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Does the import of green products encourage green technology innovation? Empirical evidence from China

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ABSTRACT

Green technology innovation capability is an important support for the realisation of Sustainable Development Goals, and it is of great significance to discuss the impact of green product imports on green technology innovation policy formulation in importing countries. Based on the panel data of 30 provincial-level regions in China from 2012 to 2020, this paper empirically examines the effect and mechanism of green product imports on green technology innovation. The empirical results show that (1) the import of green products significantly constrain China's green technology innovation. After a series of robustness tests and endogeneity tests, the conclusion is still valid, and the inhibitory effect is mainly manifested as the import technology dependence effect. (2) From the impact of green product imports on different types of green technology innovation, the inhibition effect of incremental-type green technology innovation with lower innovation is stronger than that of radical-type technology innovation with higher innovation. (3) Further test of the moderating effect shows that green R&D investment weakens the inhibitory effect of green product import in the regions with higher and lower economic development levels, while the moderating effect of intellectual property protection only exists in the regions with less economic development. (4) The heterogeneity analysis shows that the import of different types of green products has a significant difference in the impact of green technology innovation. The finding of this study provides useful suggestions for formulating reasonable policies for promoting and protecting green technology innovation.

1. Introduction and literature review

With global warming and environmental degradation increasing, Sustainable Development Goals have gained greater focus among international organisations and governments (Wu et al., 2022; Sachs et al., 2022; Lee et al., 2023). Many countries' policies have shifted to promoting sustainable development through enhanced green technology innovation (Shan et al., 2021). Green technology innovation focuses on environmental protection, resource conservation, waste recycling, and sustainable development (Wang et al., 2021; Zhou and Wang, 2022; Qin et al., 2023), which usually has a high innovation threshold and requires strong research and development capabilities. Considering domestic green technology's infancy, insufficient production capacity, and international industrial division pattern, developing countries generally adopt importing green products from developed countries or green technology, leading countries to meet the huge domestic demand. From the international trade perspective, the consensus among most scholars is that product imports usually have an important impact on technological progress and innovation (Grossman and Helpman, 1993). However, there is no consensus on the direction of import trade's impact on technological innovation. For example, Posner (1961) believed that the technology spillover effect generated by import trade promoted the technological innovation of host countries, while Arrow (1962) and Aghion et al. (2005) further found that the escape competition effect caused by import competition promotes technological innovation by local enterprises. Schumpeter (1942) and Aghion et al. (1998) argue that market competition caused by imports negatively impacts technological innovation through the crowding-out effect. Furthermore, the question

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of how importing green products affects the country's green technology innovation is unanswered.

Compared with developed countries, import channels are more important for the progress of green technology in developing countries. Taking China as an example, although the exploration of green development mode is far behind that of developed countries, with the support of relevant industrial policies, China has made remarkable achievements in paying more attention to environmental protection, resource conservation, and sustainable green economic development. China has also made considerable progress in green technology innovation in recent years. According to China National Intellectual Property Administration's statistics, green patents granted in China increased 55.41 % year-on-year to 31,100 in 2020. The average annual growth rate reached 21.73 % from 2012 to 2020. However, green products imported over the same period showed a horizontal fluctuation trend over nine years. Therefore, the question arises as to whether the import of green products has played a role in promoting green technological innovation in China. If so, what is the specific mechanism? Answering these questions requires further empirical evidence.

There are two main branches of literature similar to this study. The first one is related research based on the perspective of international trade and technological progress. As David Ricardo (1817) pointed out in *On the Principles of Political Economy and Taxation*, international trade based on relative comparative advantages can help countries obtain trade gains and improve their production levels and innovation ability. The factor endowment theory, represented by Heckscher-Ohlin (Ohlin, 1935), further pointed out that the huge difference in factor endowment between countries drives the cross-border flow of production factors, which in turn promotes each country's innovation level. The new trade theory, represented by Krugman (1979, 1980), goes deeper to the industry level, and later Grossman and Helpman (1993) found that an increase in the variety of products imported generates technological spillovers, which allow importing countries to promote domestic technological innovation by learning to imitate the technology of imported products. Coe et al. (1997) found that developing countries can obtain knowledge spillovers by importing intermediate goods and capital equipment from developed countries, resulting in higher innovation output. This viewpoint has also been supported by numerous academics' recent studies (Andrijauskiene and Dumčiuvienė, 2019; Asunka et al., 2021; Feng and Li, 2021; Huang and Pei, 2022; Shang et al., 2022).

Research has focused on the firm level with the rise of heterogeneous-firm trade theory (Melitz, 2003). Some scholars have confirmed that imports positively impact enterprise innovation (Smith, 2014; Fritsch and Görg, 2015; Gonchar and Kuznetsov, 2018; Cai et al., 2023). However, other scholars believe that imports inhibit rather than promote innovation. A study by Liu and Rosell (2013), using a sample of US firms, found that import competition reduced product diversification and thus constrained US firms' innovation and R&D activities. Ding et al. (2016) further confirmed that import competition weakens their incentives to innovate and increase productivity in the case of enterprises far from the world's technological frontier. Liu and Qiu (2016) concluded that importing intermediate inputs negatively impacts enterprise innovation, mainly because the imported intermediate inputs displace firms' internal innovation. Some studies with samples of enterprises from specific countries, such as BRICS countries (Gür, 2020), the United States (Dorn et al., 2020) and China (Liu et al., 2023), also support the view that imports weaken the innovation ability of enterprises. Additionally, it has been stated that import competition from various nations may impact innovation in various ways (Li and Zhou, 2017).

The second research branch is based on the single perspective of green products or technology innovation. Literature in this field is limited, and the discussion mainly focuses on the channels through which import trade affects technological innovation. Frankel and Rose (2005) found that expanding imports could introduce more advanced and cleaner production and pollutant discharge technologies and generate spillover benefits of green technology and innovation. Li et al. (2021) argued that import trade brings about technology spillover effects, with importing countries learning from advanced foreign production technology, improving green technology innovation by improving production processes, and reducing pollution emissions. Using a sample of Chinese firms, Huang and Pei (2022) found that imported technology spillovers directly increase innovation and indirectly affect innovation by introducing diversity. According to arguments made by other academics, the influence of various import source countries on green technology innovation varies. The impact of imports on various nations is examined in Yu et al.'s (2022) study, which concludes that imports have a facilitative effect on high-income countries' green productivity but little effect on low-income countries' green productivity. Empirical research conducted by some academics has revealed that import trade hinders the development of green technology. According to Cao and Wang (2017), China's level of green technology is raised by importing goods from developed nations. Still, green technology innovation is stifled by importing goods from less developed nations.

Numerous academics have examined the relationship between imports and technological innovation at the national and enterprise levels, according to the literature published. However, whether imports encourage or impede technological innovation has not been satisfactorily resolved, and the mechanism of influence has not been sufficiently explored. Some academics contend that knowledge spillovers from imports can boost technological innovation in importing nations, while others contend that imports stifle rather than foster innovation. Few studies systematically analyse the impact of green imports on technological innovation from the 'double green' perspective. More importantly, since green products and technologies tend to be more knowledge-intensive and require greater R&D investment, the mechanism through which green product imports affect green technology innovation may differ from the pathways and means that import trade affects technology innovation discussed in the existing literature. It can be said that the mechanism of green product imports affecting green technology innovation is still unclear. In addition, this mechanism may also be affected by other external factors and show a non-linear change trend, which has not been reflected in previous studies.

Based on reorganising the micro-statistics from the General Administration of Customs of the People's Republic of China and China National Intellectual Property Administration, and under the general guidelines of international organisations, we constructed the data set of China's green product imports and patents with classification function. Then, taking provincial regions of China as a sample, this study empirically analyses the influence and mechanism of green product import on green technology innovation and the moderating effect of green R&D and IPR protection. Furthermore, the heterogeneity analysis of the effect was conducted from the perspectives of the purpose of use, quality and attributes of green products.

Compared with the previous studies, the marginal contribution of this paper is reflected in three aspects. First, it discusses the impact of imports on technological innovation from a dual green perspective of green products and green technological innovation, which makes up for the shortcomings of the existing literature. Second, this paper builds a theoretical, analytical framework that explains the impact mechanism of green product imports on technological innovation in green fields. The internal mechanism between them and the non-linear moderating effect of green R&D and intellectual property protection have been systematically explained. Third, this study uses the provincial level as the research sample. It also builds a statistical and classification procedure for China's green product imports compatible with international standards. It was constructed to measure the import value of green products in each provincial region of China from 2012 to 2020. At the empirical level, the impact of green product imports on green technology innovation in China is examined empirically from the dual micro perspective of green products and green patents, and the non-linear effects of green product R&D investment and IPR protection are verified.

The remainder of the paper is structured as follows. Section 2 presents the theoretical mechanism and empirical hypotheses. The empirical model and data are displayed in Section 3. Section 4 gives the regression estimation and robustness test of the benchmark model. Further discussion around mechanism testing, mediating effects and heterogeneity is provided in Section 5. Section 6 presents the conclusions.

2. Theoretical analysis and hypothesis development

2.1. Theoretical mechanisms by which green product imports affect green technology innovation

The review of the previous literature shows that the impact of green product imports on green technology innovation has both a positive promotion effect and a negative inhibition effect. The positive effect mainly manifests in the technology spillover and escape competition effect. In contrast, the negative effect is displayed through the technology dependence and crowding-out effects.

2.1.1. Technology spillover effects of green product imports

According to the new trade theory, knowledge and technology can generate spillovers through the import channel (Grossman and Helpman, 1993). If the importing country is technologically backward, it can acquire more innovative products or advanced knowledge and technology from the import trade of technologically developed countries and integrate the new knowledge and technology into the product production process through learning, digestion and absorption, thus achieving technological innovation (Liu and Buck, 2007; Zhang and Zhou, 2016; Feng and Li, 2021; Zhang, 2021).

Green products that a country chooses to import frequently cannot be fully produced due to limited domestic production capacity but are required for production inputs and typically contain high-tech green technology components. The technology spillover effect caused by the import of green products is generated through three main channels.

The first is the input channel. Suppose green products imported by a country are used as intermediate or capital goods. In that case, they directly increase production efficiency and technological development when put into the production chain because they contain a high level of green technology (Gómez-Sánchez et al., 2022). In addition, the increase in the variety of imported green products can also contribute to domestic green technology innovation by expanding the scope of green technologies.

The second one is the imitation channel. To narrow the gap with the technological frontier, enterprises in the importing country choose to imitate the production process of the imported green product for imitative innovation throughout the process of putting the green product into production (Liu and Buck, 2007; Damijan and Kostevc, 2015).

The third is the channel of knowledge diffusion. After technologically-backward countries acquire advanced green products through import, more scientific research and technical personnel will contact and master advanced green technologies in learning, digesting and absorbing advanced technologies (Chen et al., 2017). With the flow of technological research and technical personnel among enterprises, more enterprises will have access to advanced green technology, spreading to the whole industry and improving the overall level of green technology innovation.

2.1.2. The escape competition effect of green product imports

In studying the nexus between competition and innovation, Arrow (1962) was the first to suggest that competition would prompt firms to create a competitive escape effect through innovation by comparing competitive and monopolistic markets. Usually, imported green products compete directly with green products produced by domestic firms (Smith, 2014). To protect market share and escape from a highly competitive environment, local firms are incentivised to increase investment in the R&D of green products and catch up with green technology leaders (Aghion et al., 2005; Liu et al., 2021). Therefore, such initiatives aimed at escaping market competition positively encourage firms to enhance their investment in green technology innovation. This effect is confirmed in a study by Bloom et al. (2016). They found that as China's export trade increased, the resulting import competition boosted the innovation output of European firms.

2.1.3. The competitive crowding-out effect of green product imports

In contrast to the escape competition effect, Schumpeter (1942) argues that competition can negatively affect firm-level innovation. With the increase in the import scale of green products, the intensified market competition significantly reduces their price and sales volume, resulting in limited profits for local enterprises and reducing the returns they can obtain from green technology innovation activities (Liu and Qiu, 2016). This situation is bound to harm domestic enterprises' R&D and innovation activities. Simultaneously, low market returns may force local enterprises to cease the production of green products due to the inability to guarantee enterprises' R&D investment (Autor et al., 2016), thus reducing the output of green technology innovation. Dorn et al. (2020) confirmed the existence of this effect in a study on the patent application data of manufacturing enterprises in the US. They found that products imported from China constrained the innovation of American enterprises.

2.1.4. Technology dependence effects of green product imports

In a situation where there is a huge green technology gap between the importing country and the source country, the importing country needs to invest in a full range of R&D in terms of learning, digesting and absorbing the technology around the imported green products to reach the advanced level elsewhere on the globe (Nyantakyi and Munemo, 2017). When the marginal benefits of green technologies obtained from R&D are lower than those obtained from import trade, firms will choose to use imported green products to get the related green technologies directly, weakening local firms' incentive to engage in green technology innovation. Thus, firms will become technologically dependent on green product imports. As Gereffi et al. (2005) argue, it can be challenging to learn how to work efficiently and independently in certain value chain activities, and some firms have to rely on external resources in some cases. Enterprises relying too heavily on importing advanced green intermediate goods and capital goods from abroad will reduce their green innovation ability.

Based on the analysis mentioned above, it can be found that the mechanisms by which green product imports affect green technology innovation in importing countries can be grouped into four categories, as shown in Fig. 1.

Due to a weak technological innovation foundation and high R&D costs, domestic innovation in developing countries generally depends on technologies imported from developed countries (Connolly, 2003; Michail and Savvides, 2018). In terms of China's practice in green development, although overall it is later than developed countries in Europe and the US, the level of green technology innovation has made significant progress, with a growth rate of 21.73 % in the number of green patent authorisations in the last nine years. Does the import of green products have a facilitating or inhibiting effect on green technology innovation? How does the mechanism of this effect work? These questions require empirical evidence using real-life data.

As shown in Fig. 1, there may be many different channels for the impact mechanism of green product imports on green technology innovation, so which channels play a role? Overall, is this effect positive or negative? These questions need further empirical evidence. Therefore, we propose the following hypothesis.

The direction of the impact of green product imports on green technology innovation is uncertainty.

Considering that the escape competition effect has the same

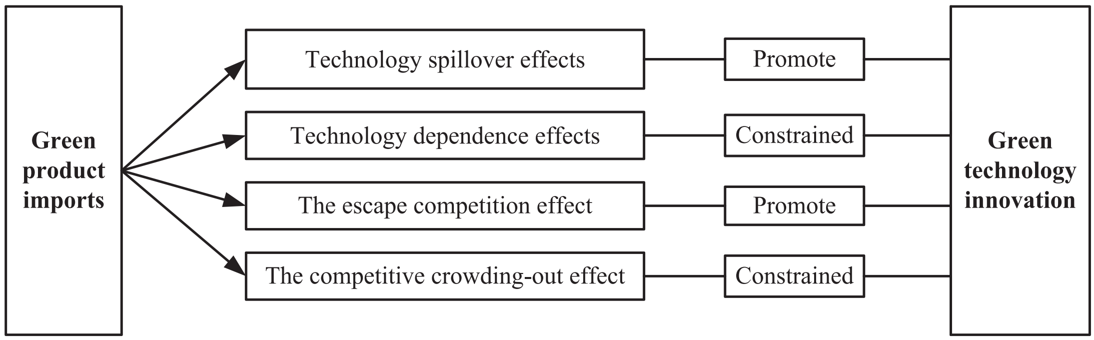

Fig. 1. The mechanisms of green products import impact green technology innovation.

influence path as a competitive crowding-out effect, the only difference is the direction of the effect, which can be collectively referred to as the import competition effect. Therefore, we examine the impact mechanism of green product imports on green technology innovation from three paths, which Hypothesis 2 explores.

H2a. The mechanism of the import of green products on China's green technological innovation is manifested as the technology spillover effects.

H2b. The mechanism of the import of green products on China's green technological innovation is manifested as the import competition effect, including the escape competition effect and competitive crowding-out effect.

H2c. The mechanism of the import of green products on China's green technological innovation is manifested as the technology dependence effects.

2.2. Non-linear impact effects

2.2.1. Green R&D investment

Green R&D investment refers to the part of R&D investment related to environmental protection and green product development, which is a direct and intrinsic factor influencing green technology innovation capability (Chen et al., 2006). Therefore, green R&D input is regarded as one of the measures of green technological innovation. Firms investing more in green R&D tend to have a strong capacity for independent innovation (Brown et al., 2017).

On the other hand, green product imports and green R&D investment are examples of exogenous factors that impact green technology innovation. Companies that invest more in green R&D typically have better capacity for independent innovation (Szczygielski et al., 2017; Dai et al., 2022), and they are less reliant on imported green products technologically. Conversely, companies that invest less in green R&D are comparatively more reliant on imported green products from abroad. Green technology obtained via independent invention competes with that obtained from imported green goods. Green technology innovation is encouraged when there is a narrow difference between the two technologies (Aghion et al., 2005); conversely, it hinders domestic green technology innovation. For this reason, it's critical to make sure that this technological divide is within acceptable bounds.

2.2.2. IPR protection

As an important support for an innovative environment, the IPR protection system significantly impacts green technology innovation (Schaefer, 2017). Innovators can apply for patents, trademarks or copyrights to ensure that their innovations are not freely used or copied by others for a certain period to obtain economic rewards, which can stimulate the motivation and commitment of innovators and promote the development and application of green technologies. Meanwhile, a robust system of IPR protection encourages innovators to communicate, collaborate, and make their innovations publicly available. This speeds up the adoption and dissemination of technology and fosters innovation by allowing knowledge to collide and mix, leading to ongoing advancements in green technology. Strengthening IPR protection helps to create a favourable environment for innovation and protects the interests of innovators, thus stimulating the output of green technology innovation.

However, excessive IPR protection may also lead to a knowledge monopoly, which is not conducive to the diffusion of green technology innovation achievements, thus inhibiting green technology innovation activities (Fang et al., 2017; Thakur-Wernz and Wernz, 2022). Innovation in green technology is hampered, and the level playing field in the market is undermined when certain innovators with strong IPR protection gain an exclusive monopoly position and use it to impede the entry and growth of other competitors. Meanwhile, excessive IPR protection can make technology more expensive to acquire and force users to pay higher fees or patent licensing costs to get the technology they require. This makes using green technologies more expensive and discourages long-term innovation.

Therefore, differences in the Green R&D investment and IPR protection level may significantly affect the effect of green product imports on green technology innovation. Accordingly, we propose the following hypothesis.

H3. Green R&D investment and IPR protection have non-linear effects on how green product imports influence green technology innovation.

3. Empirical model, variables and data

3.1. Model setting

Based on the theoretical mechanism in Fig. 1, the regression model is constructed as Eq. (1).

$$lnGTI_{i,t} = \alpha_0 + \alpha_1 lnGPI_{i,t} + \alpha_2 Z_{i,t} + \{FE\} + \varepsilon_{i,t} \quad (1)$$

where i denotes provincial regions in China and t indicates the year. $GTI_{i,t}$. This means the output of green technology innovation $GPI_{i,t}$ represents the total import of green products, $Z_{i,t}$ is the control variable, $\{FE\}$ is the individual and time-fixed effects; $\varepsilon_{i,t}$ is the error term.

3.2. Definition of variables

3.2.1. Explained variable

3.2.1.1. Green technology innovation (GTI). Referring to Ghisetti and Quatraro (2017), the number of patents granted is used as a proxy variable for GTI. Patent data can be decomposed according to the technology field, quality or output subject, which has certain advantages in measuring GTI. Green patents include green invention patents and green utility model patents. The former is based on primary innovation technologies that save energy and reduce emissions, aiming to develop new products that are differentiated in terms of structure, performance and use. The latter is based on the secondary innovation technology of energy saving and emission reduction, which aims to extend the functions and improve the technology of existing products without significantly changing the technical principles of the original products.

According to the Green Patent Inventory (World Intellectual Property Organisation, 2010), green patents can be classified into seven categories: transportation, waste management, energy conservation, alternative energy production, administrative, regulatory or design aspects, agriculture/forestry, and nuclear power generation. According to the Patent Search and Analysis platform from the China National intellectual property Administration, patents fall into two categories: invention patents and utility model patents. In addition, Beneito (2006) pointed out that invention patents are similar to innovations with more innovative content, while utility model patents are similar to incremental innovations. To further test the impact of green product imports on GTI types, this study further subdivides GTI into radical-type technology innovation (RGTI) and incremental-type green technology innovation (IGTI). The former is measured by the number of green invention patents granted, the latter measured by the number of green utility model patents granted. Data is derived from the China National intellectual property Administration.

3.2.2. Explanatory variables

3.2.2.1. Green products imports (GPI). We chose GPI to reflect the import status of green products in China. According to Eurostat's green product classification methodology and referring to the STIC2 five-digit code classification of Fraccascia et al. (2018), green products were divided into "green fuels, green energy sources, green chemicals, green machinery and transport equipment, green manufactured products, green oil products and other green products". The corresponding STIC2 five-digit code and the specific green products for each category are shown in Appendix A. Based on the import value of green products, the corresponding categories are aggregated separately to obtain the final total import value. Specifically, this can be seen in Eq. (2).

$$GPI_{i,t} = GFI_{i,t} + GESI_{i,t} + GCI_{i,t} + GMTEI_{i,t} + GMPI_{i,t} + GOPI_{i,t} + OGPI_{i,t} \quad (2)$$

where $GFI_{i,t}$, $GESI_{i,t}$, $GCI_{i,t}$, $GMTEI_{i,t}$, $GMPI_{i,t}$, $GOPI_{i,t}$ and $OGPI_{i,t}$represents imports of green fuels, green energy sources, green chemicals, green machinery and transport equipment, green manufactured products, green oil products, and other green products, respectively.

Under the classification of various purposes of use, to further test whether the impact of imported green products on GTI is heterogeneous, according to the Broad Economic Categories (BEC) (United Nations Statistical Office, 2012), green products are divided into three categories, namely green intermediate, final green consumer, and green capital products.

Therefore, according to this criterion, the import of green products can be decomposed according to Eq. (3).

$$GPI_{i,t} = IGIP_{i,t} + IGCOG_{i,t} + IGCAG_{i,t} \quad (3)$$

where $IGIP_{i,t}$, $IGCOG_{i,t}$, $IGCAG_{i,t}$, in turn, represents imported green intermediate products, imported green consumer goods, and imported green capital goods.

3.2.3. Control variables

The following variables were set as control variables to reduce the estimation bias caused by missing variables.

3.2.3.1. Industrial green production capacity (IGPC). Since ISO14001 was introduced into the environmental management system, green production has gradually changed from an option to a mandatory requirement in companies' production methods (Baah et al., 2021). As the main sector of resource consumption and pollutant emissions, the industrial sector is also the output sector of technological innovation. In industry-related fields such as industrial and transportation, chemistry and metallurgy, textiles and paper production, fixed construction, mechanical engineering, physics, electricity and other manufacturing segments, the share of inventions and utility models of patents granted reached 85.38 % in 2020. It can be found that the industrial sector's investment in pollution control has led to the upgrading of production processes, process re-engineering and technological iterations, which not only improves the IGPC but also promotes GTI (Lin and Chen, 2020). Therefore, the ratio of input to output in pollution control can measure the level of green production in a region or industry. Considering data availability, the proportion of investment completed in treating industrial pollution to value-added by industry is a proxy variable for IGPC in this study.

3.2.3.2. Government innovation support (GIS). Government investment in science and technology will enable enterprises to obtain more funding for R&D, which provides strong financial support for enterprises' GTI. This study uses the proportion of local government expenditure on science and technology to local governments' general budgetary expenditure to measure it.

3.2.3.3. Environmental protection efforts (EPE). Environmental protection expenditure represents the extent of government investment in environmental governance, which can be divided into environmental protection and pollution control. It promotes green technological innovation in terms of accelerating the construction of regional facilities, creating a good green innovation environment, and guiding the environmental awareness of innovation agents. Based on this, it is measured by the proportion of the local government's expenditure on environmental protection to the local government's general budgetary expenditure.

3.2.3.4. Regional absorptive capacity (RAC). RAC is the combined ability of enterprises in a regional economic system to acquire, digest and exchange knowledge. Escribano et al. (2009) argue that enterprises with higher absorptive capacity can manage external knowledge flows more effectively and stimulate innovative outcomes. Per capita GDP is used to measure the regional absorption capacity.

3.2.3.5. Fixed capital stock (FCS). Gross fixed capital formation heavily influences economic growth and is a direct source of economic growth, which influences GTI. The perpetual inventory method calculates gross fixed capital formation. It deflates it by using the 2012 price index for investment in fixed assets as the base period to obtain the FCS for each year.

3.2.3.6. Human capital (HC). Guo (2021) found that increasing the introduction of high-tech talent can promote the accumulation of HC and thus improve enterprises' GTI levels. Referring to Guo (2021), this study uses the number of graduates with degrees or diplomas in higher education institutions to measure HC.

3.2.3.7. Total energy consumption (TEC). As the level of energy consumption increases, the total emission of pollutants will also increase substantially, and the demand for GTI will continue to expand, providing realistic conditions for improving regional green innovation capacity. To measure the TEC, the coefficient of converting various types of energy into standard coal is used as a weight to synthesise various primary energy sources consumed.

3.3. Variable selection and data collection

Considering data availability, 30 provincial-level regions in China were taken as samples; we excluded Hong Kong, Macao, Taiwan and Tibet. The sample spans 2012 to 2020.

The data on green patents come from the China National Intellectual Property Administration. We identify the green patents belonging to each province according to the Green Patent Inventory issued by the World Intellectual Property Organisation. The import data of green products is obtained from the General Administration of Customs of China's Customs Statistics Online Query Platform and the ESP database. Other data are mostly gathered from official statistics such as the China Statistical Yearbook and the China Energy Statistical Yearbook for the relevant years. We completed the missing data in some years with the average annual growth rate of the indicator during the sample period. All the monetary value indicators have been updated to 2012 GDP constant prices.

It is worth noting that Fraccascia et al. (2018) proposed a statistical scope for green products based on the Standard International Trade Classification (SITC), Revision 2, established by the United Nations. However, the statistics of import and export goods by the General Administration of Customs of the People's Republic of China are based on the Harmonised Commodity Description and Coding System (HS, including HS2012, HS2017 and HS2022) issued by the World Customs Organisation (2020) (formerly known as the Customs Cooperation Council). Considering the above facts, a code-matching relationship between the SITC2 and HS classifications must be established.

The following steps were adopted in data collation. The first step is to convert the SITC2 code of green products to the corresponding HS2012 code by referring to the corresponding table of general product categories published by the Department of Economic and Social Affairs Statistics of the United Nations (see Appendix B for details). Second, according to the converted HS2012 code of green products, the relevant data of The General Administration of Customs of the People's Republic of China and the Express Professional Superior (EPS) database are used to sort out the import value of green products in each provincial region of China from 2012 to 2020. The variables and the sources of the data are shown in Table 1.

3.4. Descriptive statistics

Table 2 shows the descriptive statistics of each variable. The variance inflation factor (VIF) test was conducted to check the existence of multicollinearity among variables. It can be found in Table 2 that the VIF of explanatory variables are all less than 10, so it can be considered that there is no multicollinearity.

Table 2
Descriptive statistics.

Variable	N	Mean	Sd	Min	Max
lnGTI	270	7.7626	1.3211	3.6889	10.7858
lnGPI	270	9.8760	2.5105	0.3914	14.0527
lnIGPC	270	5.5257	0.8833	2.1833	8.0386
GIS	270	2.1263	1.4750	0.5392	6.7569
EPE	270	2.9950	0.9575	1.1787	6.8141
RAC	270	1.5975	0.4359	0.6391	2.8789
lnFCS	270	3.9347	0.7646	1.5510	5.4644
HC	270	2.9047	0.8244	0.1537	4.1560
lnTEC	270	2.5339	0.6483	0.4706	3.7335

Table 1
Summary of variables.

Type	Variable	Definition	Measurement	Data sources	Missing value handling	Year
Explained variable	GTI	Green technology innovation	The sum of green invention patent authorisations and green utility model patents	Patent Search and Analysis platform from the China National Intellectual Property Administration	None	2012–2020
Explanatory variable	GPI	Green product imports	The product import value of green products and the exchange rate of the US dollar against RMB	Customs statistics online enquiry platform and EPS database	None	2012–2020
Control variables	IGPC	Industrial green production capacity	The ratio of investment completed in the treatment of industrial pollution to value-added of industry	China Statistical Yearbook	None	2012–2020
	GIS	Government innovation support	The ratio of local governments' expenditure on science and technology to local governments' general budgetary expenditure	China Statistical Yearbook	None	2012–2020
	EPE	Environmental protection efforts	The ratio of local governments' expenditure on environmental protection to local governments' general budgetary expenditure	China Statistical Yearbook	None	2012–2020
	RAC	Regional absorptive capacity	Per capita GDP, and deflating using 2012 as the base period	China Statistical Yearbook	None	2012–2020
	FCS	Fixed capital stocks	Use the perpetual inventory method to calculate gross fixed capital formation and deflate it using the 2012 price index for investment in fixed assets as the base period to obtain the fixed capital stock for each year.	China Statistical Yearbook	The fixed asset investment growth rate over the prior year is used to estimate missing data for 2019 and 2020.	2012–2020
	HC	Human capital	Number of graduates with degrees or diplomas in institutions of higher education	China Statistical Yearbook	None	2012–2020
	TEC	Total energy consumption	Total primary energy consumption converted to standard coal	China Energy Statistics Yearbook	The average growth rate of the past eight years is extrapolated to fill up some lacking provincial data for 2020.	2012–2020

4. Empirical results

4.1. Baseline model

Column (1) in Table 3 shows the regression results for fixed effects without controlling for region and year. The core explanatory variable's regression coefficient is −0.0067; however, it fails the significance test at the 10 % level. Additionally, after adding the fixed effects of region and year (Column (2) of Table 3), the regression coefficient of the core explanatory variable becomes −0.0565, which has significance at the 5 % level, that is, when the import of green products increases by 1 %, the average regional green innovation level decreases by 0.0565 %. The aforementioned findings show that when region and year effects are fixed, the absolute value of the regression coefficient on the core explanatory variable (*lnGPI*) increases, which means that its inhibitory effect on GTI is enhanced. Simultaneously, we also find that the coefficient's variation range is small, indicating that the regression results are relatively robust.

Additionally, the results of control variables in Table 3 mostly match expectations. The coefficients of fixed capital stocks (lnFCS), total energy consumption (ln TEC) and regional absorptive capacity (RAC) are all positive, which is consistent with the results of Shang et al. (2022), indicating that the improvement of all these variables encourages green technology innovation. Total energy consumption (ln TEC) passed the significance test at the 1 % level. Government innovation support (GIS), environmental protection The coefficients of Government innovation support (GIS), Environmental protection efforts (EPE) and Human capital (HC) are also positive, indicating that the greater government subsidies and the larger human capital, the more favourable this is to green technological innovation, in which Human Capital (HC) passes the significance test at the 10 % level.

To further reveal the difference in GTI quality affected by the import of green products, we divided the GTI into RGTI and IGTI. Invention patents measure the former, while the latter includes utility model patents. Columns (3) and (4) in Table 3 show these two kinds of GTI regression results. It can be seen that the effect of green product imports on IGTI is −0.0631 and passes the significance test at the 5 % level, while the effect of green product imports on RGTI is not significant.

Table 3
Baseline results.

Variable	GTI	GTI	RGTI	IGTI
	(1)	(2)	(3)	(4)
lnGPI	−0.0067	−0.0565**	−0.0346	−0.0631**
	(0.015)	(0.025)	(0.044)	(0.023)
lnIGPC	−0.2200***	−0.1076	−0.0103	−0.1311
	(0.042)	(0.080)	(0.032)	(0.085)
GIS	0.2394***	0.0438	0.0702	0.0383
	(0.022)	(0.039)	(0.054)	(0.045)
EPE	0.0463**	0.0355	0.0037	0.0411
	(0.023)	(0.030)	(0.023)	(0.033)
RAC	0.7124***	0.4994	−0.5346	0.8244
	(0.078)	(0.479)	(0.909)	(0.596)
lnFCS	0.5001***	0.3086	0.8433**	0.1865
	(0.080)	(0.261)	(0.368)	(0.251)
HC	0.5371***	0.3740*	−0.0618	0.4825*
	(0.062)	(0.212)	(0.252)	(0.241)
lnTEC	0.0334	0.8865***	0.0745	1.0181***
	(0.072)	(0.281)	(0.258)	(0.326)
Year FE	No	Yes	Yes	Yes
Province FE	No	Yes	Yes	Yes
Observations	270	270	270	270
R-squared	0.928	0.918	0.893	0.903

Note: The numbers in parentheses represent standard errors for the corresponding variables.
* Statistical significance at the 10 % level.
** Statistical significance at the 5 % level.
*** Statistical significance at the 1 % level.

The reason for this phenomenon may be that IGTI mainly focuses on updating and improving the existing technology and has strong substitutability, which results in the import of green products and inhibits progressive GTI due to the strong substitution effect. Correspondingly, because of the high input cost and high technology content, the technology substitution effect of RGTI is relatively small, which makes the inhibiting effect of green product imports insignificant. Based on the above analysis, it can be concluded that the import of green products significantly negatively impacts GTI.

4.2. Robustness tests

4.2.1. Replacing the explanatory variable

According to the practice of Zhou and Wang (2022), the explained variable was replaced by green patent authorisation with the green patent application, the green invention patent applications were used to measure the RGTI and the green utility model applications were used to measure the IGTI.

Corresponding regression results can be seen in columns (1) to (3) in Table 4. It can be found that the regression results after replacing the explained variables are highly consistent with the results in Table 3. It means that the overall impact of green product imports on GTI is still significantly negative, and it has a significant negative impact on IGTI but has no impact on RGTI.

4.2.2. Adjusting the sample period

COVID-19 has seriously impacted the global supply chain, and the global trade of green products has been negatively affected. To test the stability of the baseline regression results, by referring to Silliman and Virtanen (2022), we deleted the year 2020, when the outbreak of COVID-19 was complete, from the sample and shortened the sample period to 2012–2019. After adjusting the sample period, the corresponding regression results can be shown in columns 4 to 6 in Table 4. It can be found that these results are highly consistent with the baseline regression.

4.2.3. Endogeneity tests

4.2.3.1. Instrumental variable approach. A higher level of GTI may result in a greater demand for green product imports, making the above empirical results biased by endogeneity and reverse causality. Geng et al. (2021) used Shift-Share IV to deal with endogeneity. The basic practice is to multiply the initial share by the rate of increase in imports of goods other than the original product. The estimated result is highly correlated with the actual value but not with the residual term. The green product imports in 2012 were taken as the base period level, and the average annual growth rate was used to calculate the estimated value of the green product imports each year in the sample observation period to construct the shift-share instrumental variable.

Columns (1)–(3) in Table 5 demonstrate that, for IGTI and overall innovation, the results are still robust when the instrumental variables approach endogeneity is used. Additionally, the weak instrumental variables test (Hansen J statistics) and over-identification test (C-D wald F statistics) met the significance test, indicating that the instrumental variables' setting was reasonable and the conclusion was credible. It is worth noting that after regression with instrumental variables, the impact of green product imports on RGTI is significantly negative, but its over-identification test fails (Hansen J statistics is 0.028). Therefore, it is considered that the regression result is not credible, and its true negative effect does not exist.

4.2.3.2. GMM estimation. Although a series of variables related to regional characteristics and fixed effects features such as time and region are controlled for in the baseline regression, endogenous estimation bias may still be caused by missing the unobserved heterogeneity factors

Table 4
Robustness test.

Variable	Replacing the explanatory variable			Adjusting the sample period		
	(1)	(2)	(3)	(4)	(5)	(6)
	GTI	RGTI	IGTI	GTI	RGTI	IGTI
lnGPI	−0.0537***	−0.0147	−0.1014***	−0.0629***	−0.0300	−0.0686***
	(0.018)	(0.020)	(0.025)	(0.022)	(0.050)	(0.019)
lnIGPC	−0.0659*	−0.0560**	−0.0713	0.0033	0.0228	−0.0139
	(0.033)	(0.026)	(0.048)	(0.031)	(0.038)	(0.033)
GIS	0.1049***	0.1727***	0.0296	0.0210	0.0431	0.0223
	(0.028)	(0.029)	(0.042)	(0.031)	(0.050)	(0.040)
EPE	0.0169	0.0254	0.0013	0.0141	0.0027	0.0162
	(0.022)	(0.019)	(0.030)	(0.021)	(0.023)	(0.024)
RAC	0.6850	0.5008	0.8499	−0.0323	−0.8098	0.2803
	(0.480)	(0.512)	(0.610)	(0.492)	(1.113)	(0.612)
lnFCS	0.2331	0.3379	0.1453	0.4410*	0.8125*	0.3472
	(0.278)	(0.297)	(0.284)	(0.255)	(0.406)	(0.255)
HC	0.1093	−0.0643	0.2985	0.4598**	0.1214	0.5296**
	(0.223)	(0.268)	(0.219)	(0.204)	(0.280)	(0.240)
lnTEC	0.6764**	0.3510	0.9590***	0.7306**	0.0075	0.8493**
	(0.292)	(0.280)	(0.319)	(0.290)	(0.296)	(0.355)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	270	270	270	240	240	240
R-squared	0.942	0.899	0.940	0.931	0.878	0.907

Note: The numbers in parentheses represent standard errors for the corresponding variables.
* Statistical significance at the 10 % level.
** Statistical significance at the 5 % level.
*** Statistical significance at the 1 % level.

Table 5
Endogeneity tests.

Variable	IV approach			GMM		
	(1)	(2)	(3)	(4)	(5)	(6)
	GTI	RGTI	IGTI	GTI	RGTI	IGTI
lnGPI	−0.1764***	−0.1768***	−0.1825***	−0.0528**	−0.0395	−0.0631***
	(0.056)	(0.041)	(0.070)	(0.020)	(0.053)	(0.022)
lnIGPC	−0.1653***	−0.0607**	−0.2197***	−0.0548	0.0109	−0.0768
	(0.058)	(0.027)	(0.066)	(0.060)	(0.035)	(0.060)
GIS	0.0799***	0.0985***	0.0869***	−0.0046	0.0176	−0.0152
	(0.030)	(0.037)	(0.033)	(0.032)	(0.035)	(0.041)
EPE	0.0080	−0.0153	0.0188	0.0406	0.0189	0.0541
	(0.023)	(0.020)	(0.026)	(0.030)	(0.015)	(0.045)
RAC	1.9746***	0.7752**	2.3055***	0.6990	−0.3508	0.9371
	(0.280)	(0.345)	(0.312)	(0.640)	(0.783)	(0.627)
lnFCS	−0.0170	0.9084***	−0.3137	−0.1040	0.4329	0.0130
	(0.188)	(0.235)	(0.199)	(0.413)	(0.276)	(0.398)
HC	0.4819*	−0.1272	0.6368**	0.0604	−0.0073	0.0868
	(0.254)	(0.206)	(0.298)	(0.362)	(0.268)	(0.479)
lnTEC	1.0968***	−0.3226	1.4132***	0.2908	−0.5213	0.3856
	(0.215)	(0.287)	(0.239)	(0.388)	(0.317)	(0.502)
lnGTI (−1)				0.7487**	0.2357	0.7475**
				(0.312)	(0.166)	(0.351)
AR (2)				0.209	0.275	0.284
Hansen P	0.276	4.780	0.001	0.687	0.737	0.755
p-Value	[0.5993]	[0.0288]	[0.9740]			
C-D wald F	36.846	36.846	36.846			
Year FE	Yes	Yes	Yes			
Prov FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	240	240	240	Yes	Yes	Yes
R-squared	0.834	0.808	0.813	210	210	210

Note: The numbers in parentheses represent standard errors for the corresponding variables. The C-D wald F test usually uses the 15 % critical value (11.59) as the comparison standard. Since the value of the C-D wald F statistic in the table is greater than 11.59, it can be considered that there is no endogenous instrumental variable.
* Statistical significance at the 10 % level.
** Statistical significance at the 5 % level.
*** Statistical significance at the 1 % level.

in the region. In addition, considering that the impact of innovation might last for a long time (Nesta et al., 2014), the GMM method was further used to test this.

According to the regression results in columns (4) to (6) in Table 5, the sign and significance of explanatory variables have not changed significantly compared with the benchmark model. The autocorrelation test of the residual series showed no second-order autocorrelation of the residual terms, and the Hansen P statistics of the overidentification test were greater than the significance level of 5 %. Through the tests mentioned above, it can be concluded that endogeneity does not significantly impact the baseline regression model.

5. Discussions

5.1. Mechanism tests

According to the empirical analysis in Section 5, we found that importing green products significantly inhibits China's GTI. Analysing the mechanism of this negative effect has an important role in policy-making. Therefore, more empirical data regarding the mechanism of action are required. The following econometric model is set up in this work to analyse the mechanism, with reference to Liu and Qiu (2016).

$$lnC_{i,t} = \lambda_0 + \gamma_1 lnGPI_{i,t} + \lambda_2 Z_{i,t} + \{FE\} + \varepsilon_{i,t} \tag{4}$$

Eq. (4) $lnC_{i,t}$ represents a group of channel variables; the corresponding variables are selected for the technology spillover, technology dependence, and import competition effects, respectively. The other variables have the same meanings as Eq. (1). The test results are shown in Table 6.

5.1.1. Technology spillover effects tests

Section 2 demonstrates how the technology spillover mechanism of green product imports is realised through acquiring knowledge and technology about imported products and the increase in R&D marginal revenue brought about by using imported products to promote the expansion of GTI output.

Therefore, two variables are selected as the channel variables for analysing the technology spillover effect: digestion and absorption expenditure (DAE) and Marginal benefit (MB). DEA is measured by expenditure on integrating the technology of industrial enterprises above the designated size. In contrast, MB is measured by the ratio of sales revenue of new products of industrial enterprises above the designated size to the total number of green patents granted. The former assesses the capacity for learning to absorb information and new technologies from imported goods, while the latter shows the marginal benefit of import trade spillovers on technological innovation. Considering data availability, the statistics of industrial enterprises above the designated size are adopted for the above two indicators, and the data are from the China Statistical Yearbook on Science and Technology. The regression results are displayed in columns (1) and (2) of Table 6. The core explanatory variables are not significant, which indicates that the technology spillover effect of green product imports on GTI is very weak. Therefore, the assumption that H2a can be considered invalid.

5.1.2. Import competition effects tests

As an indirect influence of import on GTI, import competition has positive and negative effects (Dorn et al., 2020). With the expansion of the import scale of green products, the import competition is constantly intensified, which motivates local enterprises to increase their R&D investment in green products to stay ahead of the competition. In contrast, the fierce competition will greatly reduce the return on GTI, which may inhibit the investment in green research and development of enterprises. We observe that R&D investment is the key to determining the positive or negative effect of imports, i.e., escape competition or competitive crowding-out effect. Therefore, the mechanism test selects green R&D investment () as a channel variable. Hypothesis H2b cannot be validated because it is clear from column (4) of Table 6 that the regression coefficient of green product imports on green R&D investment is not significant. This shows that the mechanism of import competition effects of green product imports is invalid.

5.1.3. Technology dependence effects tests

GTI often has high sunk costs, which leads to weak innovation incentives for local enterprises and high dependence on green product imports. The technology dependence on green products imports ($TDGPI_{i,t}$) is defined as follows.

$$TDGPI_{i,t} = \frac{GPI_{i,t}}{GPI_{i,t} + GRDI_{i,t}} \tag{5}$$

Eq. (5), $GPI_{i,t}$ represents the imports of green products and$GRDI_{i,t}$denotes green R&D investment. Eq. (6) can be used to measure the estimation of this value. Eq. (6) refers to Hamamoto (2006) by building a relationship between environmental constraints and R&D inputs and removing the portion of R&D inputs used to implement environmental.

$$GRDI_{i,t} = \theta_1 \times \left[\frac{\left(ERI_{i,t} - ERI_{i,t-1}\right)}{ERI_{i,t-1}}\right] \times RDI_{i,t} \tag{6}$$

θ_1 in Eq. (6) can be estimated by Eq. (7).

$$lnRDI_{i,t} = \delta + \theta_1 lnERI_{i,t} + \theta_2 lnGS_{,t} + \theta_3 lnIVA_{,t} + \eta_i + \lambda_t + \varepsilon_{i,t} \tag{7}$$

Eq. (7), $RDI_{i,t}$ represents the R&D activities funds; $ERI_{i,t}$is pollution control expenditure measured by per capita disposable income nationwide, representing the degree of environmental constraints; regions with higher incomes usually have a higher demand for environmental quality, and areas with high per capita disposable income have higher government requirements for environmental quality, so refer to Xu (2000) and Antweiler et al. (2001), using per capita disposable income to approximate alternative pollution control expenditure; $GS_{i,t}$ denotes government subsidies and is measured by the government funding portion of R&D expenditure; $IVA_{i,t}$ represents value-added of industry; δ, η_i, λ_t and $\varepsilon_{i,t}$ denote the constant term, area fixed effects, time-fixed effects and the error term, respectively.

i in Eqs. (6) and (7) denotes the 30 provincial regions of China (excluding Tibet, Hong Kong, Macao and Taiwan); t and represent the year. The GRDI estimated by Eqs. (6) and (7) was deflated using the R&D

Table 6
Mechanism tests.

Variable	Technology spillover effects		Technology dependence effects	Import competition effects
	(1)	(2)	(3)	(4)
	DAE	MB	TDGPI	GRDI
lnGPI	0.0898	0.0123	0.1222***	−0.0006
	(0.398)	(0.059)	(0.023)	(0.001)
lnIGPC	0.1636	0.0475	−0.0102	−0.0006
	(0.254)	(0.056)	(0.010)	(0.002)
GIS	0.6048**	−0.0452	−0.0206*	0.0050**
	(0.253)	(0.061)	(0.012)	(0.002)
EPE	0.0334	−0.0082	−0.0138	0.0022**
	(0.242)	(0.049)	(0.009)	(0.001)
RAC	6.8600	0.2480	−0.1734	0.0347
	(8.227)	(1.308)	(0.184)	(0.038)
lnFCS	−1.1049	0.9496*	0.2235*	0.0317**
	(1.552)	(0.494)	(0.117)	(0.014)
HC	−2.3084	−0.1835	−0.1530*	−0.0059
	(2.531)	(0.475)	(0.077)	(0.015)
lnTEC	−1.2377	−0.0244	−0.0291	−0.0090
	(1.886)	(0.400)	(0.087)	(0.015)
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Observations	270	270	270	270
R-squared	0.458	0.576	0.771	0.985

Note: The numbers in parentheses represent standard errors for the corresponding variables.
* Statistical significance at the 10 % level.
** Statistical significance at the 5 % level.
*** Statistical significance at the 1 % level.

price index, which in China is usually calculated using Eq. (8) (Zhu and Xu, 2003):

$$RDIPI_{i,t} = 0.45 \times IFAPI_{i,t} + 0.55 \times CPI_{i,t} \tag{8}$$

where $IFAPI_{i,t}$ denotes the price index for investment in fixed assets and $CPI_{i,t}$ represents the consumer price index. All data are from the China Statistical Yearbook.

The regression results from column (3) in Table 6 show that the import of green products significantly positively impacts the technology dependence on green products. It means the existence of technology dependence effects and the import of green products significantly inhibit GTI. Therefore, hypothesis H2c is confirmed.

When the above impact mechanism test and the results of the benchmark regression analysis are combined, this paper can conclude that, on the one hand, green product imports cannot significantly positively influence enterprises to promote green technological innovation through learning advanced knowledge and technology, and cannot promote enterprises to improve the marginal returns of technological innovation and promote the enthusiasm of enterprises' independent innovation. On the other hand, green product imports do not significantly affect domestic green R&D inputs, so green product imports do not affect domestic green technological innovation output via import competition escape or import competition crowding-out. However, empirical testing of the green product technology dependence effect reveals that green product imports significantly promote the country's import technology dependence and that the greater the trade volume of green product imports, the greater the country's dependence on imported green products, and thus the more unfavourable to the improvement of green technology innovation output. Overall, the impact mechanism of green product imports on green technology innovation is primarily the effect of import technology dependence, confirming hypothesis H2c. As mentioned above, although the number of green patent authorisations in China is growing rapidly due to the late start of green technology R&D, there is still a high reliance on green product imports, which leads to the lack of impetus for green innovation in domestic enterprises.

5.2. Moderating effects tests

The following econometric model is constructed to test whether hypothesis 3 and hypothesis 4 are valid, that is, whether green product imports will have a non-linear impact on GTI via the positive moderating effect of green R&D investment and IPR protection.

$$lnGTI_{i,t} = \alpha_0 + \alpha_1 lnGPI_{i,t} + \beta_1 lnM_{i,t} + \eta_1 lnGPI_{i,t} \times lnM_{i,t} + \alpha_2 Z_{i,t} + \{FE\} + \varepsilon_{i,t} \tag{9}$$

$M_{i,t}$ in Eq. (9) represents the moderator variable, which can be set as green R&D input ($GRDI_{i,t}$) and intensity of IPR protection ($IPRP_{i,t}$), respectively. Considering data availability, we define the $IPRP_{i,t}$ in a region as the ratio of technology market turnover to regional GDP. Other variables have the same meaning as Eq. (1), and the data are from the China Statistical Yearbook on Science and Technology.

It is worth noting that the actual intensity of green R&D investment and IPR protection is often affected by the level of regional economic development, which may make the moderating effects of the variable $GRDI_{i,t}$ and $IPRP_{i,t}$ on the green product imports and the green technology innovation significantly different. Referring to the World Bank's (2020) criteria for high-income countries (per capita GNP greater than US$12,500), and in combination with China's unbalanced regional economic development, we use per capita GDP to divide 30 provinces into three categories: developed region group (Beijing, Shanghai, Jiangsu, Fujian, Tianjin, Zhejiang, Guangdong), medium-developed region group (Chongqing, Hubei, Shandong, Inner Mongolia, Shaanxi, Hunan, Anhui, Liaoning, Sichuan, Jiangxi, Hainan, Ningxia), and undeveloped region group (Henan, Xinjiang, Yunnan, Shanxi, Qinghai, Jilin, Hebei, Guizhou, Guangxi, Heilongjiang, Gansu), with per capita GDP greater than US$ 12,500, between US$ 7950 and US$ 12,500, and less than US$ 7950, respectively. The moderating effect test was conducted in each of the three sub-samples and used as a benchmark model to compare the moderating effect with green R&D investment and IPR protection, with the corresponding results in columns (1), (4), and (7) in Table 7.

5.2.1. The moderating effect of green R&D investment

The test results are displayed in columns (2), (5), and (8) in Table 7. We found that in the developed region (column (2)) and undeveloped region (column (8)) groups, the regression coefficient of the interaction term between green R&D input and green product imports is positive and statistically significant. However, in the medium-developed region group (column (5)), the coefficient of this interaction term is negative and significant. This indicates that green R&D investment weakens the negative effect of green product imports on GTI in developed and underdeveloped regions.

The economically developed regions' independent innovation ability is strong, so independent innovation can effectively weaken the innovation inhibition effect of green product imports. For undeveloped regions, the overall scale of green product imports is small, which leads to greater flexibility of independent R&D. Therefore, as long as regions can invest in green research and development to a certain extent, they can obtain excess returns and have a significant moderating effect. However, the medium-developed regions have neither the technical level of the developed regions nor the higher elasticity of R&D input of underdeveloped regions, which makes the moderating effect of green R&D input significantly positive. Therefore, the R&D investment component of hypothesis H3 is confirmed.

5.2.2. The moderating effect of the intensity of IPR protection

Columns (3), (6), and (9) in Table 7 display the test results. In the developed region group, we found that the regression coefficient of the interaction term between IPR protection and green product imports is positive but not statistically significant (column (3)). The regression coefficient of this interaction term is negative in the medium-developed region group (column (6)) and is not statistically significant.

Unlike developed and moderately developed regions, in the underdeveloped region group (Column (9)), IPR protection and green product imports significantly negatively impact GTI. The regression coefficient of the interaction term of the two is positive. It passes the significance test at the 5 % level, indicating that strengthening IPR protection in underdeveloped regions will significantly enhance the inhibiting effect of green product imports on GTI.

This occurs because underdeveloped regions have a smaller green product import scale, fewer learning opportunities depending on imports and a larger distance from the world's technological frontier. If intellectual property protection is strengthened, it will only hinder enterprises from learning and imitating imported green products and further aggravate the inhibiting effect of improving regional green technology innovation ability. Based on the above analysis, we found that IPR protection has an obvious moderating effect, and the IPR protection component of hypothesis H3 is confirmed.

5.3. Heterogeneity analysis from the perspective of green product classification

To further investigate whether different types of imported green products impact GTI differently, we conducted a heterogeneity analysis from three perspectives: purposes of use, product quality and product attributes. The regression model still adopts Eq. (1).

According to the purpose of use, green products are divided into green intermediate goods, green consumer goods and green capital goods. The corresponding regression results are in columns 1 to 3 of

Table 7
Moderating effects in subsamples.

Variable	Green technology innovation – Group developed region			Green technology innovation – Group-medium-developed region			Green technology innovation – Group undeveloped region		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
lnGPI	−0.1121***	−1.2913***	−0.1833	−0.0614	0.1440***	−0.0735	−0.0468	−0.0596	−0.1530**
	(0.019)	(0.188)	(0.269)	(0.061)	(0.043)	(0.073)	(0.031)	(0.035)	(0.053)
lnIGPC	0.0217	0.0317**	0.0272*	−0.2383	−0.1918	−0.2557	−0.0286	−0.0164	−0.0196
	(0.012)	(0.013)	(0.013)	(0.143)	(0.113)	(0.145)	(0.029)	(0.025)	(0.027)
GIS	0.0146	0.0233	0.0114	0.1096	0.0943	0.1190	0.0511	−0.0518	0.0760
	(0.025)	(0.021)	(0.031)	(0.073)	(0.069)	(0.071)	(0.117)	(0.107)	(0.098)
EPE	0.0317**	0.0407***	0.0301**	0.0226	−0.0318	0.0268	−0.0027	−0.0143	−0.0149
	(0.011)	(0.010)	(0.011)	(0.048)	(0.047)	(0.050)	(0.037)	(0.027)	(0.037)
RAC	−0.8043**	−0.4768	−0.7766**	1.5290	1.5440	1.6522	−0.3923	−0.4270	−0.1644
	(0.261)	(0.324)	(0.232)	(1.114)	(1.003)	(1.146)	(0.670)	(0.368)	(0.703)
lnFCS	2.1196***	1.9448***	1.8410***	−0.0635	−0.3774	−0.0384	0.8105	0.5872*	0.9708*
	(0.261)	(0.334)	(0.417)	(0.340)	(0.500)	(0.387)	(0.602)	(0.295)	(0.456)
HC	0.2928	0.6102*	0.5121	0.1677	0.5005	0.2321	0.1753	−0.1168	−0.0574
	(0.299)	(0.257)	(0.336)	(0.362)	(0.373)	(0.346)	(0.585)	(0.289)	(0.480)
lnTEC	−1.5251***	−1.5829***	−1.1906*	1.3370***	1.7359***	1.3549***	0.1708	−0.0411	0.3357
	(0.330)	(0.257)	(0.589)	(0.282)	(0.338)	(0.260)	(0.459)	(0.310)	(0.459)
lnGRDI		−6.9359***			7.0103			14.3843***	
		(1.410)			(4.357)			(4.418)	
lnGPI×lnGRDI		0.2736***			−0.1018***			0.0374*	
		(0.043)			(0.026)			(0.019)	
lnIPRP			−0.1922			−0.0898			−0.1735**
			(0.472)			(0.215)			(0.055)
lnGPI×lnIPRP			0.0091			0.0045			0.0224**
			(0.037)			(0.020)			(0.008)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	63	63	63	108	108	108	99	99	99
R-squared	0.985	0.988	0.986	0.919	0.933	0.920	0.938	0.959	0.943

Note: The numbers in parentheses represent standard errors for the corresponding variables.
* Statistical significance at the 10 % level.
** Statistical significance at the 5 % level.
*** Statistical significance at the 1 % level.

Table 8
Heterogeneity analysis results from the perspective of the purpose of use and product quality.

Variable	Purposes of use			Product quality		
	Green intermediate goods	Green consumer goods	Green capital goods	High-value green products	Medium-value green products	Low-value green products
	(1)	(2)	(3)	(4)	(5)	(6)
lnGPI	−0.0280**	0.0005	−0.0453**	−0.0526**	−0.0327**	0.0059**
	(0.013)	(0.006)	(0.022)	(0.024)	(0.014)	(0.003)
lnIGPC	−0.1025	−0.0993	−0.0997	−0.1026	−0.0988	−0.0966
	(0.080)	(0.080)	(0.079)	(0.078)	(0.080)	(0.076)
GIS	0.0400	0.0373	0.0576	0.0523	0.0433	0.0404
	(0.043)	(0.047)	(0.038)	(0.038)	(0.042)	(0.046)
EPE	0.0342	0.0326	0.0416	0.0461	0.0319	0.0346
	(0.030)	(0.031)	(0.029)	(0.028)	(0.030)	(0.030)
RAC	0.4174	0.4513	0.5215	0.6956	0.4873	0.5188
	(0.504)	(0.553)	(0.557)	(0.540)	(0.531)	(0.565)
lnFCS	0.3287	0.3664	0.1818	0.2401	0.3778	0.4030
	(0.291)	(0.331)	(0.212)	(0.226)	(0.283)	(0.333)
HC	0.4211*	0.4568*	0.4569*	0.4536*	0.4180*	0.4911*
	(0.235)	(0.243)	(0.239)	(0.234)	(0.241)	(0.241)
lnTEC	0.8662***	0.8522***	0.9027***	0.8931***	0.8233***	0.7943***
	(0.292)	(0.302)	(0.279)	(0.267)	(0.291)	(0.287)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	270	270	270	270	270	270
R-squared	0.917	0.915	0.919	0.919	0.916	0.916

Note: The numbers in parentheses represent standard errors for the corresponding variables.
* Statistical significance at the 10 % level.
** Statistical significance at the 5 % level.
*** Statistical significance at the 1 % level.

Table 8. We found that the import of green intermediate and green capital goods has a significant negative impact on GTI. In contrast, the import of green consumer goods has no significant impact on GTI. This means that among the imported green products, the products that inhibit GTI are mainly intermediate inputs and capital equipment entering the production link. The larger the import scale of these products, the higher the dependence of local enterprises on them, thus inhibiting the country's independent R&D activities, leading to difficulty in improving the level of GTI. Because it is for final consumption, green consumer goods do not participate in production and manufacturing. Their import volume is small, so the impact on GTI is weak and insignificant.

From the product quality perspective, we refer to Hallak (2006) and use the green product unit value approximation as a proxy for green product quality. The average unit price for each product category over the sample observation period was calculated and divided as follows: the high-value group (average unit price over US$100), the medium-value group (average unit price between US$1 and US$100) and the low-value group (less than US$1). Columns 4 to 6 in Table 8 show the regression results for the corresponding groups. It can be observed that with the decline in value, the impact of green product imports on GTI changes in amplitude and direction. Among them, high-value and medium-value green imports significantly inhibit GTI, while low-value green imports have a significant positive effect. These results indicate that imported high-value green products have the strongest inhibitory effect on GTI in China. It is difficult for high-value green products to be imitated or for corresponding technologies to be mastered by domestic enterprises in the short term. Expanding the import scale of high-value green products will strengthen the dependence of domestic enterprises on them, which hinders the improvement of the GTI level. However, when low-value green products that are easily imitated are imported in large quantities, the incentive to obtain excess profits will become the driving force for domestic enterprises to engage in R&D, promoting the improvement of GTI.

Referring to the classification of green products published by Eurostat (2009) and Fraccascia et al. (2018), under the perspective of product attributes, green products are divided into green fuels, green energy sources, green chemicals, green mechanical and transport equipment, green manufactured products, green oil products and other green products. Table 9 shows the regression results for the corresponding categories. We found that green fuels, oil products and other green products positively impact GTI, but none of their impacts are significant. Green energy sources, green chemicals, green mechanical and transportation equipment, and green manufactured products negatively impact green technological innovation. Among them, green chemicals and green mechanical and transportation equipment have passed the significance test at 1 % and 10 %, respectively, strongly inhibiting GTI.

5.4. Research considerations and challenges

Unlike general research on innovation at the firm level (Skordoulis et al., 2020), the above analyses examine the relationship between green product imports and green technology innovation at the national level.

Although green product imports affect not only green innovation (Skordoulis et al., 2022), they do inhibit green technological innovation in China as a whole, which is consistent with the findings of Arrow (1962) and Aghion et al. (2005). After dividing green technological innovation into RGTI and IGTI, the results show that imports of green products are more inhibitory to IGTI. IGTI is a secondary incremental innovation compared to RGTI and is thus susceptible to the influence of exotic products. Hypothesis H2c (the mechanism of the import of green products on China's green technological innovation is manifested as the technology dependence effects) is proven to be correct, in line with the findings of Liao et al. (2023). This implies that, at this stage, the technology dependence effect is the primary impediment to green technology innovation in China, which deserves the attention of many developing countries in a similar situation.

In both higher and lower economic development regions, the non-linear effect of green R&D investment in the mechanism of green product imports affecting green technological innovation was confirmed, with firms that invest more in green R&D typically having a stronger capacity for independent innovation, and thus their technological dependence on green product imports is weaker (Szczygielski et al., 2017; Brown et al., 2017). In lower economic development regions, the non-linear effect of intellectual property protection in the mechanism of green product imports influencing green technological

Table 9
Heterogeneity analysis from the perspective of product attributes.

Variable	Green fuels	Green energy sources	Green chemicals	Green mechanical and transport equipment	Green manufactured products	Green oil products	Other green products
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
lnGPI	0.0054	−0.0101	−0.0410***	−0.0458*	−0.0106	0.0014	0.0005
	(0.004)	(0.014)	(0.012)	(0.024)	(0.012)	(0.007)	(0.008)
lnIGPC	−0.0981	−0.1013	−0.0949	−0.1000	−0.0988	−0.0994	−0.0995
	(0.078)	(0.079)	(0.081)	(0.079)	(0.078)	(0.079)	(0.080)
GIS	0.0358	0.0424	0.0329	0.0555	0.0365	0.0372	0.0368
	(0.046)	(0.042)	(0.042)	(0.038)	(0.044)	(0.047)	(0.045)
EPE	0.0319	0.0316	0.0376	0.0404	0.0351	0.0323	0.0326
	(0.030)	(0.032)	(0.029)	(0.029)	(0.032)	(0.030)	(0.031)
RAC	0.4377	0.3809	0.3529	0.5257	0.4232	0.4288	0.4441
	(0.542)	(0.536)	(0.500)	(0.555)	(0.531)	(0.514)	(0.539)
lnFCS	0.3884	0.3924	0.3740	0.1927	0.3669	0.3622	0.3684
	(0.319)	(0.308)	(0.286)	(0.211)	(0.306)	(0.346)	(0.324)
HC	0.4753*	0.4505*	0.4890**	0.4623*	0.4980**	0.4521*	0.4597*
	(0.249)	(0.247)	(0.236)	(0.239)	(0.243)	(0.260)	(0.251)
lnTEC	0.8291***	0.7901**	0.8562***	0.8971***	0.8261***	0.8526***	0.8502***
	(0.279)	(0.297)	(0.289)	(0.281)	(0.292)	(0.302)	(0.295)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	270	270	270	270	270	270	270
R-squared	0.916	0.915	0.918	0.919	0.916	0.915	0.915

Note: The numbers in parentheses represent standard errors for the corresponding variables.
* Statistical significance at the 10 % level.
** Statistical significance at the 5 % level.
*** Statistical significance at the 1 % level.

innovation is confirmed. Strengthening intellectual property protection in economically underdeveloped regions significantly increases the inhibitory effect of green product imports on green technology innovation. Excessive intellectual property protection prevents local enterprises from learning about cutting-edge technologies worldwide, which is detrimental to the diffusion of green technology innovations and thus inhibits green technology innovation activities (Gangopadhyay and Mondal, 2012).

6. Conclusions

To answer whether the import of green products promotes or inhibits domestic green technology innovation, this study constructs the statistical data set of China's green patents and green product imports according to the existing relevant classification standards. Then, it makes an empirical analysis by taking China's provincial regions as samples. Furthermore, we identify the channels through which green product imports affect GTI and the mechanisms of the moderating effects of green R&D investment and intellectual property protection.

Three primary insights for developing countries with weak green technology innovation ability are gleaned. First, the import of green products cannot always promote domestic GTI. The government should actively improve the independent production capacity of green products and develop domestic substitution plans for intermediate green products and capital goods while reducing the external dependence on key core technologies. Second, enterprises should be encouraged to invest in green R&D. The government should enhance domestic manufacturers' motivation to conduct GTI and ensure that domestic enterprises' investment in GTI is maintained at a high level. Simultaneously, the government needs to improve green research and development preferential policies for enterprises to offset the negative impact of green product import competition on enterprises' GTI and try to alleviate and eliminate the effects of technology dependence. Finally, it is necessary to consider the differences in regional economic development to formulate reasonable policies on green R&D investment and IPR protection. Developed regions should be encouraged to increase green R&D investment to improve their green technology innovation ability, while underdeveloped regions should achieve GTI catch-up through the dual incentive policy of expanding green product imports and increasing R&D investment.

The limitations of this paper stem primarily from the fact that, first and foremost, the data on product imports and green patents used are at the provincial level of scale, making it challenging to delve deeper into the heterogeneity at higher dimensions (such as the level of prefecture-level city or product). Furthermore, this paper only investigates the roles of IPR protection and green R&D investment in the mechanism of green product imports influencing green technology innovation, but green technology innovation is also influenced by factors such as industrial structure and environmental regulation (Li et al., 2023; Dong et al., 2022), and they are all likely to have an impact on it, which requires further investigation. Finally, while the scope of this paper is limited to China, the heterogeneity study of different levels of economic development can provide some reference value for countries at different levels of economic development. It can also be used in the future to study other countries with different socioeconomic characteristics, in order to conduct a more comprehensive analysis of the relationship between green product imports and green technology innovation.

CRediT authorship contribution statement

Ji Chen: Writing – original draft, Investigation, Formal analysis, Conceptualization. **Liudan Wu:** Resources, Project administration, Methodology, Investigation. **Lili Hao:** Software, Resources, Project administration, Methodology, Data curation. **Xiao Yu:** Visualization, Validation, Software, Resources. **Dalia Streimikiene:** Writing – review & editing, Supervision, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Classification of green products identified by 5-digit SITC

Classification	Family	SITC code	Green product
Green energy sources	Crude materials, inedible, except fuels	23201	Natural rubber latex; pre-vulcanized natural rubber latex
		23202	Natural rubber (other than latex)
		28201	Waste and scrap metal of iron or steel of pig or cast iron
		28202	Waste and scrap metal of iron or steel of alloy steel
		28209	Waste and scrap metal of iron or steel of other iron or steel
		28821	Copper waste and scrap
		28822	Nickel waste and scrap
		28823	Aluminum waste and scrap
		28824	Lead waste and scrap
		28825	Zinc waste and scrap (other than dust)
		28826	Tin waste and scrap
		28902	Precious metal, waste and scrap
Green fuels	Petroleum gases and other gaseous hydrocarbons	34131	Liquefied propane and butane
		34139	Liquefied gaseous hydrocarbons, nes
Green oil products	Animal and vegetable oils, fats and waxes	43143	Vegetable waxes
		43144	Spermaceti, crude or refined; insect waxes
Green chemicals	Chemicals and related products	51211	Methyl alcohol (methanol)
		52391	Hydrogen peroxide

(continued on next page)

(*continued*)

Classification	Family	SITC code	Green product
		53222	Dyeing extracts of vegetable or animal origin
		58361	Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in primary forms
		58362	Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in plate, sheet, strip, film or foil form
		58369	Acrylic and methacrylic polymers; acrylo-methacrylic copolymers in other forms (including waste and scrap)
Green manufactured products	Manufactured goods classified chiefly by materials	65121	Wool tops
		65122	Carded sheep's or lambs' wool (woolen yarn), not for retail sale
		65123	Combed sheep's or lambs' wool (worsted yarn), not for retail sale
		65124	Fine hair yarn (carded or combed), not for retail sale
		65125	Coarse hair yarn, not for retail sale
		65126	Yarn of sheep's or lamb's wool or of fine animal hair, for retail
		65127	Yarn of carded sheep's or lamb's wool, blended, not for retail
		65128	Yarn of combed sheep's or lamb's wool, blended, not for retail
		65129	Wool etc. blend yarn for retail
		65498	Fabrics, woven, of other vegetable textile fibers; of paper yarn
		69211	Iron, steel, aluminum reservoirs, tanks, etc., capacity 300 lt plus of iron or steel
		69213	Iron, steel, aluminum reservoirs, tanks, etc., capacity 300 lt plus of aluminum
Green machinery and transport equipment	Machinery and transport equipment	71621	Electric motors (including ac/dc motors), other than direct current
		71881	Water turbines
		71882	Other hydraulic engines and motors (including waterwheels)
		79381	Tugs
		79382	Special purpose vessels, floating docks, etc.
		79383	Floating structures, other than vessels
Other green products	Miscellaneous manufactured articles	89471	Fishing and hunting equipment

Appendix B. Conversion relationship between SITC2 and HS2012, SITC2 and HS2017

SITC2	HS2012	HS2017	SITC2	HS2012	HS2017	SITC2	HS2012	HS2017
23201	400110	400110	58362	391810	391810	65128	510720	510720
	400280	400280		391890	391890		510990	510990
23202	400121	400121		391910	391910		560490	560490
	400122	400122		391990	391990	65129	510990	510990
	400129	400129		392051	392051		511000	511000
	400591	400591		392059	392059		560490	560490
	400599	400599		392111	392111	65498	531100	531100
28201	720410	720410		392112	392112		580190	580190
28202	720421	720421		392113	392113		580300	580300
	720429	720429		392114	392114		581100	581100
28209	720430	720430		392119	392119		590500	590500
	720441	720441		392190	392190		630800	630800
	720449	720449		481420	481420	69211	730900	730900
28821	740400	740400		481490	481490	69213	761100	761100
28822	750300	750300	58369	391590	391590	71621	850110	850110
28823	760200	760200		391690	391690		850120	850120
28824	780200	780200		391721	391721		850140	850140
28825	790200	790200		391722	391722		850151	850151
28826	800200	800200		391723	391723		850152	850152
28902	711292	711292		391729	391729		850153	850153
	711299	711299		391731	391731	71881	841011	841011
34131	271112	271112		391732	391732		841012	841012
	271113	271113		391739	391739		841013	841013
34139	271111	271111	65121	510529	510529	71882	841011	841011
	271114	271114	65122	510610	510610		841012	841012
	271119	271119		510910	510910		841013	841013
43143	151590	151590		560490	560490		841221	841221
	152110	152110	65123	510710	510710		841229	841229
43144	152190	152190		510910	510910		841239	841239
51211	290511	290511		560490	560490		841280	841280
52391	284700	284700	65124	510810	510810	79381	890400	890400
53222	320300	320300		510820	510820	79382	890510	890510
58361	390610	390610		510910	510910		890520	890520
	390690	390690		510990	510990		890590	890590
58362	300610	300610	65125	511000	511000	79383	890710	890710
	300640	300640	65126	510910	510910		890790	890790
	300650	300650		560490	560490		890800	890800
	300660	300660	65127	510620	510620	89471	950710	950710
	300670	300670		510990	510990		950720	950720
	300691	300691		560490	560490		950730	950730
	300692	300692					950790	950790

Appendix C. Conversion of HS2012 to BEC classification

Green products HS2012	BEC code	Classification of usage
151590, 152110, 152190, 271111, 271112, 271113, 271114, 271119, 284700, 290511, 300610, 300640, 300650, 300670, 300692, 320300, 390610, 390690, 391590, 391690, 391721, 391722, 391723, 391729, 391731, 391732, 391739, 391810, 391890, 391910, 391990, 392051, 392059, 392111, 392112, 392113, 392114, 392119, 392190, 400110, 400121, 400122, 400129, 400280, 400591, 400599, 481420, 481490, 510529, 510610, 510620, 510710, 510720, 510810, 510820, 511000, 531100, 560490, 580190, 580300, 581100, 590500, 711292, 711299, 720410, 720421, 720429, 720430, 720441, 720449, 740400, 750300, 760200, 780200, 790200, 800200, 890800	111, 121, 21, 22, 31, 322, 42, 53	Intermediate goods
730900, 761100, 841011, 841012, 841013, 841221, 841229, 841239, 841280, 850110, 850120, 850140, 850151, 850152, 850153, 890400, 890510, 890520, 890590, 890790	41, 521	Capital goods
300660, 300691, 510910, 510990, 630800, 890710, 950710, 950720, 950730, 950790	61, 62, 63, 112, 122, 522	Consumer goods

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