis].

Liu, M. X., Xu, W., Zhu, X. M., and Tang, Y. (2020). The impact of trade policy uncertainty on firms' import technology sophistication-A case study of Chinese manufacturing firms. *Macroecon. Res.* (12), 70–83. doi:10.16304/j.cnki.11-3952/f.2020.12.008

Lovely, M., and Popp, D. (2011). Trade, technology, and the environment: Does access to technology promote environmental regulation? *J. Environ. Econ. Manage.* 61 (1), 16–35. doi:10.1016/j.jeem.2010.08.003

Marvasi, E. (2012). "The sophistication of China's exports, imports and intermediate products," in *The Chinese economy*, 181–209. doi:10.1007/978-3-642-28638-4_9

Melitz, M. J., and Ottaviano, G. I. P. (2008). Market size, trade, and productivity. *Rev. Econ. Stud.* 75 (1), 295–316. doi:10.1111/j.1467-937x.2007.00463.x

Mihov, I., and Sibert, A. C. (2006). Credibility and flexibility with independent monetary policy committees. *J. Money, Credit, Bank.* 38 (1), 23–46. doi:10.1353/mcb.2006.0021

Popp, D., Newell, R. G., and Jaffe, A. B. (2010). Energy, the environment, and technological change. *Handb. Econ. Innovation* 2, 873–937. doi:10.1016/S0169-7218(10)02005-8

Porter, M. E., and Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *J. Econ. Perspect.* 4 (4), 97–118. doi:10.1257/jep.9.4.97

Ren, X. S., Liu, Y. J., and Zhao, G. H. (2020). Influence of economic agglomeration on carbon emission intensity and its transmission mechanism. *China's Popul. Resour. Environ.* 30 (4), 95–103. doi:10.12062/cpre.20200113

Saadi, M. (2020). Remittance inflows and export complexity: New evidence from developing and emerging countries. *J. Dev. Stud.* (1), 1–27. doi:10.1080/00220388.2020.1755653

Shepotylo, O., and Stuckatz, J. (2017). *Political uncertainty, FDI, and trade in intermediate goods: Evidence from Ukrainian firms*. New York: Social Science Electronic Publishing.

Solarin, S. A., Usama, A., Ibrahim, M., and Ozturk, I. (2017). Investigating the pollution haven hypothesis in Ghana: An empirical investigation. *Energy* 124 (1), 706–719. doi:10.1016/j.energy.2017.02.089

Steinhorst, J., and Matthies, E. (2016). Monetary or environmental appeals for saving electricity?–Potentials for spillover on low carbon policy acceptability. *Energy Policy* 93 (1), 335–344. doi:10.1016/j.enpol.2016.03.020

Wang, Z., Wei, S. J., and Galina, H. (2010). *What accounts for the rising sophistication of China's exports? China's growing role in world trade*. Chicago: University of Chicago Press. doi:10.7208/9780226239729-004

Wei, H., Lian, H. J., and Zhang, Y. (2020). Basic situation and countermeasures of China's high-tech product imports. *International Trade* (12), 20–28+40. doi:10.14114/j.cnki.itrade.2020.12.004

Wong, C. Y., Siow, G., Li, R., and Kwe, K. T. (2013). The impact of China on the emerging world: New growth patterns in Chinese import-export activities. *Inzinerine Ekon. Eng. Econ.* 24 (4), 309–319. doi:10.5755/j01.ee.24.4.3239

Xie, R. H., Yuan, Y. J., and Huang, J. J. (2017). Different types of environmental regulations and heterogeneous influence on 'green' productivity: Evidence from China. *Ecol. Econ.* 132 (2132), 104–112. doi:10.1016/j.ecolecon.2016.10.019

Yadav, N. (2014). The role of internet use on international trade: Evidence from asian and sub-saharan african enterprises. *Glob. Econ. J.* 14 (2), 189–214. doi:10.1515/gej-2013-0038

Yang, F., Zhou, Y., and He, C. F. (2016). Industrial organization, industrial agglomeration and China's manufacturing industry pollution. *J. Peking Univ. Nat. Sci. Ed.* 52 (3), 563–573. doi:10.13209/j.0479-8023.2016.058

Yang, X. Y., and Zhao, X. h. (2022). The Import technology complexity of producer service industry and the innovation of manufacturing enterprises. Soft Science. Available online at: http://kns.cnki.net/kcms/detail/51.1268.G3.20220512.1144.002.html (accessed on June 14, 2022).

Yue, Y. S., Li, B., and Li, R. (2016). Does the Internet increase firms' import technology complexity-an empirical study based on multiplicative matching. *Int. trade issues* (12), 131–141. doi:10.13510/j.cnki.jit.2016.12.012

Zhang, A. L., and Yin, M. L. (2019). Technological innovation, demographics and the complexity of China's manufacturing exports. *Soft Sci.* 33 (05), 29