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THE EFFECTS OF INTERNATIONAL SANCTIONS ON GREEN INNOVATIONS

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Abstract. Since China is facing a complicated international situation and sustainable development requirement at the same time, this paper examines the effects of external uncertainty, international sanctions, on green innovations by adopting the system generalized method of moments (GMM) estimation for 30 provinces (autonomous region and municipalities) from 1997 to 2019. We employ green inventions as the dependent variable and 5 indicators of sanctions (including unilateral, plurilateral, multilateral, economic, and intensity) as the main explanatory variables alternately. For further robustness tests, we use substitution variable green utility models, adopt sub-samples in different regions, change the empirical methodology, and add omitted variables. We also examine the mechanism effects of three possible channels. The conclusion is that plurilateral and economic sanctions both present significant negative impacts on green innovations, whereas China was not affected by unilateral or multilateral sanctions during the sample period. GDP, interpersonal globalization, and environment are proved to be the possible channels through which sanctions affect green innovations. Our research findings should assist Chinese-listed companies suffering from sanctions to make better responses on their way to green innovations.

Keywords: GMM model, international sanctions, green innovations.

JEL Classification: F5, O3, Q5.

Introduction

Sustainable development is still the theme and direction of the world today, and green innovation is an important driving force to promote sustainable development. From the macro perspective, green innovation is of great significance to improve environmental conditions and achieve sustainable development. From the micro point of view, green innovation is also an important way for enterprises to improve production efficiency and enhance core

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competitiveness. However, according to data from World Intellectual Property Organization (WIPO), green patent applications have been declining since 2014, but their growth rates after 2017 have risen slowly than before. However, as one of the ten countries with the highest number of green patent applications granted by the Patent Cooperation Treaty (PCT), China had the highest annual growth rate of such applications among these countries at 18.7%, while most of the remaining countries experienced a decline with negative annual growth rates[1]. Because China stands out from the rest of the world under the situation of slow development of green innovation, the study and discussion of its green innovation will certainly attract attention.

As an external political shock, international sanctions are generally defined as the actual measures imposed by nations or international organizations that aim to threaten or punish the target countries and force them to change their political behavior (Lacy & Niou, 2010; Karimi & Haghpanah, 2015). The influence of sanctions on various factors in different domains have been proven by many researchers, including trade, GDP growth, human rights, democracy, corruption, energy efficiency, energy security, and environmental performance (Yang et al., 2009; Neuenkirch & Neumeier, 2015; Peksen, 2009; Peksen & Drury, 2010; Kamali et al., 2016; Chen et al., 2019; Wen et al., 2020; Fu et al., 2020). Moreover, the interdependence theory shows that the increasing interdependence of countries in many fields resulting from globalization allows sanctions to take effect very quickly and also provides more opportunities and means for international sanctions (Cox & Drury, 2006).

Enterprises can be the cause of environmental pollution and should take more responsibility for solving environmental problems (Li et al., 2018). Green innovation is one solution for corporations to reduce pollution emissions. Although economic globalization brings more opportunities to Chinese corporations, it also makes them more vulnerable to international uncertainties. Thus, when domestic economic growth and recovery face uncertainty and weak prospects, corporations are likely to cut R&D costs, which may lead to poor green innovation performance (Narayan, 2021). From the International Patent Classification (IPC) Green Inventory published World Intellectual Property Organization (WIPO), energy is one main area of green innovation (Jiao et al., 2020). Under the complex international situation and the development background of green transformation, energy sustainability is not only a goal that all countries desire to improve, but also a victim under the influence of international sanctions. The economic sanctions imposed by Europe and the United States on the energy trade of some highly energy-dependent countries not only bring uncertainty to the global energy pattern, but also have a serious impact on the energy upgrading and energy technology innovation of the target countries, even affecting the progress of global green innovation. It is thus necessary to consider the effects of these political uncertainties on green innovations, but scant existing literature explores the relationship between green innovations and political factors, especially shocks from international conflicts. We look to fill this gap by studying the impacts of external political shocks on green innovations such as international sanctions.

[1] Data source: https://www.wipo.int/export/sites/www/pressroom/en/documents/pr_2020_851_annex.pdf. The top 10 countries in terms of PCT authorized green patent applications in 2019 are Japan, China, the United States, Germany, South Korea, France, the United Kingdom, the Netherlands, Denmark, and Canada.

The research question of this paper is whether the imposition of international sanctions will have an impact on green innovation in China. Actually, with increased awareness of climate change, Chinese government has been enacting stricter environmental protection laws in recent years – for example, the State Council issued the Opinions on Comprehensively Strengthening Ecological and Environmental Protection and Resolutely Fighting the Battle against Pollution in June 2018, and the Guiding Opinions on Building a Modern Environmental Governance System was introduced in March 2020. In addition, China's new vision of innovative, coordinated, green, open and inclusive development has attracted much attention from other countries and provided a plan of action for green and sustainable development. Under the pressure of government regulation, Chinese companies need to improve their green innovation capabilities to meet the government's environmental requirements. Nevertheless, as the largest developing country in the world, China is usually the target country of sanctions and has long been affected by them. Thus, a study of sanctions in the China context will serve as a guide for other emerging economies in the same situation.

For this issue, we apply the system generalized method of moments (GMM) estimation for 30 provinces (autonomous region and municipalities) in China from 1997 to 2019 with green inventions as the dependent variable and sanction indicators as main explanatory variables. The effects on substitution variable-green utility model and the effects on provinces located in different regions are also investigated for the robustness test. We arrive at the conclusion that plurilateral and economic sanctions both present significant negative impacts on green innovations, whereas China was not affected by unilateral and multilateral sanctions during the sample period and negative effects from sanctions get worse with the increase of intensity.

Our study contributes to the existing literature in the following aspects. First, to our knowledge this study test the effects of international sanctions on green innovations by employing empirical methodology for the first time. We examine the effects of various types of international sanctions on green innovations: unilateral, plurilateral, multilateral, economic sanctions, as well as the intensity of sanctions. Second, we employ the two-step system generalized method of moments (GMM) method to test the effects of international sanctions on green innovations, by not only considering the dynamic characteristic of the dependent variable, but also solving the endogeneity problem (Blundell & Bond, 1998; Feng et al., 2021b). Third, besides investigating the effects of international sanctions on green inventions, we further estimate the effects on green utility models, which could be regarded as the substitution variable of green inventions. We also investigate the effects on green innovations of provinces located in different regions for robustness tests, as well as changing empirical method and adding omitted variables. Fourth, the sample of the study are provinces in China, which is different from most previous studies exploring green innovation in developed countries. Due to considerable differences between developed countries and emerging economies like China in economic conditions, political background, and other aspects, this paper also adds value to the green innovation literature. In addition, according to the sanction database, most of the sanctioned countries are emerging economies like China. This paper has important guiding significance for other emerging economies to improve green innovation under international sanctions.

The remaining sections of this paper run as follows. Section 1 is the literature review and hypotheses' development which proposes two hypotheses based on the existing literature related to international sanctions and green innovations. Section 2 describes all variables and introduces empirical method. Section 3 analyzes the empirical results and conducts robustness tests. The last section offers the conclusion and provides suggestions for government policy.

1. Literature review and hypotheses' development

The effects of international sanctions on green innovations may be induced through economic, political, energy, and environmental fields as follows.

From the perspective of the economic field, a gravity estimation employed by Caruso (2003) shows that international trade will be negatively affected due to the broad scope and severe actions of sanctions. Yang et al. (2009) presented a similar conclusion that the impositions of both unilateral and multilateral sanctions show negative impacts on bilateral trade (both imports and exports). As GDP growth is also one of the objective influences by international sanctions, Neuenkirch and Neumeier (2015) evaluated the impacts of sanctions on it and made a comparison between the consequences from U.S. and UN sanctions. There is no doubt that sanctions targeted for economy decelerate GDP growth, and it is notable that the consequences of UN sanctions are more severe than U.S. sanctions. Another economic factor that can be affected by international sanctions is income. There is evidence suggesting that economic sanctions affect income inequality unfavorably, and the effects vary greatly due to the different sanction instruments and sanction duration (Afesorgbor & Mahadevan, 2016). A better level of economic development represents a higher degree of innovation ability (Raghupathi & Raghupathi, 2017), because a country with better economic conditions could provide more financial support for the improvement of environment-related technologies (Guloglu & Tekin, 2012), and the increased demand for new products in the process of economic growth will motivate innovations (Aflaki et al., 2015). Most financial support for innovation invests in R&D expenditure, and such expenditures directly influence innovation capacity. The result obtained by Ho et al. (2018) indicated that the R&D input measured by the number of R&D researchers and amount of R&D expenditures per capita respectively contributes to the improvement of technical innovation performance. Pradhan et al. (2018) and Wen et al. (2018) reached the same viewpoint. Foreign direct investment (FDI) is another factor that may affect innovations as proven by many scholars. Antonietti et al. (2015) and Law et al. (2018) both pointed out that the technology spillover effect results in a significantly positive effect of FDI on innovation.

The political field can also be included in the influence channel of international sanctions on green innovation. Peksen (2009) applied empirical analysis with panel data and found that international sanctions cause human rights to be ignored by a government, making sanctions fail to improve human rights. The research result from Islamic countries by Ebrahimi et al. (2015) is consistent with Peksen (2009). The former indicated that international sanctions worsen human rights for the people of Iran and Iraq, comprising of life, health, education, development, and enjoyment of adequate life standards. Human capital is the source of technological innovation and an important force to promote the development and progress of science and technology (Dakhli & Clercq, 2004), while education plays a significant role in the cultivation of innovative and technical talents (Chang et al., 2016). The existing literature stated that students' education level positively correlates with independent thinking ability and exploration spirit (Lau et al., 2015). Roper et al. (2017) and Wang et al. (2019) both provided empirical support that education has a positive effect on innovation performance. Democracy is another subject that has been studied by many scholars. Some researchers proved that the level of freedom and democracy in the sanctioned countries will be greatly reduced under the threat of international sanctions, especially comprehensive sanctions (Peksen & Drury, 2010). Oechslin (2014) found a similar consequence that international sanctions with a goal of regime change and democratization are usually ineffective. However, autocracy and corruption both present an adverse relationship with innovation performance, meaning that the deeper the degree of autocracy or corruption is, the lower is the innovation level (Wang et al., 2021; Wen et al., 2018). Another political factor is formal institutions. Lee and Law (2017) arrived at a conclusion by detailed empirical analysis that the quality improvement of formal institutions promotes the innovation level of countries. Government intervention also has obvious effects on innovation, but the results are controversial. Brunnermeier and Cohen (2003) indicated that government monitoring and enforcement activities on green innovation do not stimulate innovation performance, which is consistent with Abdullah et al. (2016) in that government support may be the external barrier to green process innovations and green system innovation. However, Horbach (2006) held the opposite view that environmental regulation and environmental management tools implemented by governments encourage environmental innovation.

As to the energy and environmental fields, western countries often impose sanctions over oil and energy issues, and so international sanctions have a close correlation with energy. Ahmadi (2018) obtained the result that the petroleum production of Iran has decreased after suffering from U.S. and UN sanctions by empirically analyzing a series of data, and the growth of Iran's oil and gas sector has also been hampered. Chen et al. (2019) presented that unilateral, U.S., and economic sanctions show a greater negative effect on energy efficiency than EU, UN, and non-economic sanctions, while plurilateral sanctions may result in an unconsidered positive effect due to potential contradictions and disagreements arising from different interests between imposing parties. Direct evidence that international sanctions affect the environment has been provided by Fu et al. (2020). The results showed that the imposition of U.S., EU, unilateral, plurilateral, and economic sanctions lower the Environmental Performance Index of sanctioned countries through a decrease of GDP. There are also specific factors that may influence innovations in environmental domains. For example, stringent standards of air pollutants lead to more domestic patenting of pollution abatement equipment (Popp, 2006), and a collaborative process of aligning the innovations and the organizational values enables the application of water management innovations (Van Buuren et al., 2013). Some countries even have drawn up special projects to encourage related innovations, such as Clean Development Mechanism for solid waste management innovation in India (Potdar et al., 2016) and Waste Recovery Project in Indonesia (Zurbruegg et al., 2012).

We thus find indirect evidence of the correlation between international sanctions and green innovations from studies relevant to the international sanctions' aftereffects of other aspects and the influencing factors of green innovations. Therefore, we develop the first hypothesis as follows.

Hypothesis 1: The imposition of international sanctions presents a negative impact on green innovations.

In order to get a deeper understanding of international sanctions, we also introduce the types of sanctions and form a classification. Kaempfer and Lowenberg (1999), Bapat and Morgan (2009), and Kazerooni et al. (2015) classified international sanctions into the following categories – unilateral, plurilateral, and multilateral – and analyzed the different impacts of these sanctions on several fields. It can be proved that multilateral sanctions often work less on achieving political results since cooperation among members is unable to be strengthened through multilateral alliances (Kaempfer & Lowenberg, 1999). An empirical study using the Hufbauer, Schott, and Elliot dataset did support that unilateral sanctions are often more effective than multilateral sanctions (Bapat & Morgan, 2009). Yang et al. (2009), Neuenkirch and Neumeier (2015), Chen et al. (2019) as well as Fu et al. (2020) divided international sanctions into U.S., EU, and UN sanctions based on the sender of sanctions. There is evidence that the unfavourable effect from U.S. sanctions on GDP growth is smaller than that of UN sanctions and of less duration (Neuenkirch & Neumeier, 2015). This result is similar to the U.S. and UN sanctions' impacts on energy efficiency (Chen et al., 2019).

In the environmental field the sanctions' effects from various senders are different from the results of the literature above. Fu et al. (2020) showed that U.S. and EU sanctions significantly decrease the Environmental Performance Index, while UN sanctions have no obvious effect, because other governments are less willing to enforce them and add additional constraints to achieve their own purposes. The classifications above are the most common categories of international sanctions. Our paper consolidates existing classifications of international sanctions and fully examine the impacts of seven indicators of international sanctions: U.S., EU, UN, unilateral, plurilateral, economic sanctions and sanctions intensity. Therefore, this study uses different indicators of international sanctions as the main explanatory factors to test the effects on green innovations and develop the next hypothesis.

Hypothesis 2: Different types of international sanctions have different impacts on green innovations.

Previous studies on green innovation are mostly carried out in the field of environmental science and engineering. However, green innovation can help achieve ecological and environmental goals and also is one of the important factors for the success of economic markets (Lee & Kim, 2011), because technological breakthroughs usually bring significant economic benefits (Feng et al., 2021a). The focus on green innovations has increased the number of studies discussing academic issues in this field with the existing literature mainly examining environment-related innovations and technologies from three angles: enterprise level, industry level, and macro-level. Alhadid and Abu-Rumman (2014), Abdullah et al. (2016), Li et al. (2018), and Tang et al. (2018) discussed the topic of green innovations from the perspective of enterprises or organizations. Research studies at the industry level usually have presented green innovation from the perspective of an industry or a technology (Brunnermeier & Cohen, 2003). The research subjects of green innovation at the macro-level are mainly economic regions, countries, and the world (Frondel et al., 2007; Horbach, 2006). The literature on the influencing factors of green innovation occupies a large proportion of the issues related to green innovation. We note implications from macro-level factors that influence green innovations include economic situation, government research and development (R&D) expenditure, education, foreign direct investment (FDI), and government policy (Ho et al., 2018; Antonietti et al., 2015; Roper et al., 2017). For firms and organizations, firm age, size, and core competence could affect environmental innovation capacity. Chinese research studies on green innovation have also focused on the driving mechanism and influencing factors. Zhou et al. (2021), Luo et al. (2021), Zhou and Wang (2022) analyzed several influencing factors of green innovation in provinces and cities of China from a macro-level perspective, including industrial structure, higher productivity, research and development (R&D) efficiency, innovation input, foreign direct investment, and environmental regulation. Song et al. (2021), Tan and Zhu (2022) discussed the green innovation of Chinese listed companies from the perspective of enterprises.

In summary, the impacts of international sanctions on green innovations overall have rarely been studied. Most papers of the previous literature discussed the impact of sanctions on economic, political, energy and other aspects. As for the influencing factors of green innovation, most of them are domestic macro-level factors or internal micro-level factors of enterprises, and international uncertainty is not taken into account.

2. Variables and methodology

2.1. Variables

We employ annual data for a panel of 30 provinces from China (listed in Appendix Table A2) to investigate the effects of international sanctions on green innovations over the period 1997–2019[2]. The data we employ are mostly from *German Institute of Global and Area Studies* (*GIGA*) *Sanctions Dataset*, *Global Sanctions Database* (*GSDB*) (Felbermayr et al., 2020; Kirilakha et al., 2021), *Green Patent Research Database* (*GPRD*), *National Bureau of Statistics*, and *China Environmental Statistics Yearbook*.

2.1.1. Dependent variable

We employ green inventions as a proxy for green innovations in our study. Green inventions represent the number of obtained green inventions developed by listed companies in that region. The data are from Green Patent Research Database (GPRD) of Chinese Listed Companies Management Research Series in Chinese Research Data Services (CNRDS) Platform. This database is a professional database developed by combining China's patent data and the green patent classification number standard published by the World Intellectual Property

[2] Since Chongqing, formerly part of Sichuan Province, was raised to municipality status in 1997, in order to divide the data of provinces and municipalities more clearly and avoid double calculation of data, the sample period in this study is 1997–2019.

Office and presents patent statistics and indicators that are suitable for tracking innovations in environment-related technologies. They allow the assessment of provinces' and firms' innovation performances as well as the design of governments' environmental and innovation policies.

2.1.2. Explanatory variables

International sanctions can be divided into many forms, and various cases of sanctions may result in different effects on the target countries (Kazerooni et al., 2015). To examine how different types of international sanctions impact green innovations with varying effects, Following Portela and Soest (2012), Chen et al. (2019), and Fu et al. (2020), we classify international sanctions more specifically, consisting of unilateral, plurilateral, multilateral, economic sanctions, and the intensity of sanctions. *Unilateral* refers to whether a country suffer the international sanctions imposed by either the United States or the European Union separately; *Plurilateral* means whether a country was imposed international sanctions from the U.S. and the EU simultaneously; *Multilateral* indicate the international sanctions enforced by United Nations; *Economic* represents that the sanctions influence the target state's economy; *Intensity* means the intensity scale of international sanctions.

In order to comprehensively analyze the development of a green innovation market, other driving factors should also be considered. Several control variables that are proven to affect the green innovation market are provided in our study. We present them as follows.

GDP: A good economic situation of a country offers financial support for the improvement of environment-related technologies. Research and development (R&D) activities of the countries subject to international sanctions may be restricted since international sanctions adversely affect the economy (Zhang, 2008; Hufbauer et al., 2009; Neuenkirch & Neumeier, 2015). Gross domestic product (GDP) is usually used to measure the economic development level. Therefore, we follow Zheng et al. (2021) and use GDP to represent the economic development level for the sample provinces. Based on the gross regional product and gross regional product index (last year=100), we calculate the real GDP of each province according to the following formula:

$$RGDP_n = RGDP_0 \times [1 + (Index_n - 100)\%]. \quad (1)$$

FDI: The effect of foreign direct investment (FDI) on green innovations is a bit complicated. On one hand, FDI may provide more capital support for a country's innovative R&D activities; on the other hand, there may exist excessive technological dependences on transnational corporation, resulting in countries lacking any motivation to develop environmental innovations. Wang et al. (2019) investigated the effect of FDI on innovation. Therefore, we employ the variable *FDI*, which refers to the ratio of total investment of foreign-invested enterprises to GDP, to analyze its effect on green innovations.

Education: The cultivation of innovative talents should not be separated from education. Governments can increase total government expenditure on education to train and support more R&D specialists for environmental innovation. Moreover, a better education system also strengthens the awareness of environmental protection (Fu et al., 2020). Therefore, we choose *Education* as a control variable in our study, measured by total educational expenditure.

Regulation: Because of multiple market failures, investment in environment-related innovation would be inadequate without government intervention (Nemet, 2007). Policy instruments can stimulate the innovation and adoption of environmental technologies. Azevedo and Pereira (2010) also proved that environmental regulation is a determinant for the adoption of environmental technology and brings huge investment to processes and products related to the environment. Thus, we calculate the Environmental Regulation Index by the method of Ren et al. (2020) to set a variable *Regulation* that measures the intensity of environmental regulation in each province. A higher value of *Regulation* denotes more pollution emissions and weaker intensity of environmental regulation.

Emission: Stefano et al. (2012) indicated that more market demand will further drive technological change. Environmental degradation increases the desire for green products and green consumption and subsequently expands demand in the innovation market. Thus, it drives people to promote technological development of environmental protection. Knowledge as well as technology can be used to reduce the amount of pollution and the costs of pollution control (Nentjes & Wiersma, 1988; Kolstad, 2010). We thus take *Emission* as a control variable to denote industrial sulfur dioxide (SO_2) emissions.

2.2. Empirical methodology

After an international sanction is enacted, we need to estimate what effects its imposition had. The evaluation looks at whether it is a success or failure. We note the dynamic effect of the dependent variable that current development of green innovations may on the basis of previous green technologies, and the endogeneity problems in dynamic models that technological innovations may weaken the impact of external uncertainties. (Chen et al., 2021). Thus, we follow Blundell and Bond (1998) to employ the two-step GMM estimation to examine the effects of international sanctions on green innovations, which combines the advantages of difference GMM and level GMM estimations. The dynamic panel model of our study is:

$$GI_{i,t} = \alpha_0 + \alpha_1 GI_{i,t-1} + \alpha_2 Sanction_{i,t} + \alpha_3 Control_{i,t} + \varepsilon_{i,t}, \quad (2)$$

where *GI* stands for green inventions, *Sanction* denotes the main explanatory variables of international sanction indicators (*Plurilateral*, *Economic*, and *Intensity*) for which we test the effects by the system GMM model separately and alternately, $Control_{i,t}$ represents the control variables that influence green innovations, involving *GDP*, *FDI*, *Education*, *Regulation*, and *Emission*, and $\varepsilon_{i,t}$ is the error term. However, the data of some variables vary greatly and fluctuate widely among sample provinces. To solve the problem of inconvenient calculation, the logarithms of green inventions, GDP, Education, and Emission are adopted in this paper to lower heteroscedasticity and get more concise results (Narayan & Popp, 2010).

3. Empirical results

3.1. Main results

Table 1 lists the empirical results of the GMM estimation method for the green innovations[3]. We do not report the results of *Unilateral* and *Multilateral* since China was not hit by unilateral and multilateral sanctions during 1997–2019. Model 1 to Model 3 show the effects of 3 indicators of international sanctions on green innovations, consisting of plurilateral, economic sanctions, and the intensity of sanctions.

As Table 1 shows, the p-value of AR(1) supports the rejection of the null hypothesis, while AR(2) and Hansen test both seem to validate the null hypothesis, meaning that the GMM estimation results are valid and credible. The coefficients of the lagged green inventions are insignificantly positive in all models, which implies that the number of green inventions in one year will not affect the number obtained in the following year. As to the sanction indicators, we see that the coefficient of the explanatory variable *Plurilateral* is –23.199 at the 1% significance level, indicating that the infliction of plurilateral sanctions adversely affects the number of green inventions, which decreased by about 23, and the negative effect is significant. The reason is that the plurilateral sanctions bring unfavourable effects to international trade and economic growth (Hufbauer et al., 2009; Neuenkirch & Neumeier, 2015), and so the negative impact will spread to corporate earnings. Academic communication among R&D specialists is also limited by sanctions. Therefore, plurilateral sanctions reduce the number of green inventions in Chinese-listed companies through a lack of R&D financial support and contact restriction of technology and labor (Zhang, 2008; Baffour & Amal, 2011; Zaitseva et al., 2016). Fu et al. (2020) had a similar result about the effects of plurilateral sanctions on environmental performance. However, some studies have found different consequences in which the effects of plurilateral sanctions are sometimes offset when the U.S. and EU implement sanctions collectively, because countries imposing sanctions may have conflicts of interest due to their primary motivation of respective benefits (Miers & Morgan, 2002; Drezner, 2003), which makes plurilateral sanctions no longer have a negative effect and may even turn counterproductive (Chen et al., 2019). Similarly, the coefficient of *Economic* is –22.511 and similarly significantly negative at the 1% level, implying that the adverse consequence of economic sanctions, about 22 fewer inventions, is obvious as well. The negative value of –11.272 in column 3 shows that for every level of increase in sanctions' intensity, the number of green inventions falls by about 11. Chen et al. (2019) and Fu et al. (2020) used the same classification for sanctions and examine the effects of economic sanctions and sanctions' intensity on energy efficiency and environmental performance. Economic sanctions also had negative impacts on those two, because of the high frequency and the close relationship with key factors affecting them. The adverse outcomes on energy efficiency and environment worsen as the intensity increases as well. Thus, the empirical results support our Hypothesis 1. Given the difference in the degree of negative influences of plurilateral and economic sanctions, our result also supports Hypothesis 2.

[3] As the data show that China has been continuously subjected to plurilateral sanctions by the United States and the European Union from 1997 to 2019, the values of sanction indicators *Plurilateral* and *Economic* are all equal to 1 and do not change. To make better empirical estimation, we adjust some values to 1.0001 or 0.9999 to obtain results with a minimum impact. Similarly, the values of *Intensity* are all equal to 2, and we adjust a few to 1.9999 or 2.0001.

Table 1. Estimation results of the GMM model (Dependent variable: Green inventions)

Variable	Model 1	Model 2	Model 3
L.log (GI)	0.102 (0.097)	0.107 (0.093)	0.097 (0.087)
Plurilateral	–23.199*** (2.460)		
Economic		–22.511*** (2.449)	
Intensity			–11.272*** (1.159)
GDP	–0.200 (0.319)	–0.093 (0.310)	–0.080 (0.289)
FDI	0.296 (0.244)	0.259 (0.215)	0.248 (0.204)
Education	1.914*** (0.289)	1.817*** (0.285)	1.814*** (0.266)
Regulation	–0.237 (0.151)	–0.288** (0.140)	–0.289** (0.140)
Emission	–0.047 (0.069)	–0.062 (0.064)	–0.064 (0.065)
Observations	579	579	579
AR(1)	0.000	0.000	0.000
AR(2)	0.639	0.603	0.553
Hansen test	0.130	0.259	0.477

Notes: Corrected standard errors are the values in parentheses. *, **, and *** mean significance at the 10%, 5%, and 1% levels, respectively.

We also obtain important information from the results of the control variables. It can be seen that the coefficient of *Education* passes the 1% significance level and is positive in all models, showing that the educational expenditure of provinces will promote the improvement of green innovation capacity. The higher educational input that a province provides makes for more financial support toward R&D activities and cultivates more R&D specialists for not only scientific institutions, but also listed companies (Zhang, 2008). Similarly, the coefficient of *Regulation* is significantly negative at the 5% level in most columns. According to the description of this indicator, we know that a higher value of *Regulation* means weaker environmental regulation, implying that the lack of pollutants' regulation restrains green innovations since companies no longer have to spend money developing new technologies to meet emissions standards. Except for the control variables above, nothing else is significant in the models.

3.2. Robustness tests

Considering the important factors that may lead to a biased empirical results, heterogeneity is a typical one that often exists in economic models (Bettendorf & Dijkgraaf, 2010). Diversity in the important attributes of the sample provinces (autonomous region and municipalities) may lead to great variations in the impacts of international sanctions on green innovations (Song et al., 2020), especially the different economic conditions and province situations among different regions. Data show that the east region in China has the highest per capita GDP, followed by the central region, while the economic development of west China is relatively weak (Xu et al., 2016). Due to the large output value resulting from the highest economic level in the east region, green innovation spurs the demand for and the increase of its energy consumption and pollution emissions. The highest economic openness of the east region also makes it more vulnerable to international sanctions than the central and west regions. Thus, in order to minimize heterogeneity in our empirical analysis to make the results more robust, we divide the 30 provinces (autonomous region and municipalities) into three regions (east, central, and west) based on their economic development level and geographical locations to further examine the effects of international sanctions. Appendix Table A2 shows the provinces covered by each region.

Table 2. Estimation results of the GMM model for different regions

Variable	Model 1	Model 2	Model 3
East region			
L.log(GI)	0.280 (0.256)	0.248 (0.189)	0.281 (0.186)
Plurilateral	–29.730** (12.127)		
Economic		–25.243*** (8.209)	
Intensity			–13.084** (4.715)
Control variables	Yes	Yes	Yes
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	233	233	233
Hansen test	0.159	0.621	0.482
Central region			
L.log(GI)	0.032 (0.124)	0.069 (0.089)	0.045 (0.114)
Plurilateral	–23.356*** (5.919)		
US			
EU			
Economic		–21.035*** (5.059)	
Intensity			–11.070*** (2.872)
Control variables	Yes	Yes	Yes
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	178	178	178
Hansen test	0.511	0.901	0.509
West region			
L.log(GI)	0.024 (0.174)	0.021 (0.089)	0.073 (0.093)
Plurilateral	–24.618*** (4.599)		
US			
EU			
Economic		–23.466*** (2.536)	
Intensity			–11.661*** (1.515)
Control variables	Yes	Yes	Yes
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	168	168	168
Sargan test	0.720	0.854	0.498

Notes: Corrected standard errors are the values in parentheses. *, **, and *** mean significance at the 10%, 5%, and 1% levels, respectively.

In Table 2 the p-values of Sargan or Hansen test suggest that our estimation results are generally reliable. We see that the coefficients of all sanction indicators are significantly negative, meaning that no matter in which region, international sanctions definitely reduce the number of green invention patents developed by local listed companies, further validating our basic results. Moreover, the imposition of international sanctions has the greatest negative impact on green innovation in the east region, which is more vulnerable to sanctions due to its high market openness and large-scale foreign investment.

In addition to green inventions, there is a more practical type of patents-green utility models. We obtain data from GPRD and use a green utility model as a substitution variable for green invention to confirm that whether our basic empirical results are robust. The p-values of AR(1), AR(2), and Hansen test ensure the validity of the results in Table 3. In this table the coefficients of *Plurilateral*, *Economic*, and *Intensity* are all significantly negative, suggesting that the inhibiting effects of these sanctions on green innovation are robust, whereas the adverse effects on the green utility model are less than that on green inventions. One finding in this table that the basic empirical results do not show is that the coefficient of the lagged green utility model is significantly positive at the 5% level in all columns, meaning that the number of green utility models in one year has a positive effect on the number of such patents in the following year.

We change the methodology to do another robustness test. Table 4 shows the valid estimation results of difference GMM (DIF-GMM) model, because the Sargan test values of all models are appropriate. We see that the coefficients of *Plurilateral*, *Economic*, and *Intensity* are all negative and significant at the 10%, 1%, and 5% levels, respectively. Thus, we conclude that our basic empirical results are robust through the results of other method.

Table 3. Estimation results of the GMM model (Substitution variable: Green utility models)

Variable	Model 1	Model 2	Model 3
L.log (GUM)	0.266** (0.111)	0.266**(0.111)	0.285** (0.109)
Plurilateral	–10.979*** (1.203)		
Economic		–10.710***(1.138)	
Intensity			–5.350*** (0.594)
GDP	0.506 (0.328)	0.394 (0.318)	0.371 (0.291)
FDI	0.057 (0.116)	0.048 (0.117)	0.023 (0.112)
Education	0.786*** (0.150)	0.820*** (0.141)	0.835*** (0.133)
Regulation	–0.067 (0.122)	–0.038 (0.118)	–0.021 (0.115)
Emission	–0.197*** (0.043)	–0.203*** (0.041)	–0.201*** (0.044)
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	600	600	600
AR(1)	0.001	0.000	0.001
AR(2)	0.640	0.681	0.655
Hansen test	0.400	0.407	0.356

Notes: Corrected standard errors are the values in parentheses. *, **, and *** mean significance at the 10%, 5%, and 1% levels, respectively.

Table 4. Estimation results of the DIF-GMM model

Variable	Model 1	Model 2	Model 3
L.log (GI)	0.317^{***} (0.099)	0.555^{***} (0.130)	0.367^{***} (0.106)
Plurilateral	-11.575^{*} (6.981)		
Economic		-10.469^{***} (3.742)	
Intensity			-7.013^{**} (3.400)
GDP	2.132^{*} (1.261)	–0.004 (0.153)	1.281^{**} (0.578)
FDI	–0.065 (0.086)	0.084 (0.106)	–0.091 (0.388)
Education	–0.567 (0.400)	0.847^{**} (0.339)	0.103 (0.345)
Regulation	–0.403 (0.262)	-0.196^{**} (0.075)	–0.108 (0.226)
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	600	600	600
Sargan test	0.115	0.189	0.566

Notes: Corrected standard errors are the values in parentheses. *, **, and *** mean significance at the 10%, 5%, and 1% levels, respectively.

Finally, another important cause of endogeneity problems is omitted variables (Afesorgbor, 2019; Chang et al., 2019). To significantly reduce the undesirable consequence of omitted variable bias on the empirical results, this paper aims to control the other factors affecting the green innovation of the provinces as comprehensively as possible to carry out the robustness test. We add three possible omitted variables, *Infra*, *Finance*, and *Urban*, to do a further test. *Infra* refers to provincial infrastructure level assessed by highway mileage, *Finance* indicates government expenditure measured by general budget expenditure of local finance, and *Urban* is urbanization level calculated by the ratio of non-agricultural population to total population in each province. As shown in Table 5, the coefficients of all sanction variables are still significantly negative after the inclusion of omitted variables, proving that the adverse impacts from sanctions to green innovations are constant.

3.3. Mechanism tests

There is theoretical evidence for believing that international sanctions threaten the development of green innovations. We believe that suffering from international sanctions can influence green innovations through three possible channels. We therefore analyze how international sanctions affect green innovation and then do the mechanism test of these three channels by using GMM estimation.

First, according to the sanction measures that list the nature of a sanction imposed along with a basic classification from Portela and Soest (2012), commodity embargo and comprehensive trade embargo, the two most common measures of international sanctions, directly decrease exports and imports of target countries (Hufbauer et al., 2009), while financial sanctions and aid sanctions decelerate economic growth progress due to the ban on financial transactions and the suspension of international aid (Neuenkirch & Neumeier, 2015).

Table 5. Estimation results of the GMM model for adding omitted variables

Variable	Model 1	Model 2	Model 3
L.log (GI)	0.046 (0.071)	0.059 (0.071)	0.063 (0.066)
Plurilateral	–24.133*** (3.316)		
Economic		–23.837*** (3.145)	
Intensity			–11.883*** (1.520)
GDP	–0.089 (0.242)	–0.099 (0.227)	–0.068 (0.214)
FDI	–0.103 (0.163)	–0.071 (0.099)	–0.050 (0.103)
Education	1.895*** (0.341)	1.884*** (0.321)	1.867*** (0.306)
Regulation	–0.186 (0.134)	–0.192 (0.124)	–0.212* (0.122)
Infra	–0.051 (0.051)	–0.052 (0.040)	–0.051 (0.042)
Finance	–0.025* (0.015)	–0.027** (0.013)	–0.027** (0.013)
Urban	–0.176 (0.441)	–0.057 (0.416)	–0.094 (0.439)
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	600	600	600
Hansen test	0.159	0.791	0.697

Notes: Corrected standard errors are the values in parentheses. *, **, and *** mean significance at the 10%, 5%, and 1% levels, respectively.

Thus, there is literature support for the adverse effect of international sanctions on the economic development of a country. Government expenditures are an integral part of economic growth (Fu & Chang, 2021). Research and development (R&D) activities subject to international sanctions may then be restricted due to the scarcity of government financial support (Zhang, 2008). Thus, we use GDP to measure economic development of the provinces and do the mechanism test. Panel A in Table 6 shows the results of the first possible channel, *GDP*. We see that the coefficients of *Plurilateral*, *Economic*, and *Intensity* are all negative at the 5% significance level, meaning that the imposition of plurilateral sanctions and economic sanctions both decrease GDP, and GDP falls even more as sanctions intensify. We conclude that international sanctions influence green innovation through GDP.

Second, aside from economic and financial sanction measures, other actions such as diplomatic sanctions, flight bans, and visa bans set a form of communication limitation among R&D specialists of countries that impedes any improvement in the level of interpersonal globalization, as technological innovations are accelerated by the large-scale global circulation of capital, technology, and labor (Baffour & Amal, 2011; Zaitseva et al., 2016). Therefore, green innovations may meet with hindrance from the imposition of international sanctions through restrictions on professional talents, technology, and capital contact. We get the data of interpersonal globalization from *KOF Globalisation Index* and examine its mechanism effect (Gygli et al., 2019). The results in Panel B of Table 6 reveal that the coefficients of the three sanction variables are all significantly negative at the 1% level, indicating that sanctions have adverse effects on interpersonal globalization, which is proven to serve as an important channel between international sanctions and green innovation.

Table 6. Estimation results of the influencing channels

Variable	Model 1	Model 2	Model 3
Panel A: GDP			
L.GDP	0.844*** (0.057)	0.843***(0.058)	0.845*** (0.056)
Plurilateral	–0.411** (0.158)		
Economic		–0.416** (0.158)	
Intensity			–0.206** (0.078)
Control variables	Yes	Yes	Yes
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	600	600	600
Hansen test	0.246	0.188	0.270
Panel B: Interpersonal globalization			
L. Inter	0.851*** (0.031)	0.843*** (0.025)	0.843*** (0.025)
Plurilateral	–68.858*** (6.877)		
Economic		–61.851*** (6.154)	
Intensity			–30.924*** (3.077)
Control variables	Yes	Yes	Yes
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	600	600	600
Hansen test	0.668	0.365	0.365
Panel C: Environment			
L. Environment	0.398** (0.175)	1.365*** (0.056)	0.350* (0.204)
	(0.175)	(0.056)	(0.204)
Plurilateral	–17.278*** (5.796)		
Economic		0.856 (0.521)	
Intensity			–9.191*** (3.122)
Control variables	Yes	Yes	Yes
Province	Yes	Yes	Yes
Year	Yes	Yes	Yes
Observations	600	600	600
Hansen test	0.137	0.434	0.169

Notes: Corrected standard errors are the values in parentheses. *, **, and *** mean significance at the 10%, 5%, and 1% levels, respectively.

Third, international sanctions can be also counterproductive for environmental quality with undesirable environmental consequences, and the reduction of green consumption will lead to less of a positive effect of environmental protection since sanctions negatively affect income (Kolstad, 2016). Chen et al. (2019) prove directly that energy efficiency, the important factor of environmental pollution, decreases when a country is under sanctions. Moreover, international sanctions also threaten the outcome of environmental performance, including environmental health and ecosystem vitality (Fu et al., 2020). Environmental degradation forces people to improve the ability and technology of environmental protection. Hence, technological development is driven from the increase of market demand caused by the international sanctions (Stefano et al., 2012). In order to test the mechanism effect of environmental quality as market demand for green innovation, we utilize SO_2 emissions to evaluate environmental quality. As Panel C in Table 6 shows, the coefficients of *Plurilateral* and *Intensity* are negative at the 1% significance level, which means the effect of environmental quality is relatively complicated. Sanctions will make high-polluting enterprises with foreign investment reduce output and emissions due to the withdrawal of funds, thus decreasing the demand for green innovation, which means this may also worsen the environment and stimulate green innovation.

Conclusions and future direction

There are many researches in the existing literature that have examined the impacts of international sanctions on various domains in the target countries, prompting our paper to fill the gap in the domain of green innovation. We prove herein that the imposition of international sanctions has negative impacts on green innovation by using the GMM model with data from 1997 to 2019 for a sample of 30 provinces (autonomous region and municipalities) in China. We then test the effects of international sanctions on provinces located in three different regions and also investigate the effects on a substitution variable-green utility model for the robustness test. The basic result of green invention shows that plurilateral, U.S., EU, and economic sanctions negatively affect the number of green inventions developed by a listed company's inventors in China, and the impact deepens with the increase in the intensity scale of sanctions, while listed companies in each province are not affected by unilateral and UN sanctions since China was not subject to either type of sanction during the sample period.

Our research further finds that some control variables influence green innovations significantly. The increase of educational expenditure and the regulation of pollutant emissions both promote environmental technology innovation. As to provinces in different regions, the results present that the impositions of international sanctions have significantly inhibiting effects on green innovations in any region, with the greatest impact in the east region. Not just for green invention patents, international sanctions also have adverse effects on the substitution variable-green utility model patents.

From the conclusions above, we offer some policy suggestions for green innovations in China. First, due to the disagreements and contradictions on the distribution of interests between two different sanction senders, Chinese-listed companies subjected to sanctions can minimize the destructiveness and effectiveness of international sanctions by raising questions between the imposing countries that exhibit potential contradictions. They can also look for opportunities to conduct international cooperation in capital, technology, and labor with companies in other countries to promote R&D activities and environmental technological innovations.

Second, the effects brought by the control variables *Education* and *Regulation* also provide suggestions. Under a favorable economic development situation, the provincial governments can increase their total expenditure on education, which would encourage more R&D specialists to carry out green innovation activities, and also help train more technological talents for green innovation since a better education cultivates a deeper innovative capacity and awareness of environmental protection. The provincial governments should strengthen the regulation of pollutants so that they can play a strong guiding role in green innovation.

Third and finally, green innovation in the east region is most adversely affected by the sanctions, because of its large-scale foreign investment and foreign trade. Thus, governments in the east region should instead actively help foreign investment transfer to industries and companies with low environmental pollution or environmental technology enterprises so as to stabilize the scale and quality of green innovation. In summary, our study is the first in the literature to provide evidence that international sanctions affect green innovations. We hope to help China seriously deal with the threat produced by the imposition of international sanctions and to promote environmental technologies and innovation activities during any tensions in international relations.

Some limitations of this study provide direction and make room for future research. Since China was not hit by unilateral and UN sanctions during 1997–2019, we cannot further compare the consequences of sanctions with different characteristics on China. Future research may contribute to this topic by taking into consideration other sanctioned countries or other sanction categories.

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References

Abdullah, M., Zailani, S., Iranmanesh, M., & Jayaraman, K. (2016). Barriers to green innovation initiatives among manufacturers: The Malaysian case. *Review of Managerial Science*, *10*(4), 1–27. https://doi.org/10.1007/s11846-015-0173-9

Afesorgbor, S. K. (2019). The impact of economic sanctions on international trade: How do threatened sanctions compare with imposed sanctions? *European Journal of Political Economy*, *56*, 11–26. https://doi.org/10.1016/j.ejpoleco.2018.06.002

Afesorgbor, S. K., & Mahadevan, R. (2016). The impact of economic sanctions on income inequality of target states. *World Development*, 83, 1–11. https://doi.org/10.1016/j.worlddev.2016.03.015

Aflaki, S., Basher, S. A., & Masini, A. (2015). Does economic growth matter? Technology-push, demand-pull and endogenous drivers of innovation in the renewable energy industry. *Social Science Electronic Publishing*, *5*(28), 6393–6400.

Ahmadi, A. (2018). The impact of economic sanctions and the JCPOA on energy sector of Iran. *Global Trade and Customs Journal*, *13*(5), 198–223. https://doi.org/10.54648/GTCJ2018023

Alhadid, A. Y., & Abu-Rumman, A. H. (2014). The impact of green innovation on organizational performance, environmental management behavior as a moderate variable: An analytical study on Nuqul Group in Jordan. *International Journal of Business* & *Management*, *9*(7), 51–58. https://doi.org/10.5539/ijbm.v9n7p51

Antonietti, R., Bronzini, R., & Cainelli, G. (2015). Inward greenfield FDI and innovation. *Economia E Politica Industriale*, *42*(1), 93–116. https://doi.org/10.1007/s40812-014-0007-9

Azevedo, A. M. M. de, & Pereira, N. M. (2010). Environmental regulation and innovation in high-pollution industries: A case study in a Brazilian refinery. *International Journal of Technology Management & Sustainable Development*, *9*(2), 133–148. https://doi.org/10.1386/tmsd.9.2.133_1

Baffour, A, G., & Amal, M. (2011). Impact of globalization. *European Business Review*, *23*(1), 120–132. https://doi.org/10.1108/09555341111098026

Bapat, N. A., & Morgan, C. T. (2009). Multilateral versus unilateral sanctions reconsidered: A test using new data. *International Studies Quarterly*, *53*(4), 1075–1094. https://doi.org/10.1111/j.1468-2478.2009.00569.x

Bettendorf, L., & Dijkgraaf, E. (2010). Religion and income: heterogeneity between countries. *Journal of Economic Behavior & Organization*, *74*(1–2), 12–29. https://doi.org/10.1016/j.jebo.2010.02.003

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, *87*(1), 115–143. https://doi.org/10.1016/S0304-4076(98)00009-8

Brunnermeier, S. B., & Cohen, M. A. (2003). Determinants of environmental innovation in us manufacturing industries. *Journal of Environmental Economics and Management*, *45*(2), 278–293. https://doi.org/10.1016/S0095-0696(02)00058-X

Caruso, R. (2003). The impact of international economic sanctions on trade: An empirical analysis. *Peace Economics, Peace Science and Public Policy*, *9*(2). https://doi.org/10.2202/1554-8597.1061

Chang, F., Min, W., Shi, Y., Kenny, K., & Loyalka, P. (2016). Educational expectations and dropout behavior among junior high students in rural China. *China & World Economy*, *24*(3), 67–85. https://doi.org/10.1111/cwe.12159

Chang, X., Chen, Y., Wang, S. Q., Zhang, K., & Zhang, W. (2019). Credit default swaps and corporate innovation. *Journal of Financial Economics*, *134*(2), 474–500. https://doi.org/10.1016/j.jfineco.2017.12.012

Chen, D., Hu, H. Q., & Zheng, M. B. (2021). How does energy production respond to the COVID-19 pandemic? Evidence from China. *Asian Economics Letters*, *2*(2). https://doi.org/10.46557/001c.22324

Chen, Y. E., Fu, Q., Zhao, X. X, Yuan, X. M., & Chang, C. P. (2019). International sanctions' impact on energy efficiency in target states. *Economic Modelling*, *82*, 21–34. https://doi.org/10.1016/j.econmod.2019.07.022

Cox, D. G., & Drury, A. C. (2006). Democratic sanctions: Connecting the democratic peace and economic sanctions. *Journal of Peace Research*, *43*(6), 709–722. https://doi.org/10.1177/0022343306068104

Dakhli, M., & Clercq, D. D. (2004). Human capital, social capital, and innovation: A multi-country study. *Entrepreneurship & Regional Development*, *16*(2), 107–128. https://doi.org/10.1080/08985620410001677835

Drezner, D. (2003). The hidden hand of economic coercion. *International Organization*, *57*(3), 643–659. https://doi.org/10.1017/S0020818303573052

Ebrahimi, M., Jalalian, A., & Esfandyari, L. (2015). The impacts of economic sanctions on human rights in countries of Iran and Iraq. *World Scientific News*, *10*, 12–27.

Felbermayr, G., Kirilakha, A., Syropoulos, C., Yalcin, E., & Yotov, Y. V. (2020). The global sanctions data base. *European Economic Review*, *129*, 103561. https://doi.org/10.1016/j.euroecorev.2020.103561

Feng, G. F., Wang, Q. J., Chu, Y., Wen, J., & Chang, C. P. (2021a). Does the shale gas boom change the natural gas price-production relationship? Evidence from the U.S. market. *Energy Economics*, *93*, 104327. https://doi.org/10.1016/j.eneco.2019.03.001

Feng, G. F., Yang, H. C., Gong, Q., & Chang, C. P. (2021b). What is the exchange rate volatility response to COVID-19 and government interventions? *Economic Analysis and Policy*, *69*, 705–719. https://doi.org/10.1016/j.eap.2021.01.018

Frondel, M., Horbach, J., & Rennings, K. (2007). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. *Business Strategy and the Environment*, *16*(8), 571–584. https://doi.org/10.1002/bse.496

Fu, Q., & Chang, C. P. (2021). How do pandemics affect government expenditures? *Asian Economics Letters*, *2*(1). https://doi.org/10.46557/001c.21147

Fu, Q., Chen, Y. E., Jang, C. L., & Chang, C. P. (2020). The impact of international sanctions on environmental performance. *Science of The Total Environment*, *745*, 141007. https://doi.org/10.1016/j.scitotenv.2020.141007

Guloglu, B., & Tekin, R. B. (2012). A panel causality analysis of the relationship among research and development, innovation, and economic growth in high-income OECD countries. *Eurasian Economic Review*, *2*(1), 32–47.

Gygli, S., Florian, H., Niklas, P., & Jan-Egbert, S. (2019): The KOF Globalisation Index – revisited. *Review of International Organizations*, *14*(3), 543–574. https://doi.org/10.1007/s11558-019-09344-2

Ho, C. Y., Huang, S., Shi, H., & Wu, J. (2018). Financial deepening and innovation: The role of political institutions. *World Development*, *109*, 1–13. https://doi.org/10.1016/j.worlddev.2018.02.022

Horbach, J. (2006). Determinants of environmental innovation – New evidence from German panel data sources. *Research Policy*, *37*(1), 163–173. https://doi.org/10.1016/j.respol.2007.08.006

Hufbauer, G., Schott, J., Elliott, K. A., & Oegg, B. (2009). *Economic sanctions reconsidered: History and current policy* (3rd ed.). Institute for International Economics, Washington, DC.

Jiao, J., Chen, C., & Bai, Y. (2020). Is green technology vertical spillovers more significant in mitigating carbon intensity? Evidence from Chinese industries. *Journal of Cleaner Production*, *257*, 120354. https://doi.org/10.1016/j.jclepro.2020.120354

Kaempfer, W. H., & Lowenberg, A. D. (1999). Unilateral versus multilateral international sanctions: A public choice perspective. *International Studies Quarterly*, *43*(1), 37–58. https://doi.org/10.1111/0020-8833.00110

Kamali, T., Mashayekh, M., & Jandaghi, G. (2016). The impact of economic sanctions on corruption in target countries: A cross country study. *World Scientific News*, *45*(2), 276–291.

Karimi, M., & Haghpanah, S. (2015). The effects of economic sanctions on disease specific clinical outcomes of patients with thalassemia and hemophilia in Iran. *Health Policy*, *119*(2), 239–243. https://doi.org/10.1016/j.healthpol.2014.12.011

Kazerooni, A., Ghorbani, A., & Saghafi, R. (2015). A study of unilateral and multilateral sanctions effectiveness on Iran's non-oil foreign trade products. *Quarterly Journal of Applied Theories of Economics*, *2*(1), 83–98.

Kirilakha, A., Felbermayr, G., Syropoulos, C., Yalcin, E., & Yotov, Y. V. (2021). The Global Sanctions Data Base: An update that includes the years of the Trump presidency. In P. A. G. van Bergeijk (Ed.), *Research handbook on economic sanctions* (pp. 62–106). Edward Elgar. https://doi.org/10.4337/9781839102721.00010

Kolstad, C. D. (2010). Regulatory choice with pollution and innovation. *Social Ence Electronic Publishing*, *73*(1), 65–78.

Kolstad, C. D. (2016). *Environmental economics* (2nd ed., C. Peng & X. F. Wang, Trans.). China Renmin University Press.

Lacy, D., & Niou, E. M. S. (2010). A theory of economic sanctions and issue linkage: The roles of preferences, information, and threats. *Journal of Politics*, *66*(1), 25–42. https://doi.org/10.1046/j.1468-2508.2004.00140.x

Lau, C. K. M., Yang, F. S., Zhang, Z., & Leung, V. K. K. (2015). Determinants of innovative activities: Evidence from Europe and central Asia region. *The Singapore Economic Review*, *60*(01), 1550004. https://doi.org/10.1142/S0217590815500046

Law, S. H., Lee, W. C., & Singh, N. (2018). Revisiting the finance-innovation nexus: Evidence from a non-linear approach. *Journal of Innovation & Knowledge*, *3*(3), 143–153. https://doi.org/10.1016/j.jik.2017.02.001

Lee, K. H., & Kim, J. W. (2011). Integrating suppliers into green product innovation development: An empirical case study in the semiconductor industry. *Business Strategy & the Environment*, *20*(8), 527–538. https://doi.org/10.1002/bse.714

Lee, W. C., & Law, S. H. (2017). Roles of formal institutions and social capital in innovation activities: A cross-country analysis. *Global Economic Review*, *46*(3), 203–231. https://doi.org/10.1080/1226508X.2017.1292859

Li, D., Huang, M., Ren, S., Chen, X., & Ning, L. (2018). Environmental legitimacy, green innovation, and corporate carbon disclosure: Evidence from CDP China 100. *Journal of Business Ethics*, *150*(4), 1089–1104. https://doi.org/10.1007/s10551-016-3187-6

Luo, Y., Salman, M., & Lu, Z. (2021). Heterogeneous impacts of environmental regulations and foreign direct investment on green innovation across different regions in China. *Science of The Total Environment*, *759*(2), 143744. https://doi.org/10.1016/j.scitotenv.2020.143744

Miers, A. C., & Morgan, C. T. (2002). Multilateral sanctions and foreign policy success: Can too many cooks spoil the broth? *International Interactions*, *28*(2), 117–136. https://doi.org/10.1080/03050620212099

Narayan, P. K., & Popp, S. (2010). A new unit root test with two structural breaks in level and slope at unknown time. *Journal of Applied Statistics*, *37*(9), 1425–1438. https://doi.org/10.1080/02664760903039883

Narayan, P. K. (2021). Covid-19 research outcomes: An agenda for future research. *Economic Analysis and Policy*, *71*, 439–445. https://doi.org/10.1016/j.eap.2021.06.006

Nemet, G. F. (2007). *Policy and innovation in low-carbon energy technologies* [PhD Dissertation]. Energy and Resources Group. Berkeley, CA, University of California.

Nentjes, A., & Wiersma, D. (1988). Innovation and pollution control. *International Journal of Social Economics*, *15*(3/4), 51–70. https://doi.org/10.1108/eb014103

Neuenkirch, M., & Neumeier, F. (2015). The impact of UN and US economic sanctions on GDP growth. *European Journal of Political Economy*, *40*, 110–125. https://doi.org/10.1016/j.ejpoleco.2015.09.001

Oechslin, M. (2014). Targeting autocrats: Economic sanctions and regime change. *European Journal of Political Economy*, *36*, 24–40. https://doi.org/10.1016/j.ejpoleco.2014.07.003

Peksen, D. (2009). Better or worse? The effect of economic sanctions on human rights. *Journal of Peace Research*, *46*(1), 59–77. https://doi.org/10.1177/0022343308098404

Peksen, D., & Drury, A. C. (2010). Coercive or corrosive: The negative impact of economic sanctions on democracy. *International Interactions*, *36*(3), 240–264. https://doi.org/10.1080/03050629.2010.502436

Popp, D. (2006). International innovation and diffusion of air pollution control technologies: The effects of NOX and SO_2 regulation in the US, Japan, and Germany. *Journal of Environmental Economics & Management*, *51*(1), 46–71. https://doi.org/10.1016/j.jeem.2005.04.006

Portela, C., & Soest, C. V. (2012). *GIGA Sanctions dataset codebook.* Version 18 June 2012. German Institute for Global and Area Studies.

Potdar, A., Singh, A., Unnikrishnan, S., Naik, N., Naik, M., & Nimkar, I. (2016). Innovation in solid waste management through Clean Development Mechanism in India and other countries. *Process Safety and Environmental Protection*, *101*, 160–169. https://doi.org/10.1016/j.psep.2015.07.009

Pradhan, R. P., Arvin, M. B., Nair, M., Bennett, S. E., Bahmani, S., & Hall, J. H. (2018). Endogenous dynamics between innovation, financial markets, venture capital and economic growth: Evidence from Europe. *Journal of Multinational Financial Management*, *45*, 15–34. https://doi.org/10.1016/j.mulfin.2018.01.002

Raghupathi, V., & Raghupathi, W. (2017). Innovation at country-level: Association between economic development and patents. *Journal of Innovation and Entrepreneurship*, *6*(1), 1–20. https://doi.org/10.1186/s13731-017-0065-0

Ren, X. S., Liu, Y. J., & Zhao, G. H. (2020). The impact and transmission mechanism of economic agglomeration on carbon intensity. *China Population*, *Resources and Environment*, *30*(4), 95–106 (in Chinese).

Roper, S., Love, J. H., & Bonner, K. (2017). Firms' knowledge search and local knowledge externalities in innovation performance. *Research Policy*, *46*(1), 43–56. https://doi.org/10.1016/j.respol.2016.10.004

Song, C. Q., Chang, C. P., & Gong, Q. (2020). Economic growth, corruption, and financial development: Global evidence. *Economic Modeling*, *94*, 822–830. https://doi.org/10.1016/j.econmod.2020.02.022

Song, W., Yu, H., & Xu, H. (2021). Effects of green human resource management and managerial environmental concern on green innovation. *European Journal of Innovation Management*, *24*(3), 951–967. https://doi.org/10.1108/EJIM-11-2019-0315

Stefano, G. D., Gambardella, A., & Verona, G. (2012). Technology push and demand pull perspectives in innovation studies: Current findings and future research directions. *Research Policy*, *41*(8), 1283–1295. https://doi.org/10.1016/j.respol.2012.03.021

Tan, Y., & Zhu, Z. (2022). The effect of ESG rating events on corporate green innovation in China: The mediating role of financial constraints and managers' environmental awareness. *Technology in Society*, *68*, 101906. https://doi.org/10.1016/j.techsoc.2022.101906

Tang, M., Walsh, G., Lerner, D., Fitza, M. A., & Li, Q. (2018). Green innovation, managerial concern and firm performance: An empirical study. *Business Strategy* & *the Environment*, *27*(1), 39–51. https://doi.org/10.1002/bse.1981

Van Buuren, A., Eshuis, J., & Bressers, N. (2013). The governance of innovation in Dutch regional water management: Organizing fit between organizational values and innovative concepts. *Public Management Review*, *17*(5), 679–697. https://doi.org/10.1080/14719037.2013.841457

Wang, Q. J., Feng, G. F., Chen, Y. E., Wen, J., & Chang, C. P. (2019). The impacts of government ideology on innovation: What are the main implications? *Research Policy*, *48*(5), 1232–1247. https://doi.org/10.1016/j.respol.2018.12.009

Wang, Q. J., Feng, G. F., Wang, H. J., & Chang, C. P. (2021). The impacts of democracy on innovation: Revisited evidence. *Technovation*, *108*, 102333. https://doi.org/10.1016/j.technovation.2021.102333

Wen, J., Wang, Q. J., Feng, G. F., Chen, S. W, & Chang, C. P. (2018). Corruption and innovation: Linear and non-linear investigations of OECD countries. *The Singapore Economic Review*, 1–27.

Wen, J., Zhao, X. X., Wang, Q. J., & Chang, C. P. (2020). The impact of international sanctions on energy security. *Energy* & *Environment*, *32*(3), 458–480. https://doi.org/10.1177/0958305X20937686

Xu, S. C., He, Z. X., Long, R. Y., & Shen, W. X., Ji, S.-B., & Chen, Q.-B. (2016). Impacts of economic growth and urbanization on CO_2 emissions: Regional differences in China based on panel estimation. *Regional Environmental Change*, *16*(3), 777–787. https://doi.org/10.1007/s10113-015-0795-0

Yang, J., Askari, H., Forrer, J., & Zhu, L. (2009). How do US economic sanctions affect EU's trade with target countries? *World Economy*, *32*(8), 1223–1244. https://doi.org/10.1111/j.1467-9701.2009.01190.x

Zaitseva, N. A., Larionova, A. A., Yumatov, K. V., Korsunova, N. M., & Dmitrieva, N. V. (2016). Assessment of the impact of globalization on the introduction of innovative technology companies in the hospitality industry. *International Journal of Environmental* & *Science Education*, *11*(14), 7176–7185.

Zhang, G. L. (2008, October). Economic analysis of government financial support for scientific and technological innovation. In *2008 4th International Conference on Wireless Communications*, *Networking and Mobile Computing* (pp. 1–4). Dalian, China. IEEE. https://doi.org/10.1109/WiCom.2008.2648

Zheng, M. B., Feng, G. F., Jang, C. L., Chang, C. P. (2021). Terrorism and green innovation in renewable energy. *Energy Economics*, *104*, 105695. https://doi.org/10.1016/j.eneco.2021.105695

Zhou, F., & Wang, X. (2022). The carbon emissions trading scheme and green technology innovation in China: A new structural economics perspective. *Economic Analysis and Policy*, *74*(C), 365–381. https://doi.org/10.1016/j.eap.2022.03.007

Zhou, X., Yu, Y., Yang, F., & Shi, Q. (2021). Spatial-temporal heterogeneity of green innovation in China. *Journal of Cleaner Production*, *282*(1), 124464. https://doi.org/10.1016/j.jclepro.2020.124464

Zurbruegg, C., Gfrerer, M., Ashadi, H., Brenner, W., & Kueper, D. (2012). Determinants of sustainability in solid waste management – the Gianyar Waste Recovery Project in Indonesia. *Waste Management*, *32*(11), 2126–2133. https://doi.org/10.1016/j.wasman.2012.01.011

APPENDIX

Table A1. Definitions of variables and data sources

Variable	Definition	Source
Unilateral	whether a country suffer the international sanctions imposed by either the U.S. or the EU separately	GIGA Sanctions Dataset & GSDB
Plurilateral	whether a country was imposed international sanctions from the U.S. and the EU simultaneously	GIGA Sanctions Dataset & GSDB
Multilateral	whether a country was imposed international sanctions from United Nations	GIGA Sanctions Dataset & GSDB
Economic	international sanctions that affect the economy of the target country	GIGA Sanctions Dataset & GSDB
Intensity	formal intensity scale of sanctions	GIGA Sanctions Dataset & GSDB
Green inventions	number of green inventions authorized in the province in that year	Green Patent Research Database
Green utility models	number of green utility models authorized in the province in that year	Green Patent Research Database
GDP	real gross domestic product in the province	National Bureau of Statistics
FDI	ratio of total investment of foreign-invested enterprises to GDP	National Bureau of Statistics
Education	total educational expenditure in the province	National Bureau of Statistics
Regulation	intensity of environmental regulation in the province	China Environmental Statistics Yearbook
Emission	industrial sulfur dioxide (SO_2) emissions	China Environmental Statistics Yearbook

Table A2. List of sample provinces

Province (autonomous region and municipality)		
Anhui	Beijing	Fujian
Gansu	Guangdong	Guangxi
Guizhou	Hainan	Hebei
Henan	Heilongjiang	Hubei
Hunan	Jilin	Jiangsu
Jiangxi	Liaoning	Inner Mongolia
Ningxia	Qinghai	Shandong
Shanxi	Shaanxi	Shanghai
Sichuan	Tianjin	Xinjiang
Yunnan	Zhejiang	Chongqing

Province (autonomous region and municipality) in different regions	
East region	Beijing, Fujian, Guangdong, Guangxi, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin, Zhejiang
Central region	Anhui, Henan, Heilongjiang, Hubei, Hunan, Jilin, Jiangxi, Inner Mongolia, Shanxi,
West region	Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, Yunnan, Chongqing