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The impact of FDI inflows on CO_2 emissions in EU countries

Master's Thesis

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In Prague on 2024.7.30 Zhijing Huang

References

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Abstract

Foreign direct investment (FDI) is a key pathway for upgrading modern green technologies and promoting economic development, but the research on the impact of FDI on carbon dioxide (CO_2) emissions and the relevant mechanisms remains inconclusive and lacks systematic exploration. This study first reviews three theoretical foundations of FDI and environmental pollutants: the pollution haven hypothesis, the scale effect hypothesis and the pollution halo hypothesis. Subsequently, the study innovatively discusses the moderating effects of institutional quality and economic growth based on related research on institutional quality and carbon emissions, and the Environmental Kuznets Curve (EKC) hypothesis. Using a sample of 27 European Union (EU) countries from 2000 to 2020, this study adopts the two-step system generalized method of moments (GMM) method and finds that FDI significantly increases production-based CO_2 emissions but has a significant negative impact on consumption-based CO_2 emissions. Moreover, by introducing interaction terms, this study finds that both institutional quality and economic growth can mitigate the impact of FDI on production-based CO_2 emissions. Therefore, governments need to strengthen environmental management and implement policies to encourage green consumption among the public.

Keywords

FDI; CO_2 emissions; pollution haven hypothesis; Environmental Kuznets Curve; GMM

Abstrakt

Přímé zahraniční investice (FDI) jsou klíčovou cestou k modernizaci moderních ekologických technologií a podpoře hospodářského rozvoje, ale výzkum vlivu FDI na emise oxidu uhličitého (CO_2) a příslušných mechanismů je stále nepřesvědčivý a chybí systematický průzkum. Tato studie nejprve přezkoumává tři teoretické základy přímých zahraničních investic a znečišťujících látek v životním prostředí: hypotézu o znečištění, hypotézu o efektu rozsahu a hypotézu o aureole znečištění. Následně se studie inovativně zabývá moderujícími účinky institucionální kvality a hospodářského růstu na základě souvisejícího výzkumu institucionální kvality a emisí uhlíku a hypotézy Kuznetsovy křivky životního prostředí (EKC). Na vzorku 27 zemí Evropské unie (EU) z let 2000 až 2020 tato studie používá dvoukrokovou systémovou zobecněnou metodu momentů (GMM) a zjišťuje, že přímé zahraniční investice významně zvyšují emise CO_2 založené na výrobě, ale mají významný negativní dopad na emise CO_2 založené na spotřebě. Zavedením interakčních členů navíc tato studie zjistila, že institucionální kvalita i hospodářský růst mohou zmírnit dopad FDI na emise CO_2 z výroby. Vlády proto musí posílit environmentální řízení a provádět politiky na podporu ekologické spotřeby mezi veřejností.

Klíčová slova

FDI; emise CO_2; hypotéza o ráji znečištění; Kuznetsova křivka životního prostředí; GMM

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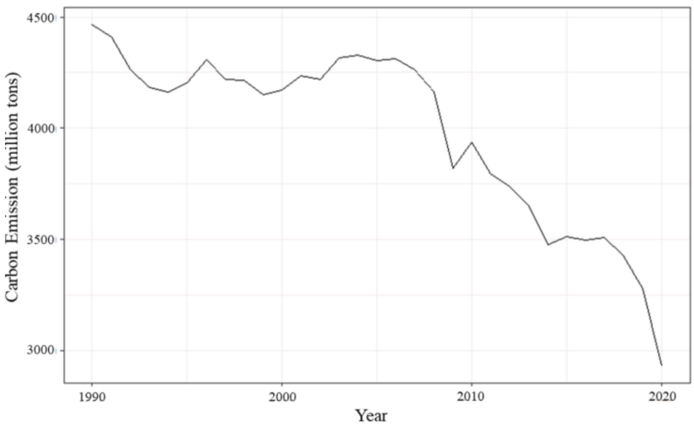
Introduction

Over the past two decades, the problem of global climate change has become more and more serious, with greenhouse gas emissions rising steadily. This has led to more frequent extreme weather events and severe damage to the ecosystems. The majority of greenhouse gas emissions is carbon dioxide (CO_2), which is the main cause of climate change and global warming (Nejat et al., 2015). In response to this challenge, the international community has adopted a series of important climate treaties. In 1992, the United Nations Framework Convention on Climate Change was adopted, signalling the start of worldwide efforts to stabilise atmospheric concentrations of anthropogenic greenhouse gases (Bodansky, 1993). Furthermore, the international community signed the Kyoto Protocol in 1997, requiring developed countries to lower their emissions by 5.2% below the 1990 emission levels between 2008 and 2012 (Breidenich et al., 1998). This agreement introduced flexible mechanisms such as Joint Implementation, Emissions Trading and Clean Development Mechanism, allowing countries to achieve their reduction goals more efficiently through international cooperation and market-based approaches. Despite the great efforts made by the international community in reducing emissions, global greenhouse gas emissions still went up. To further combat climate change, the international community reached an agreement at the 2015 Paris Climate Conference. The Paris Agreement intends to control the increase of global temperature to well below 2°C above pre-industrial levels, with the target to restrict this warming to 1.5 °C (UNEP, 2015).

As a leader of global climate policy formulation, the European Union (EU) has implemented a number of measures over the past two decades to reduce carbon emissions. During the first commitment period (2008-2012) of the Kyoto Protocol, EU aimed to reduce greenhouse gas emissions by 8% below the emission levels of 1990 (European Commission, 2013). This target was allocated among member states, with each country's reduction target tailored to its relative wealth and economic situation. In the second commitment period (2013-2020), the EU set an even more ambitious goal to jointly reduce emissions by 20% below 1990 base year emissions (European Union, 2011). To achieve these targets, the EU enacted the Emissions Trading Directive in 2003, establishing the EU Emissions Trading System (EU ETS). This system sets caps on CO_2 emissions for energy production and high-energy-consuming industrial sectors and allows for the trading of emission allowances, covering approximately 45% of the EU's total CO_2 emissions (European Commission, 2005). Since the launch of the EU ETS, it has become the world's largest emissions trading system (Convery, 2009). Figure 1 shows the trend of carbon emissions in the EU from 1990 to 2020 (Liu, Xie and Wang, 2023), demonstrating the positive impact of these policies. Looking ahead, the European Commission is committed to making Europe the first climate-neutral continent by 2050. (European Commission, 2019).

Figure 1: The trend of carbon emissions of the EU between 1990 and 2020 (Liu, Xie and Wang, 2023)



With the globalization and European integration, the flow of international capital, especially foreign direct investment (FDI), has become more frequent in the EU (Dellis, Sondermann and Vansteenkiste, 2020). Although this trend promoted economic growth of the EU, it affected environmental quality to some extent. On the one hand, FDI inflows may impose environmental burdens, which is in line with the core ideas of pollution haven hypothesis and scale effect hypothesis. Large flows of foreign investment into energy-intensive such as chemicals, steel and cement manufacturing can cause the increase of pollutant emissions (Javorcik and Wei, 2003). On the other hand, FDI may improve the EU's environmental quality, which is consistent with the core ideas of pollution halo hypothesis. Multinational corporations (MNCs) often have strict environmental standards and advanced technologies, which can be introduced to the host countries (Gosens, Lu and Coenen, 2015). This transfer of management expertise and technology can help local enterprises to improve their environmental standards and reduce pollutant emissions.

FDI not only has a direct impact on carbon emissions, this relationship can also be moderated by other factors such as institutional quality and economic growth. Firstly, a high-quality regulatory framework includes stringent environmental standards, efficient monitoring and enforcement mechanisms (Gunningham, 2011). It ensures that companies must comply with environmental regulations when pursuing economic benefits, thereby controlling carbon emissions. Moreover, high-quality regulatory systems usually have high transparency and public participation (Lathrop and Ruma, 2010). Information disclosure and the pressure from the public can prompt companies to comply with environmental regulations, thus reducing carbon emissions. Secondly, the Environmental Kuznets Curve (EKC) hypothesis describes the inverted U-shaped relationship between economic growth and environmental quality. Specifically, as income per capita increases, pollution emission initially rises but starts to decrease once exceeding a certain income level (Kaika and Zervas, 2013). Economic development has brought substantial capital accumulation to the EU, equipping the EU with strong research and development (R&D) capabilities (Crescenzi and Rodríguez-Pose, 2011). This enables enterprises to more easily acquire and apply advanced environmental technologies, thus reducing carbon emissions in their production processes.

Therefore, this study proposed two research questions: 1) Are FDI inflows contributing to CO_2 emissions in EU countries positively or negatively? 2) Do institutional quality and economic growth moderate this relationship?

Although a growing number of scholars have explored the impact of FDI on CO_2 emissions, certain research gaps persist. Differences in national selection, data duration and econometric methods lead to the variation of results. This study makes three contributions. Firstly, in terms of research scope, most scholars only focus on the impact of FDI on CO_2 emissions in developing and emerging markets. For the European region, most of studies concentrate on Central and Eastern Europe. But this study takes the EU as a whole and investigates the impact of FDI inflows on CO_2 emissions between 2000 and 2020. Secondly, regarding the research methodology, most scholars only focus on the direct impact of FDI on CO_2 emissions. This study innovatively incorporates institutional quality and economic growth into the baseline regression model to further explore the moderating effects. Lastly, for the dependent variable, besides examining the impact of FDI on production-based CO_2 emissions that is the common concern of existing literature, this study also pioneeringly discusses the impact of FDI on consumption-based CO_2 emissions.

The remainder of this study is organized as follows. In the first section, this study reviews existing researches from both theoretical and empirical perspectives. The second section focuses on methodology and data. The third section presents the results of the baseline and moderated regressions, and has a further discussion by replacing the dependent variable from production-based CO_2 emissions to consumption-based CO_2 emissions. At last, this study summarises the empirical findings and provides policy recommendations.

1. Literature review

1.1 FDI and carbon emissions

The relationship between FDI and carbon emissions is mainly based on three hypotheses: the pollution haven hypothesis, the scale effect hypothesis and the pollution halo hypothesis. The pollution haven hypothesis and the scale effect hypothesis suggest that FDI causes the increase of carbon emissions. On the contrary, pollution halo hypothesis indicates that FDI can improve air quality.

1.1.1 Pollution haven hypothesis

The pollution haven hypothesis was first proposed by Pethig (1976) and was further refined by Copeland, Taylor and Columbia (1993), who modelled the interactions between trade, environmental policy and industry location in order to provide a foundational theoretical framework. Their work demonstrated that different environmental regulations could influence corporate location decisions, creating the pollution havens. Specifically, this hypothesis was initially developed in the context of the North American Free Trade Agreement and linked the environmental regulations, trade patterns and pollution levels. Under trade liberalization, pollution-intensive industries would relocate from developed countries with strict environmental regulations such as the United States, to developing countries with more lenient environmental standards such as Mexico (Gill, Viswanathan and Karim, 2018). This relocation would result in developing countries becoming pollution havens, leading to environmental degradation.

The pollution haven hypothesis is based on the theory of comparative advantage that refers to the lower opportunity cost of producing a specific good within a country relative to other goods (Ricardo, 1817). Even if a country produces all goods less efficiently than other countries, it can still benefit from international trade by specialising in and exporting goods that have a comparative advantage. Therefore, countries should specialise in production based on differences in relative production costs and then trade their products (Krugman, Obstfeld and Melitz, 2018). This specialisation enables each country to maximise the efficiency of resource allocation, thus enhancing global economic welfare.

When applying comparative advantage to environmental economics, it implies that countries with looser environmental regulations have a comparative advantage in highly polluting industries (Cole, Elliott and Shimamoto, 2005; Dean, Lovely and Wang, 2009), because factories in these countries can produce at lower costs without bearing the high environmental compliance costs. As a result, developing countries with lax environmental regulations often attract the investments of pollution-intensive industries, and these countries gradually specialise in the production and export of pollution-intensive products. This occurs not only because of the low regulatory costs in these countries, but also because they seek to increase employment rates and boost economic growth by attracting such industries (Bokpin, 2017). However, this has brought a series of environmental pollution problems. On the contrary, firms in developed countries must adopt environmentally-friendly production techniques because of strict environmental regulations. Therefore, developed countries gradually form a comparative advantage in clean technology and low-carbon industries, focusing on the production and export of relatively cleaner goods (Porter and Linde, 1995). This divergence in global production and trade patterns results in developed countries outsourcing pollution-intensive industries to developing countries. Finally, these developing countries became pollution havens.

The relocation of highly polluting industries from developed countries to developing countries is through two main channels: goods trade and FDI (Antweiler, Copeland and Taylor, 2001; Blonigen and Davies, 2004; Frankel and Rose, 2003). The FDI channel is the focus of this study. Firstly, the goods trade channel is the outsourcing of high-carbon industries from developed to developing countries, followed by the reimport of these products back to the developed countries through international trade. This channel helps developed countries to reduce high-pollution production activities domestically while still obtaining the necessary products. The study by Cole, Elliott and Zhang (2017) suggests that this pattern of production outsourcing and reimport has become increasingly common in global trade. But this pattern complicates global production networks, making the track of pollution sources and the share of environmental responsibilities more challenging (Peters et al., 2012). Secondly, the FDI channel refers to that foreign companies invest in developing countries with loose environmental laws in order to reduce their environmental compliance costs. This channel enables developed countries to reduce environmental pressure while taking advantage of the low labour costs and other resource benefits in developing countries. There are three main reasons why developing countries become pollution havens through

FDI inflows. Firstly, FDI inflows are often accompanied by technology transfer and capital flow, which is sometimes harmful to environment (Jenkins, 2005). This is because developing countries often lack sufficient technologies and regulatory abilities to deal with the complex environmental issues brought by high-pollution industries, which deteriorates the environmental quality. Secondly, foreign investors driven by profit maximization might overexploit natural resources, further worsening environmental issues (Leonard, 2006). For example, in African countries, foreign investment to the mining sector often damages the ecological system due to outdated environmental laws (Gochero and Boopen, 2020). Lastly, governments in developing countries sometimes lower environmental standards to attract FDI, reducing the effectiveness of environmental protection measures (Cole, Elliott and Fredriksson, 2006). This phenomenon is particularly evident in some Latin American countries (Gallagher and Zarsky, 2007). Although some policies can attract more FDI inflows and promote economic growth in the short term, the negative impact on the environment cannot be ignored in the long term.

Many scholars have studied the pollution haven hypothesis by testing the relationship between environmental regulations and the FDI inflows. They use different methodologies including qualitative analysis and quantitative analysis in order to explore the implications of pollution haven hypothesis in different contexts.

Some scholars have explored the pollution haven hypothesis through industry-specific research and case studies. Sarraf et al. (2010) conducted an 11-month qualitative study in 2009 on the Ship Breaking and Recycling Industry in Bangladesh and Pakistan. The authors performed environmental audits of hazardous waste from ships scheduled to dismantle and listed the pollutants, finding that the ship-breaking process released large amounts of pollutants. Additionally, surveys to the Chittagong and Gadani regions showed that these areas had relatively weak environmental and occupational health regulations. This demonstrates that loose environmental regulations and Ineffective enforcement created pollution havens for the Ship Breaking and Recycling Industry, emphasising the negative environmental influence in the pollution haven hypothesis especially in areas with weak regulatory capacity. However, Mani and Wheeler (1998) pointed out the non-universality of the pollution haven hypothesis through case studies. Although this study found that the production share of high polluting industries declined in Organisation for Economic Cooperation and Development (OECD) countries and increased steadily in developing countries (consistent with the predictions of the pollution haven hypothesis), this effect is limited and temporary. There are three main reasons. Firstly, the ratio of consumption to production of pollution-intensive products in developing countries is close to one, suggesting that most of the production and consumption of pollution-intensive products takes place domestically. Secondly, with income growing, the elasticity of demand for basic pollution-intensive products decreases, reducing the consumption of these products. Finally, changes in energy prices and energy subsidies affect costs of pollution-intensive industries, preventing these industries move to pollution havens to some extent.

Progress in econometric techniques have improved the precision and reliability of studies on the pollution haven hypothesis. Firstly, List and Co (2000) employed a conditional logit model to explore the impact of state regulations on the location decisions of foreign enterprises to establish new plants in the United States from 1986 to 1993. They analyse the heterogeneity of pollution-intensive and non-pollution-intensive industries by including interaction terms. In order to fairly measure the regulatory effort of states, this study used a combination of four indicators, including state government expenditures on air, water and solid waste control, corporate expenditures on pollution control, a comprehensive environmental protection index and state efforts to control pollution. The results showed that stricter pollution regulations impede foreign firms' decisions to build new plants in the United States. The sensitivity of industries to environmental regulations varied by their pollution intensity, so pollution-intensive industries is more sensitive. This is consistent with the core ideas of pollution haven hypothesis. Xing and Kolstad (2002) refined the analysis by focusing on industries requiring lots of pollution control costs such as chemicals, and industries requiring less pollution control costs such as food products, in the United States from 1985 to 1990. They employed a semi-logarithmic linear model of FDI determinants and analysed the relationship between FDI and the laxity of host country environmental regulations. They used sulphur emissions as a proxy for environmental quality and established two equations to represent the determinants of FDI and pollutant emissions, respectively. The study found that, for highly polluting industries, the increase in sulphur emissions was highly correlated with the loose environmental regulations. Countries with looser environmental regulations attracted more FDI of such industries, which is consistent with pollution haven hypothesis. However, the impact of environmental regulations on FDI is insignificant for industries with low pollution control costs.

From an international perspective, Wagner and Timmins (2008) expanded the research scope of pollution haven hypothesis by analysing the outward FDI of German manufacturing industries to 163 countries between 1996 and 2003. They specifically selected six industries with different pollution intensity. In the first stage of regression, they used the generalized method of moments (GMM) to address endogenous issues. Considering the externality of FDI agglomeration effects, the study used FDI stock as a proxy for agglomeration effects in the second stage of regression, and employed the linear regression model to analyse the impact of environmental regulatory stringency, FDI stock and the distance from Germany on FDI flows. The results showed significant pollution haven effects in the chemical sector. Moreover, Baek (2016) adopted the Pooled Mean Group estimator to examine the long-term relationships between variables and reveal the speed of adjustment of variables to long-run equilibrium. Based on data from five ASEAN countries from 1981 to 2010, this study investigated the impact of FDI, income and energy consumption on CO_2 emissions. It was found that due to the loose environmental regulations in the host countries, FDI inflows increased CO_2 emissions in these countries. This also strongly support the pollution haven hypothesis. Lastly, Levinson and Taylor (2008) investigated the impact of environmental regulations on trade flows by combining theoretical models with empirical analysis. This study demonstrated the biases in previous studies caused by unobserved heterogeneity, endogeneity and aggregation issues by a simple model, and then proposed a multi-sector partial equilibrium model using geographic distribution as an instrumental variable. By analysing trade data of North America between 1977 and 1986, they found that industries with the highest increases in pollution control costs had the largest increases in net imports. This finding suggests that firms relocate highly polluting production to countries with looser environmental regulations to reduce environmental compliance costs, which give evidence to the pollution haven hypothesis.

1.1.2 Scale effect hypothesis

The scale effect hypothesis explains that FDI inflows can increase carbon emissions from another perspective. When foreign enterprises operate at full capacity in the host country, the environmental quality will get worse (Latief et al., 2021). This is because foreign enterprises are often concentrated in resource-intensive and pollution-intensive industries. And during the expansion of production scales, these industries produce lots of pollutants, thus exacerbating the environmental issues of the host country.

According to the scale effect hypothesis, the environmental impacts of FDI on host countries are mainly realised through the following five aspects, with the interactions of each aspect further exacerbating environmental degradation. To begin with, FDI brings capital, technology and management experience, which enhances the production capacity and economic activity in host countries. More economic activities cause more resource consumption and waste emissions, which directly increases environmental pressure (Bruyn, Bergh and Opschoor, 1998). Then, foreign enterprises further expand production scales through efficient production methods and economies of scale. After that, since FDI is often concentrated in resource-intensive and pollution-intensive industries, the expansion of production inevitably brings more resource consumption and pollution emissions, further deteriorating environmental quality (Dasgupta et al., 2002). Meanwhile, although FDI may bring advanced production technologies, these technologies are always not effectively used for environmental protection. This is because foreign companies tend to prioritise economic benefits over environmental benefits, leading to the insufficient realisation of the environmental protection capacity of advanced technologies (Wheeler, 2001). In addition, although the technological diffusion and productivity improvements brought by FDI can promote economic growth, these benefits are often offset by environmental costs in the early stages of economic development (Osano and Koine, 2016). Finally, government failure and market failure in some countries result in difficulties in the effective implementation of environmental protection policies. This phenomenon is common in developing countries at the early stages of economic development (Faure, Goodwin and Weber, 2010), which further exacerbates environmental problems.

Some scholars have tested the scale effect hypothesis through different methods and data, and this study reviewed empirical studies based on the scope of the researches. Firstly, several researchers examined the scale effect hypothesis for multiple countries within a specific region. Halliru, Loganathan and Hassan (2020) used panel data for six West African countries (Benin, Gambia, Ghana, Nigeria, Senegal and Togo) from 1970 to 2017 to explore the impact of FDI, economic development, energy consumption, human capital and biocapacity on carbon emissions. They found an N-shaped relationship between FDI and carbon emissions through panel quartile estimation. This is because these countries attracted large amounts of FDI into the sectors of oil, mining and agriculture, which placed heavy burden to the environment. Therefore, the results strongly supported the scale effect hypothesis. Secondly, some scholars focused on a specific country. Based on data of China's 30 provinces between 2004 and 2015, Gong et al.'s (2019) decomposed the carbon emission factors through Kaya's constant equation and established a model to explore the scale effect of carbon emissions due to factor market distortion and two-way FDI. Under China's coal-dominated energy structure, they found that inward FDI increased carbon emissions and worsened factor market distortions through the scale effect. They also pointed out that outward FDI reduces regional economic scale and carbon emissions by transferring overcapacity, which further supports the mechanism of the expansion of economic activities on the environment in the scale effect hypothesis.

1.1.3 Pollution halo hypothesis

Contrary to the pollution haven hypothesis and the scale effect hypothesis, the pollution halo hypothesis suggests that FDI inflows will introduce modern clean technology and environmental management experience into the host countries, which will decrease the carbon emissions and improve the environmental quality of the host countries.

FDI alleviates environmental problems of the host country from four aspects. Firstly, FDI reduces carbon emissions of firms in host countries by increasing the efficiency of resource use (Hao et al., 2019). For instance, MNCs usually adopt more efficient production equipment and processes. This not only directly improves the environmental performance of production processes, but also prompts local firms to improve their environmental standards and technology levels through demonstration effects and competitive pressure (Feng, Zeng and Ming, 2018). Secondly, FDI can enhance the environmental technology level of host countries through knowledge diffusion, technology spillovers and technology transfer (Blomstrom and Kokko, 1998). MNCs often provide local training and technical guidance to help local employees master advanced environmental technologies and management practices (Hobday and Rush, 2007). This diffusion of knowledge and technology not only helps local enterprises to enhance the environmental protection capability, but also improves environmental protection standards of the whole industry. Thirdly, the capital brought by FDI provides important financial support for the host country's environmental protection projects (Harrison, 1994). During the investment process, MNCs need large amounts of funds to build factories that meet high environmental standards and local environmental infrastructure such as wastewater sedimentation tanks, gas absorption towers and dust collectors (Zhang et al., 2020). Lastly, FDI can improve local environmental regulations to some extent. In order to have a good global image and reputation, foreign enterprises often adopt environmental standards that exceed the legal requirements of the host country (Peng and Lin, 2007). This not only enhances their environmental performance and also sets higher environmental benchmarks for the host country, thus encouraging the local government to modify and improve the standards of environmental regulations.

A large number of scholars have provided empirical evidence to support the pollution halo hypothesis. This study reviews the researches based on their scope, from small to large. China, attracting the most FDI among developing countries, is an ideal environment for studying the effects of the pollution halo hypothesis (Broadman, Sun and Mundial, 1997). In order to examine whether globalisation has pushed firms to exceed local government requirements for environmental self-regulation by increasing multinational ownership, cross-border customer linkages and exports to developed countries, Christmann and Taylor (2001) collected data of 118 enterprises in Shenzhen and Shanghai (including multinationals, partially foreign-owned and fully locally-owned firms). Using ordinary least squares (OLS) regression analyses, they found that higher proportions of multinational ownership are associated with higher levels of environmental compliance and higher possibilities of adopting ISO 14000 environmental management standards. This result is consistent with the core ideas of the pollution halo hypothesis. Because of the degree of environmental stringency varies across Chinese provinces, Hao and Liu (2014) further collated data of 29 provinces in China between 1995 and 2011. Their aim was to explore the indirect and direct impacts of FDI and international trade on CO_2 emissions. By employing two jointly estimated equations, including the traditional quadratic formula of the EKC and an economic growth equation, they got the conclusions same with the story of the pollution halo hypothesis. Specifically, they found that the negative direct impact of FDI on CO_2 emissions exceeded the positive indirect impact of FDI on CO_2 emissions, which makes the total impact of FDI on CO_2 emissions negative. This demonstrates that FDI reduces total pollution through the introduction of advanced clean technology and management practice.

Expanding the scope of research from China to more developing countries, Eskeland and Harrison (2003) explored the FDI inflows to Côte d'Ivoire, Morocco, Mexico and Venezuela. In Côte d'Ivoire, they found a significant positive correlation between the cost of pollution control and FDI inflows, while in Venezuela, the correlation was significantly negative.

However, these relationships became insignificant when fixed effects were introduced. This suggests that the impact of pollution control costs on FDI inflows is neither significant nor consistent. Furthermore, by comparing the emission behaviours of foreign and local firms within the same manufacturing sectors, the study found that foreign firms always adopted more efficient pollution control technologies in host countries, which significantly reduces pollution emissions. This result also strongly supports the pollution halo hypothesis. Additionally, Tamazian, Chousa and Vadlamannati (2009) pointed out that while many scholars have explored the relationship between economic development and environmental degradation, few scholars comprehensively studied financial development. Therefore, their study not only measured economic development through Gross Domestic Product (GDP) growth rate, the industrial share of GDP and R&D expenditure but also assessed financial development by several indicators including stock market capitalization, FDI, the ratio of bank assets to GDP, finance liberalization and finance openness and capital account convertibility. Using a sample of the BRIC countries between 1992 and 2004, they used a standard reduced-form modelling approach and established a random-effect model. The results showed that well-developed capital markets, banking sectors and more FDI contribute to reducing CO_2 emissions per capita. This is because a more developed financial system can attract more investment related to R&D, thus enhancing technological efficiency and improving environmental quality. They give evidence to support the pollution halo hypothesis.

Instead of limiting the research scope to developing countries, Mert and Bölük (2016) explored the impact of FDI and green energy consumption on CO_2 emissions of 21 Kyoto Protocol Annex countries in order to test the universality of the pollution halo hypothesis. This study employed a panel cointegration framework and conducted unit root and cointegration tests based on the unbalanced panel data between 1995 and 2011. It was found that the long-term elasticities of green energy consumption and FDI with respect to CO_2 emissions were negative, suggesting that the increase of green energy consumption and FDI inflows would be beneficial for the improvement of air quality. Therefore, FDI plays an important role in improving environmental standards and introducing advanced environmental protection technologies, which supports the pollution halo hypothesis.

Therefore, based on the understanding of these three hypotheses, this study proposes Hypothesis 1 as follows: FDI inflows has a significant and positive contribution to CO_2 emissions.

1.2 Moderators and carbon emissions

1.2.1 Institutional quality and carbon emissions

Many scholars suggest institutional quality as a key source of comparative advantage for countries or regions (Acemoglu, Antràs and Helpman, 2007; Costinot, 2009; Hall and Soskice, 2001). Institutional quality not only influences economic development and social stability, but also plays an important role in environmental management and sustainable development. High-quality institutions can reduce the negative environmental externalities of MNCs in host countries through stringent environmental regulations and effective enforcement (Neves, Marques and Patrício, 2020). Under this context, institutional quality acts as a moderator that can influence the extent to which FDI affects carbon emissions.

High-quality institutions weaken the negative environmental impacts of FDI through strict environmental regulation and enforcement, low levels of corruption, social capital and public participation, technological innovation and international cooperation.

Firstly, institutional quality moderates the impact of FDI on carbon emissions through stringent environmental regulations and enforcement. Strict environmental regulation reduces pollution emissions mainly through the establishment and enforcement of high standards of environmental laws and policies (Yirong, 2022). It requires companies to adopt more environmentally-friendly methods and technologies during their production processes and ensures continuous improvement in environmental protection measures to meet standards. Effective enforcement mechanisms ensure the practical implementation of environmental regulations mainly through regular inspections, penalties for violations and mandatory corrections (Tosun, 2012). This further motivates MNCs' to comply with environmental standards and promotes the widespread use of green technologies. Specifically, countries with high institutional quality typically have well-developed legal frameworks and transparent enforcement mechanisms (Radaelli and Francesco, 2013), where companies need to face high compliance costs and strict scrutiny. This encourages companies to invest in environmentally-friendly technologies for the long term rather than relying on short-term cost-saving strategies (Cainelli, Mazzanti and Zoboli, 2011). Additionally, governments in these countries often cooperate with firms, academic institutions and non-governmental organisations to promote the development and application of green technologies (Harangozó and Zilahy, 2015). The combined effects of these measures not only improve local environmental quality, but also enhance application of environmentally-friendly technologies globally.

Secondly, institutional quality further influences the impact of FDI on carbon emissions through lower levels of corruption. Low levels of corruption ensure transparent and fair enforcement of environmental regulations, reducing the possibilities that companies will evade their environmental responsibilities through bribery, tax evasion and other illegal means, thus prompting them to focus on investing in green technologies (Kolstad and Wiig, 2009; O'Higgins, 2006). In addition, low levels of corruption reduce the likelihood of embezzlement and increase the efficiency of government officials, (Chatterji, Levine and Toffel, 2009), thereby improving the efficiency of the allocation of funds for environmental protection. Therefore, in countries or regions with lower levels of corruption, MNCs prefer to invest in long-term green technologies, which improves air quality in the host country (Castro and Nunes, 2013).

Third, public participation and social capital in high-quality institutions are also important for environmental governance. Public concern and participation in environmental issues not only exert pressure on MNCs to adopt cleaner technologies and improve environmental standards (Stern and Dietz, 2008), but also improves the effectiveness and transparency of environmental policy implementation through information disclosure and public scrutiny (Haufler, 2010). For example, the public can expose and restrain irregular environmental practices of companies through environmental organizations, community activities and media coverage (Neu, Warsame and Pedwell, 1998). This increases transparency of environmental information and motivates companies to improve their environmental performance under public pressure. In addition, social capital can support local environmental projects, enabling communities to work together to solve environmental issues (Rydin and Pennington, 2000), thus further strengthening environmental protection.

Fourth, institutional quality can moderate the impact of FDI on carbon emissions by promoting technological innovation and knowledge diffusion. High-quality institutions support for R&D through policies such as intellectual property protection and provide a competitive market (Leiponen and Byma, 2009). These measures motivate both MNCs and local firms to invest in R&D, causing the development of more efficient low-carbon technologies. This technological innovation not only improves firms' productivity and environmental performance, but encourages other companies to develop and adopt advanced environmental technologies (Ouyang, Li and Du, 2020), thus raising the standards of whole industry. Furthermore, high-quality institutions ensure the efficient dissemination of technology and knowledge to maximize environmental benefits. When MNCs enter the host country markets, they usually bring advanced environmental methods and management experience, which are diffused among local firms through employee training, collaborative R&D and supply chain management (Saliola and Zanfei, 2009). This knowledge diffusion helps more employees of local companies to master the process and expertise of protecting the environment, thus reducing regional carbon emissions.

Fifthly, international cooperation and policy coordination under the framework of high-quality institutions can moderate the environment impact of FDI. To begin with, high-quality institutional countries actively participate in international environmental organizations like the United Nations Environment Programme, sharing and acquiring the latest environmental technologies and policy experiences (Raustiala, 1997). This cooperation in global environmental governance contributes to a common response to challenges such as environmental pollution and climate change. Additionally, these countries sign and comply with international environmental agreements like “the Paris Agreement” and “the Kyoto Protocol” (Savaresi, 2016; Shishlov, Morel and Bellassen, 2016). They have committed to reducing carbon emissions (Iwata and Okada, 2012), and promote the formation and implementation of environment domestic policies. Also, by adopting internationally recognized best environmental practices, countries with high-quality institutions accordingly increase their environmental governance standards (Jänicke, 2005).

Some empirical studies have demonstrated the important role of institutional quality in improving the environmental quality. Based on data from 177 countries between 2002 and 2019, Khan, Weili and Khan (2022) employed the two-step system GMM to establish the model. This study not only analysed the impact of FDI, green energy consumption, economic growth and financial development on carbon emissions but also examined the moderating effects of institutional quality by introducing interaction terms. They found that the interaction terms constructed by institutional quality and other variables were significantly negative, suggesting that high-quality institutions can weaken the negative impacts of FDI on environment. Similarly, Hunjra et al. (2020) explored the moderating effects of institutional quality by introducing interaction terms. They investigated the relationship between environment and financial development, and how institutional quality moderates this relationship, based on a sample of five South Asian countries including India, Bangladesh, Nepal, Sri Lanka and Pakistan between 1984 and 2018. They used the corruption index to measure institutional quality. The regression model showed that institutional quality significantly weakens the negative impacts of energy consumption, economic development and financial development on the environment. This finding supports that improving institutional quality can promote sustainable environmental development. In addition, Wu and Madni (2021) tested the threshold effects of institutional quality on environmental protection in Belt and Road Initiative (BRI) economies. Their study collected data from 33 BRI countries between 1986 and 2017. Using panel threshold regression techniques, they determined the threshold level of the impact of institutional quality on CO_2 emissions. Countries with institutional quality above this threshold did not show significant contributions to CO_2 emissions from financial development, industrialization, transportation and GDP per capita. On the contrary, countries with institutional quality below this threshold experienced significant increases in CO_2 emissions caused by these factors. This result also gives evidence that high-quality institutions can help to control the air quality.

Therefore, this study proposes Hypothesis 2 as follows: Institutional quality mitigates the impact of FDI inflows on CO_2 emissions.

1.2.2 Economic growth and carbon emissions

The EKC hypothesis is an important theoretical basis for studying the relationship between air quality and economic growth. The EKC hypothesis was first proposed by Grossman and Krueger (1991) when studying the North American Free Trade Agreement. This study set up a simplified regression equation incorporating time trends, geographic location and trade density as explanatory variables, based on the data of air quality from Global Environmental Monitoring System including sulphur dioxide and particulate matter. The results showed that there is an inverted U-shaped relationship between environment quality and income per capita. At the beginning, environmental quality becomes worse with income growth, but it improves once income per capita reaches a turning point of 4000 to 5000 dollars approximately. Therefore, the EKC hypothesis indicates the inverted U-shaped relationship between income and environmental deterioration: The quality of environment declines in the early stages of economic development but improves once economic growth surpasses a certain threshold (Shafik and Bandyopadhyay, 1992).

The EKC hypothesis provides a foundation to understand how economic growth as a moderator variable influences the impact of FDI on carbon emissions. In the early stages of economic development, FDI inflows place a huge burden to the environment (Yilanci and Pata, 2020). This is because at this stage, weak awareness of environmental protection and short-term profit motivation of firms lead to large amounts of pollutant emissions. However, with economic growth, the advanced green technologies and management experiences brought by FDI are gradually applied. Also, the government, companies, and residents will raise awareness of environmental protection, which causes the reduction in carbon emissions (Shahbaz, Nasir and Roubaud, 2018).

Economic growth influences environment quality through scale effects, structural effects and technological effects (Pasche, 2002; Sohag, Kalugina and Samargandi, 2019). Firstly, when income per capita grows, the economic scale expands, requiring more resource inputs and more output. However, this increase in output leads to more carbon emissions (Bibi and Jamil, 2020), thereby degrading environmental quality in the early stages of economic development, which is the core ideas of the scale effect hypothesis discussed in the previous section. Secondly, economic growth is usually accompanied by structure transformation of economies from heavy industries to service and technology-intensive industries (Tamazian and Rao, 2010), which mitigates the environmental problems to some extent. Finally, the income growth and market expansion brought about by economic growth can promote research and innovation. Specifically, when level of income grows, host countries can attract more FDI, which brings advanced environmental technologies and management methods (Pata and Caglar, 2020). The foreign investment promotes technological development, encouraging firms to adopt more environmentally-friendly production practices, thus reducing carbon emissions.

As research continues to deepen, scholars have expanded the theoretical explanation of EKC in this respect of environmental regulation and environmental protection investment. Firstly, in the early stage of economic development, low national income and weak government financial foundation lead governments to pay more attention to economic growth and ignore environmental legislation (Kahuthu, 2006). Consequently, pollution emissions increase with economic growth. However, when the economy further develops, the government's fiscal strength and management capacity increased, and a series of environmental regulations are enacted to reduce environmental pollution (Gill, Viswanathan and Hassan, 2018). The increase in environmental protection investment explains the relationship between economic growth and environment from another aspect. Capital is divided into two parts: One for goods production, generating pollutants, and the other for environmental improvement, enhancing ecological quality (Dinda, 2004). In low-income stages, most capital is used for production, thus polluting the environment. Later, as economic development progresses and capital accumulates, the increase in the investment of environmental protection projects such as employing environmental experts and purchasing energy-saving equipment helps to reduces emissions. Therefore, the transformation from insufficient to sufficient environmental investments also leads to the inverted U-shaped relationship between environment quality and the level of income.

A large number of scholars have validated the existence of the EKC hypothesis, in which the dependent variables are mainly sulphur and carbon emissions. Based on cross-sectional data from 55 developed and developing countries, Panayotou (1993) estimate log-linear and log-quadratic models, with income and population density as independent variables. He established regression equations for deforestation rates and pollution emissions including nitrogen oxides, particulate matter and sulphur dioxide, and estimated the parameters by OLS techniques. The study found the inverted U-shaped relationship: Deforestation rates and pollution emissions initially increase and then decrease with the income level. The turning point of income for deforestation is between $800 and $1,200, and the turning point of income for pollution emissions is between $3,800 to $5,500. This suggests that environmental deterioration is inevitable in the early stages of economic development, but environmental quality will improve with economic growth. This result is in line with the core ideas of the EKC hypothesis. Furthermore, Torras and Boyce (1998) expanded the EKC hypothesis by incorporating additional variables such as income distribution and political factors, obtaining a more comprehensive understanding on the relationship between economic growth, income inequality and environmental quality. They used air and water pollution indicators including sulphur dioxide, particulates, dissolved oxygen and faecal coliforms of over 1000 regions in the database of Global Environmental Monitoring System. Using OLS regression techniques, the study established models to estimate the relationship between, income per capita, the degree of pollution, income inequality, literacy rate, civil liberty and political right. Additionally, they used cubic polynomial forms of income variables to capture potential inverted U-shaped relationships. The results showed the inverted U-shaped relationship between pollutants and income, strongly supporting the EKC hypothesis. Moreover, by introducing the variable of power distribution, the study also revealed that more equal power distribution can effectively improve environmental quality. Some scholars have shifted their focus to carbon emissions. Schmalensee, Stoker and Judson (1998) explored the relationship between GDP per capita and CO_2 emissions per capita through OLS techniques for a sample of 141 countries between 1950 and 1990. Their study employed a flexible form of the income effect, incorporating time and country fixed effects. They found that in the early stages of economic development, CO_2 emissions increase with the growth of income, but decrease once surpassing a certain income level. The results give evidence to the EKC hypothesis. Additionally, they used the same population and economic growth assumptions in the Intergovernmental Panel on Climate Change for predictions and solved the prediction uncertainties.

However, an increasing number of scholars have questioned the EKC hypothesis (Copeland and Taylor, 2004; Ekins, 1997; Stern, 1998). Theoretically, the EKC hypothesis assumes that income is an exogenous variable and ignores the feedback from environmental damage on economic production (Arrow et al., 1996). If high levels of economic activity are unsustainable, rapid economic growth would bring adverse effects. Moreover, the relationship in the EKC hypothesis may primarily result from the effect of international trade on the distribution of dirty industries (Stern, Common and Barbier, 1996). From an empirical perspective, Özokcu and Özdemir (2017) analysed data of 52 emerging countries and 26 high-income OECD countries between 1980 and 2010. By applying Driscoll-Kraay standard errors to a fixed effects model, they established two models: The first one examined the relationship between GDP per capita and CO_2 emissions per capita, while the second one added energy use per capita as an independent variable. The results indicated an N-shaped relationship in emerging countries and an inverted N-shaped relationship in OECD countries, neither of which supports the EKC hypothesis.

Therefore, this study proposes Hypothesis 3 as follows: Economic growth mitigates the impact of FDI inflows on CO_2 emissions.

2. Methodology and data

2.1 Model specification

2.1.1 Baseline regression

This study uses the two-way fixed effects regression technique, whose advantage over other methods is to control unobserved characteristics associated with units and time. Specifically, when estimating a linear model, incorporating unit fixed effects primarily aims to remove the time averages associated with each unit, followed by the application of pooled OLS technique to these adjusted data. In addition, time fixed effects are taken into account to eliminate variables whose long-term trends have the same effects on all units, which are common in the economy (Wooldridge, 2021). Accordingly, this study has established the following baseline model to explore the relationship between FDI and CO_2 emissions:

$$lnCO_{2\,it} = \alpha_0 + \alpha_1 FDI_{it} + \sum_{j=1}^{k} \beta_j C_{j,it} + \nu_i + \sigma_t + \varepsilon_{it} \quad (1)$$

In Equation (1), i represents the countries of the EU, and t represents each year. $lnCO_{2\,it}$ is the logarithmic form of total CO_2 emissions of country i in year t, which is the dependent variable. FDI_{it} represents the net inflow of FDI as a percentage of the GDP of country i in year t, which is the core explanatory variable. α_0 and α_1 represent the constant term and the coefficient of FDI_{it}, respectively. $C_{j,it}$ denotes the control variables, with k being the number of control variables and β_j representing the coefficient for each control variable. ν_i and σ_t denote the country fixed effects and year fixed effects, respectively, ε_{it} represents the error term.

This study focuses on α_1, which represents the contribution of the core explanatory variable FDI_{it} to the dependent variable $lnCO_{2\,it}$. When α_1 is significant and positive, it demonstrates that FDI can significantly and positively contribute to CO_2 emissions. Therefore, Hypothesis 1 will hold true.

2.1.2 Moderated regression

This study not only examines the direct relationship between FDI and CO_2 emissions but also the moderating effects of institutional quality and economic growth. When the association strength between two variables is influenced by a third variable, this third variable refers to a moderator variable (Fritz and Arthur, 2017). Unlike the individual effects that moderator variable and core independent variable have on the dependent variable, they together produce a combined effect known as an interaction. Therefore, the following model extend the baseline model by incorporating the moderator variable and its interaction with the core independent variable in order to analyse the moderating effects:

$$lnCO_{2\,it} = \alpha_0 + \alpha_1 FDI_{it} + \phi lnInstQuality_{it} + \theta lnInstQuality_{it} * FDI_{it} + \sum_{j=1}^{k} \beta_j CV_{j,it} + \nu_i + \sigma_t + \varepsilon_{it} \quad (2)$$

In Equation (2), $lnInstQuality_{it}$ represents the institutional quality of country i in year t, measured by the logarithmic form of the overall score for economic freedom. It is the first moderator variable in this study, with its coefficient denoted by ϕ. The moderating effect is specifically reflected in the interaction term of $lnInstQuality_{it}$ and FDI_{it}

($lnInstQuality_{it} * FDI_{it}$), with its coefficient represented by θ. If θ is significantly negative, it indicates that institutional quality has a moderating effect to mitigate the direct impact of FDI inflows on CO_2 emissions. This will be in line with Hypothesis 2.

$$lnCO_{2\,it} = \alpha_0 + \alpha_1 FDI_{it} + \delta lnGDP_{it} + \gamma lnGDP_{it} * FDI_{it} + \sum_{j=1}^{k} \beta_j CV_{j,it} + \nu_i + \sigma_t + \varepsilon_{it} \quad (3)$$

In Equation (3), $lnGDP_{it}$ represents the economic growth of country i in year t, measured by the logarithmic form of the real GDP. This is the second moderator variable discussed in this study, with its coefficient denoted by δ. The moderating effect is specifically reflected in the interaction term of $lnGDP_{it}$ and FDI_{it} ($lnGDP_{it} * FDI_{it}$), with the coefficient denoted by γ. If γ is significant and negative, it demonstrates that economic growth has a moderating effect to weaken the direct impact of FDI inflows on CO_2 emissions. This will be consistent with Hypothesis 3.

2.2 Variable definitions

2.2.1 Dependent variable

CO_2 emission is the dependent variable in this study, measuring the degree of environmental pollution. CO_2 emissions are calculated by analysing the by-products of energy production and use, with extra emphasis on cement production and combustion of fossil fuel, because they are the main sources of anthropogenic CO_2 emissions (Worrell et al., 2001). Specifically, following the European Commission's methodology for measuring CO_2 emissions, the calculation process begins from determining the energy consumption and the emission factors corresponding to each type of fuel. For example, calculate the CO_2 emissions during the cement production process. Generally, approximately 0.5 tons of CO_2 are emitted for every ton of cement produced. Finally, sum up the CO_2 emissions from all sources, which is usually reported in kilotons (Szabó et al., 2003).

The formula is written as follows:

$$CO_2 = \sum(Fuel_i \times F_i) + Cement \times F_{cement} \quad (4)$$

Where, $Fuel_i$ denotes the consumption of fuel i, F_i represents the CO_2 emission factor of fuel i (the amount of CO_2 produced per unit of fuel burned). Cement denotes the amount of cement produced, and F_{cement} denotes the CO_2 emission factor of cement (the amount of CO_2 produced per tonne of cement produced).

This study uses the logarithmic form of CO_2 emissions, which is consistent with previous research (Aslanidis, 2009; Can and Gozgor, 2017; Ganda, 2019). Using the logarithm of CO_2 emissions helps to reduce skewness and scale differences of the data (Kim, Yu and Hassan, 2018).

2.2.2 Core explanatory variable

In order to explore the impact of FDI on CO_2 emissions, FDI is considered as the core explanatory variable. Following the approach of Zhu et al. (2016), this study uses the percentage of net inflows of FDI to GDP, reported in the official statistics by the World Bank, to measure the FDI inflows.

2.2.3 Control variables

Incorporating control variables into research not only mathematically reduces variance related to the non-focal variables (Carlson and Wu, 2012), but also corrects potential deficiencies in the data collection process (Bernerth and Aguinis, 2015). Therefore, it can reduce model estimation bias and enhances the validity and reliability of the results.

Based on existing literature, this study considers seven control variables to control for other factors that might influence FDI decisions. These variables are trade openness (Open), R&D input (R&D), tourism (lnTourism), capital formation (Capital), labour (Labour), inflation (Inflation) and industry (lnIndustry).

(1) Trade openness

Diversified global economic activities has made trade openness an important factor influencing environmental pollution. Ren et al. (2014) employed the single regional input-output model and discovered that China's increasing trade surplus caused a rapid growth of the country's carbon emissions. Furthermore, Copeland, Taylor and Columbia (1993) investigated the relationship between international trade and pollution based on the North-South trade model. It was found that free trade improved environmental quality of developed countries but deteriorated environmental conditions of developing nations. To control for the effect of this external factor, this study references the measurement proposed by Mahadevan and Sun (2020), which is measured by the percentage of the sum of exports and imports to GDP, and incorporates it (Open) as a control variable in the model.

(2) R&D input

With the increasing integration of technology and productivity, the development of science and technology has become a key factor to promote economic growth. More R&D input implies more R&D activities. R&D activities can improve the productivity efficiency and introduce emissions-reducing technologies through the development of advanced environmental technologies and equipment, thus improving environmental quality to some extent. However, R&D activities usually involve lots of prototype development and technical trials that require large amounts of electricity to power high-precision equipment. Particularly under continuous and high-frequency use, this type of equipment consumes a lot of energy, thereby increasing overall carbon emissions. For example, the early stage of development of new solar panel and battery technologies often requires repeated testing and material processing. Before reaching expected standards, the process of development consumes large amounts of electricity and other resources (Chu, 2012). Therefore, even though R&D input can support technological progress and long-term environmental improvement, they may lead to increased carbon emissions in the short term and medium term. Using the Tapio decoupling model, Wang and Zhang (2020) found that the impact of R&D input on carbon emissions shows significant spatial differences and R&D input promotes the decoupling of carbon emissions from economic development in BRICS countries. To control for the influence of R&D input, this study uses the proportion of R&D expenditure to GDP (R&D) to measure it and incorporate it into the model.

(3) Tourism

Tourism has promoted economic development in Europe, but its impact on the environment has been debated. On the one hand, the post-industrial era has transformed society from traditional manufacturing and agriculture to a more modern and service-oriented economy (Koçak, Ulucak and Ulucak, 2020). Tourism, as a representative of the service sector, has a lower energy and carbon intensity than the heavy industry sector, so the overall carbon emissions of society might decrease. On the other hand, tourism relies on fossil fuels to support transportation systems, leading to the increase of CO_2 emissions and environmental degradation. Particularly, the development of aviation industry has increased CO_2 emissions in recent years (Terrenoire et al., 2019). It is discovered that tourism led to the increase of carbon emissions in Eastern European countries but decrease in Western Europe countries (Paramati, Shahbaz and Alam, 2017). In order to exclude the impact of tourism, this study incorporates it (lnTourism) as a control variable, which is measured by the logarithm form of international tourism receipts.

(4) Capital formation

Eighteen per cent of global greenhouse gas emissions are attributed to capital formation (Hertwich and Peters, 2009). The relationship between capital formation and air quality differs across regions due to different investment strategies that are based on their capacities and trade opportunities. If the majority of capital is invested to the low-carbon technologies, it can offset the scale effect. In contrast, if capital is largely invested in high-carbon products, it will exacerbate environmental degradation by the scale and composition. Prakash and Sethi (2023) divided two periods (before and after liberalization) in India around 1991 and used an autoregressive distributed lag model. It is found that capital formation significantly contributes to carbon emissions only after liberalization. To isolate the impact of capital formation, this study incorporates it (Capital) into the model and uses the measurement approach by Södersten, Wood and Hertwich (2017). They measure the capital formation by the total of gross fixed capital formation, which includes all land improvements and the acquisition of plants, machinery and equipment.

(5) Labour

During the economic development, the labour force shifted from the primary and secondary industries to the tertiary industry, which made the relationship between the labour force and the environment a focus of academic discussion. Recently, human resource management strategies centred on innovation are anticipated to create a snowball effect on the environment. This is because employee-driven innovations promote more new energy solutions in order to reduce the reliance on traditional energy sources and promote environmental sustainability (Lasisi et al., 2020). Abdullahii and Maji (2019), using the difference GMM method, observed that an increase in labour force is accompanied by higher level of greenhouse gas emissions. On the contrary, Zhao and Luo (2017), employed an autoregressive distributed lag model and found that employment significantly contributes positively to the use of renewable energy, although this impact is negatively moderated by GDP. Therefore, in the long term, the level of social development influences the impact of labour on air quality. To eliminate the impact of labour factors, this study adopts the proportion of the population aged 15 and above participating in economic activities (Labour) as the proxy variable of labour factor, following the labour measurement method by Amoah, Alagidede and Sare (2023).

(6) Inflation

Inflation affects consumer and business decision-making in several ways. From the point of view of the business, when inflation rates decrease, the prices of raw materials fall, thereby increasing demand and purchase for these materials. Then, businesses will carry out more production and operation activities, particularly within the manufacturing sector, emit large amounts of pollutant gas. From the point of view of the consumers, the nature of inflation is a consumption tax (Erosa and Ventura, 2002), where higher inflation rates compel consumers to reduce their use of energy-intensive services and products, thus reducing consumption of oil, natural gas and electricity, and avoiding environmental degradation to some extent. Gilles Grolleau and Weber (2024) used a fixed effects model to analyse a large number of countries and then found that core inflation rates significantly reduce CO_2

emissions per capita. To minimize estimation biases of the model, inflation (Inflation) was incorporated as a control variable in the analytical framework.

(7) Industry

In the process of modern industrialization, the focus of society has shifted from agriculture to industry (Liu and Bae, 2018). Firstly, industrialisation led to more economic activities, particularly in the expansion of manufacturing sectors. These sectors often require large amounts of mechanical equipment and production lines, which consume a lot of energy during operation. The energy supply usually relies on readily available and low-cost fossil fuels such as gas and coal, thereby releasing lots of greenhouse gases. Furthermore, carbon-intensive technologies and production methods are widely used in industrial production processes, such as blast furnace steelmaking and cement production, which inevitably emit large amounts of industrial CO_2 due to chemical reactions involved in the processes. Wang et al. (2011) fitted an error correction model for carbon emissions under the conditions of heavy chemical industry in China, and found that more output of heavy industry leads to the rise of China's carbon emissions. To control for the industrial factor, this study employs the logarithm of industrial added value (lnIndustry) as the proxy variable for industry factor.

2.2.4 Moderator variables

(1) Institutional quality

Behera, Haldar and Sethi (2024) suggest that economic freedom can measure the quality of a country's institution because greater economic freedom implies higher transparency and less government corruption. The commonly used indices of economic freedom come from the "Economic Freedom of the World Annual Reports" reported by the Fraser Institute and the "Index of Economic Freedom" published by the Heritage Foundation. Since the former one mainly focuses on outcome variables, while the latter one primarily reflects institutional variables related to government control (Chortareas, Girardone and Ventouri, 2013), this study adopts the overall score of economic freedom from the Heritage Foundation to measure institutional quality. In addition, the logarithmic form of the total score (lnInstQuality) is used to reduce data skewness.

Specifically, The Heritage Foundation calculates the Economic Freedom Index by assessing twelve qualitative and quantitative indicators divided into four categories: Rule of Law, Government Size, Regulatory Efficiency and Open Markets. The scale for each indicator ranges from 0 to 100, with higher scores indicating greater freedom. These twelve indicators contain: integrity of government, tax burden, efficiency of the judiciary, fiscal health, freedom of commerce, monetary freedom, freedom of investment, financial freedom, property rights, government spending, labour freedom, freedom of trade. Finally, the overall score of the economic freedom is determined by the average value of these twelve indicators.

(2) Economic growth

GDP is the sum of the market value of all final services and goods produced in the boundaries of a region or country during a certain period of time, and consists of four main components: consumption by individuals and businesses, government spending, total investment (including commercial and residential construction) and net exports. Changes in GDP can reflect the extent to which an economy is expanding or contracting; for example, when GDP grows, it indicates that more services and goods are being produced and consumed, which is usually positively correlated with increased employment, higher corporate profits and higher incomes for residents, reflecting an expanding economy. Therefore, by observing changes in GDP, researchers can visualise the economic growth or recession of a country or region (Gould, 2013; van der Wurff, Bakker and Picard, 2008).

Since the real GDP eliminates the effect of inflation on economic growth compared to the nominal GDP, real GDP provides a better basis to judge the long-term economic performance of a region or country than nominal GDP. In addition, in order to stabilise the variance in the sample, this study uses the logarithmic form of the real GDP (lnGDP) to measure economic growth.

2.2.5 Data sources

The variable definitions and data sources are shown in Table 1. This study uses a balanced sample of 27 EU countries between 2000 and 2020, with a total of 567 observations. The 27

EU countries contain: Czech Republic, Hungary, Netherlands, Ireland, Italy, Estonia, Latvia, Lithuania, Croatia, Luxembourg, Bulgaria, Germany, Poland, France, Romania, Slovakia, Greece, Slovenia, Belgium, Spain, Sweden, Austria, Denmark, Finland, Republic of Cyprus, Portugal and Malta. All data are available in the World Bank database, except for institutional quality (lnInstQuality), which is obtained from the Heritage Foundation.

Table 1: Variable definitions and data sources

Variable	Definition	Source
$lnCO_2$	Logarithm of CO_2 emissions	World Bank database
FDI	The percentage of net FDI inflows as a proportion of GDP	World Bank database
Open	The percentage of total exports and imports as a proportion of GDP	World Bank database
R&D	Gross domestic expenditures on R&D, displayed as a ratio of GDP	World Bank database
lnTourism	Logarithm of international tourism, receipts for travel items	World Bank database
Capital	Gross fixed capital formation	World Bank database
Labour	Proportion of the population ages 15 and older (modelled ILO estimate)	World Bank database
Inflation	Inflation as measured by the consumer price index	World Bank database
lnIndustry	Logarithm of Industry (including construction), value added	World Bank database
lnInstQuality	Logarithm of overall score of economic freedom	Heritage Foundation
lnGDP	Logarithmic form of the real GDP	World Bank database

2.3 Data characteristics

2.3.1 Descriptive statistics

Table 2 displays the descriptive statistics of the variables, the number of observations for all variables is 567 and there are no missing values.

Firstly, as the dependent variable of this study, "lnCO_2" has a mean and median value of 10.82, indicating a relatively symmetrical distribution of the data. Its maximum value of 13.65 and minimum value of 7.210, implying that the logarithmic form of CO_2 emissions fluctuates in a limited range without extreme skewness. It may reflect that some countries rely on carbon-intensive energy, while others may have already shifted to cleaner energy sources. Its standard deviation (1.372) suggests that although some countries in the EU have relatively uniform levels of emissions, there are some that are well above or well below the average. This difference may be influenced by the degree of industrialisation, energy structure, policy regulation and other environmental factors in the EU countries. Secondly, as the core explanatory variable of this study, the mean of "FDI" is 12.17 and the median is 3.476. The fact that the mean is much higher than the median suggests that the data distribution may be right-skewed. Most of the EU countries have a low share of net FDI inflows, while a few countries have a very high share. This is because a small group of countries have attracted a large amount of FDI. The relatively large range of data (-117.4 to 449.1) suggests that the share of net FDI inflows may have experienced sharp fluctuations in some EU countries. In this case, negative values indicate outflows of foreign capital or investment recovery, while high positive values reflect strong inflows of foreign capital. The high standard deviation of 40.63 further proves that the share of net FDI inflows is extremely volatile across different EU countries. This volatility may be influenced by various factors such as national macroeconomic policies, political stability, market potential, labour costs and the international trade environment.

The data characteristics of the control variables are discussed below. The standard deviation of "Open" is 0.639, which reflects the relatively low degree of volatility of market openness in this sample. The median of "R&D" is 1.239, and the mean is 1.472 that is slightly higher than the median, suggesting a positively skewed distribution. This indicates that the share of R&D investment is below the average in most EU countries, but there are a few countries that are far ahead of the rest. And "lnTourism" has a mean and median of 22.40, which shows certain symmetry the distribution of this series. The significant difference between the maximum value of 54.27 and the minimum value of 10.69 for “Capital” indicates that some EU countries may have adopted very aggressive investment strategies or may have experienced large-scale infrastructure development and capital investment during the study period. For “Labour”, the relatively low minimum value (47.82) may indicate that some EU countries have a high proportion of the informal economy or facing problems such as high unemployment rates and poor quality of employment. The relatively high maximum value (66.62) may reflect high labour force participation rates, which may be associated with active labour market policies, high levels of urbanisation and education in some EU countries. The fluctuation of “Inflation” is more volatile, ranging from negative inflation (-4.478 per cent) to highly positive inflation (45.67 per cent), which may reflect changes in economic policies, economic stability and market conditions in different EU countries. For “lnIndustry”, the relatively low standard deviation (1.631) indicates that the levels of industrial output are spread out over a small range in the EU, which may reflect the similarity in the productivity and size of the industrial sector in the EU.

As the moderator variable in this study, “lnInstQuality” has a relatively small standard deviation (0.0981), indicating that the data distribution of the logarithm of overall score of economic freedom is concentrated across the EU countries. It indicates that there is likely a high degree of consistency and stability in the quality of institutions across different EU countries. For the other moderator variable, “lnGDP” has a mean (26.33) that is greater than the median (26.15), which indicates that this series is positively skewed. This is usually because of the unequal distribution across the data set, which demonstrates certain variation of the logarithmic form of the real GDP across EU countries. This reflects not only the differences in the size of the economies of different countries, but may also reflect changes in the macroeconomic environment, such as the global economic crisis, regional recessions or rapid growth.

Table 2: Descriptive statistics

Variable	N	Mean	p50	Min	Max	SD

$lnCO_2$	567	10.82	10.82	7.210	13.65	1.372
FDI	567	12.17	3.476	-117.4	449.1	40.63
Open	567	1.168	1.001	0.367	3.711	0.639
R&D	567	1.472	1.239	0.227	4.021	0.900
lnTourism	567	22.40	22.40	18.59	25.12	1.295
Capital	567	22.32	22.01	10.69	54.27	4.250
Labour	567	57.71	58.58	47.82	66.62	4.550
Inflation	567	2.477	2.055	-4.478	45.67	3.320
lnIndustry	567	24.34	24.55	20.76	27.71	1.631
lnInstQuality	567	4.215	4.221	3.857	4.414	0.0981
lnGDP	567	26.33	26.15	22.51	31.35	2.043

2.3.2 Correlation analysis

As shown in Table 3, the correlation coefficient matrix provides important information of the linear relationships between variables.

Firstly, the correlation coefficient between the dependent variable ($lnCO_2$) and the core explanatory variable (FDI) is -0.218, suggesting that an increase in FDI may be associated with less CO_2 emissions. And it is necessary to recognize that correlation does not mean causation, and the observed relationship could be affected by the confounding factors not captured in the correlation coefficient. For instance, countries attracting more FDI might also be those that have invested in green technologies or enacted stringent environmental regulations, which could be the actual drivers behind reduced CO_2 emissions. In the following empirical study, regression analysis will be employed. A positive regression coefficient will mean that, after controlling for other variables in the model, FDI inflows can significantly and positively contribute to CO_2 emissions. The opposite sign of correlation and regression coefficients may be because of the incorporation of additional control variables in the regression model (Li, Yi and Cui, 2017).

Secondly, most of the correlation coefficients are less than the threshold of 0.7. Therefore, the preliminary judgement of this section is that there is no multicollinearity issue. However, for the reliability and accuracy of the study, the following section will employ the variance inflation factor (VIF) to test for multicollinearity in the model.

Lastly, for the moderator variables, the correlation coefficient between lnInstQuality and $lnCO_2$ is -0.217, indicating that higher levels of institutional quality might be correlated with less CO_2 emissions. In contrast, the correlation coefficient between lnGDP and $lnCO_2$ is 0.752, suggesting that higher economic output tends to be correlated with higher CO_2 emissions. In empirical analyses, more attention is usually paid to the positive or negative sign of the interaction terms, which indicates whether the impact of the core explanatory variable on the dependent variable is strengthened or weakened by the moderator variables.

Table 3: Correlation coefficient matrix

	$lnCO_2$	FDI	Open	R&D	lnToursim	Capital	Labour
$lnCO_2$	1						
FDI	-0.281	1					
Open	-0.585	0.269	1				
R&D	0.326	-0.167	-0.157	1			
lnTourism	0.761	-0.154	-0.346	0.393	1		
Capital	-0.0295	-0.0625	-0.0303	-0.0339	-0.223	1	
Labour	-0.0961	-0.0330	0.0682	0.382	-0.112	0.153	1
Inflation	-0.00440	-0.0262	-0.126	-0.258	-0.296	0.237	-0.0468
lnIndustry	0.918	-0.276	-0.470	0.530	0.823	-0.0252	0.0524
lnInstQuality	-0.217	0.132	0.225	0.107	-0.0975	-0.147	0.0161
lnGDP	0.752	-0.222	-0.368	0.450	0.629	0.0145	-0.0120
	Inflation	lnIndustry	lnInstQuality	lnGDP			
Inflation	1						
lnIndustry	-0.159	1					
lnInstQuality	-0.119	-0.173	1				
lnGDP	-0.0460	0.779	-0.228	1			

2.3.3 Test multicollinearity

Multicollinearity refers to the high interrelations among predictor variables, which can expand the confidence intervals of the predictors and reduce their reliability likelihood values, leading to less credible results (Franke, 2010). The VIF is a tool to measure the extent of variance inflation. When VIF is greater than or equal to 10, it indicates the presence of potentially harmful covariance in the model (Shrestha, 2020). Therefore, this study carries out the multicollinearity test using VIF in order to ensure the reliability of the model interpretation. Table 4 shows that the value of VIF for all variables is less than 5, with the maximum value of VIF is 4.78 and the mean value of VIF is 2.12, which indicates that the model does not suffer from the problem of multicollinearity.

Table 4: VIF

Variable	VIF	1/VIF
lnIndustry	4.780	0.209
lnTourism	4.070	0.246
R&D	1.780	0.562
Open	1.410	0.710
Labour	1.330	0.753
Inflation	1.260	0.791
Capital	1.180	0.844
FDI	1.130	0.884
Mean	2.120	

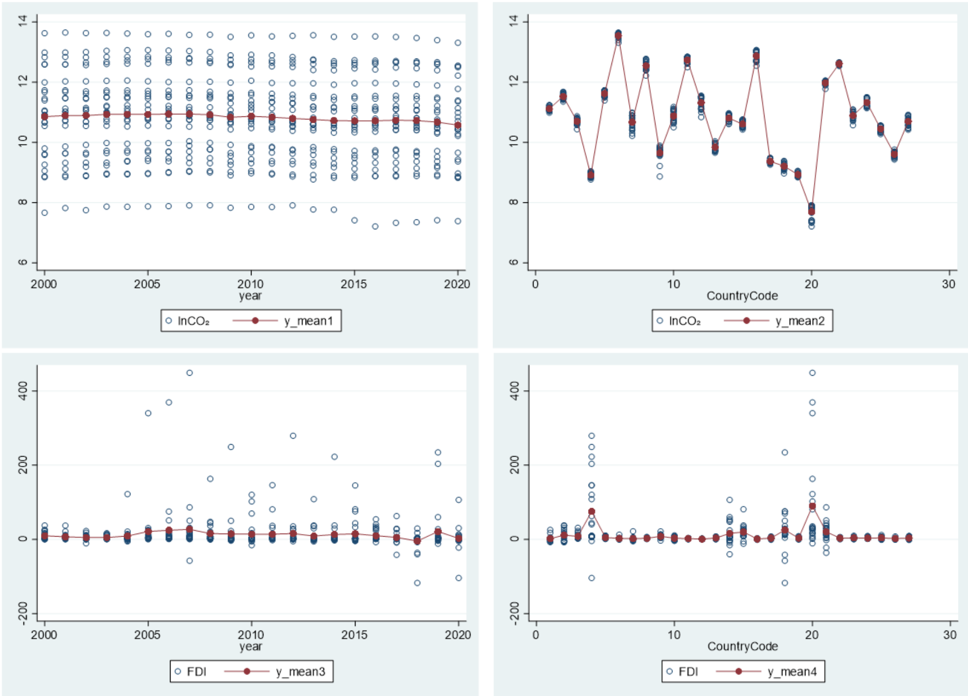
2.3.4 Analysis of averages over time and over cross section units

The scatterplot in Figure 2 allows for the observation of the specific distribution of the data, and the line graph therein allows for the analysis of the average trend of the data.

Firstly, for the dependent variable ($lnCO_2$), the top-left graph illustrates that there is no obvious long-term trend in the average value during the study period, despite a significant degree of dispersion among data points across different years. This indicates that CO_2 emissions among EU countries remained relatively stable on a macro level from 2000 to 2020. In addition, the top-right graph shows the distribution of observed CO_2 emissions data points and their means across different nations. The fluctuating trend line reveals significant disparities in CO_2 emissions of different EU countries, which may be attributed to different policies, levels of industrialization and energy use efficiencies.

Secondly, for the core explanatory variable (FDI), the bottom-left graph indicates that the average trend of FDI is approximately to zero during the study period, except for some outliers. This implies that there was no significant growing or declining trend in FDI within the EU countries over the period from 2000 to 2020. Additionally, the mild fluctuations of the average trend line in the bottom-right graph suggest that FDI across EU countries is relatively uniform, with no evident long-term increase or decrease.

Figure 2: Analysis of averages over time and over cross section units

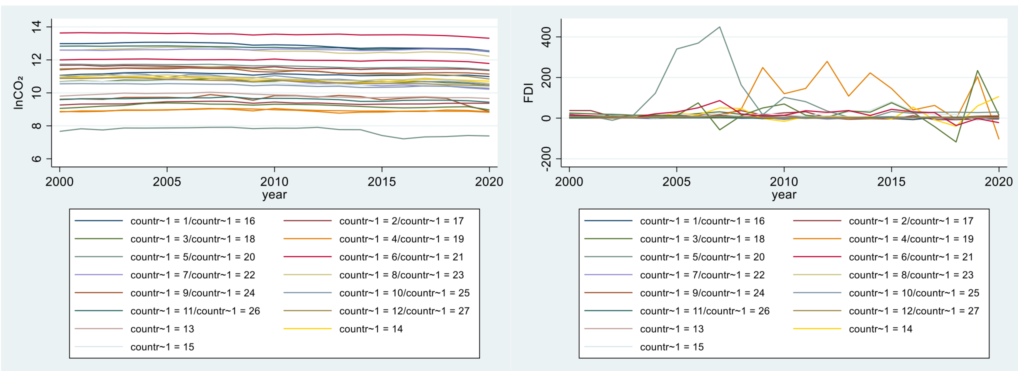


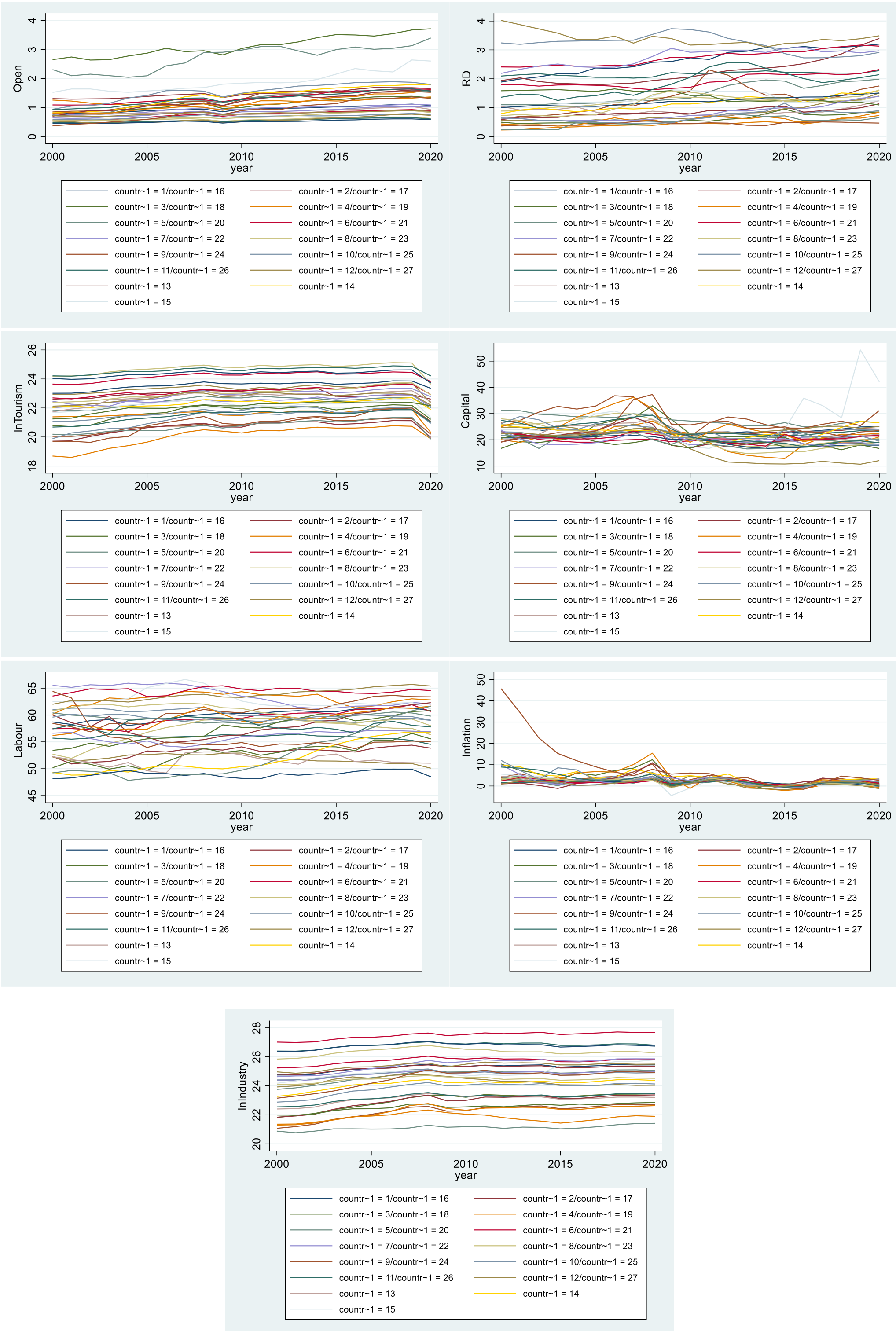
2.4 Stationarity analysis

This study tests the stationarity of each panel series in two steps in order to avoid spurious regression. Firstly, a preliminary visual assessment of the variables' stationarity is conducted through graphical analysis. Secondly, in order to get more reliable conclusions, statistical tests are performed.

Figure 3 is a rough visual assessment of variable stationarity. The superimposed lines for each variable reveal potential trends and variations across panel units over time. Persistent upward or downward movements may indicate non-stationarity, suggesting the existence of unit roots. Specifically, the figure of the series “$\ln CO_2$” does not show significant trends or fluctuations, tentatively indicating stationarity. The series “FDI” shows volatility, especially with a peak in one unit around 2005, but in general, this series does not display pronounced trends or non-stationary behaviour specific to any unit. The series “Open” reveals a gradual increasing trend in several units, which could indicate non-stationarity if these trends reflect a systematic increase over time rather than random fluctuations. The series “R&D” is trending upwards across several panel units, suggesting the potential non-stationarity unless the trend constitutes part of the series' long-term equilibrium fluctuation. The series “lnTourism” shows relatively parallel lines, which may suggest stationarity across the panel units. The series “Capital” fluctuate relatively violently with significant deviations from the mean, particularly with several sharp peaks, suggesting possible non-stationarity or the impact of external shocks. The series “Labour” displays a general upward trend across most units. If this persistent growth is a long-term trend rather than reversion to a stable mean, it may indicate a non-stationary process. Despite a significant decline in the early period for one unit, the series “Inflation” returns to stability without any notable trends for the remainder of the panel, indicating potential stationarity. For the series “lnIndustry”, some units show slight upward trends, which may indicate non-stationarity if these trends persist over time.

Figure 3: Stationarity: visual analysis





The above is limited to a visual analysis to the figure, in order to obtain more reliable conclusions, the unit root test is carried out to further examine the potential seasonal patterns, structural breaks and heterogeneity among the observed units (Perron, 2006). This study adopts the Fisher-ADF test, which has the advantage of not only being able to choose different lag orders for different ADF regressions, but also of being able to derive different unit root tests (Maddala and Wu, 2002). As shown in Table 5, all four statistics for each variable reject the null hypothesis of the existence of a unit root at the 1% significance level, indicating that all series are stationary. This helps to derivate accurate estimations and conduct reliable economic analysis.

Table 5: Stationarity: Fisher-ADF test

	(1) Inv. chi-squared	(2) Inv. normal	(3) Inv. logit t	(4) Modified inv. chi-squared
lnCO_2	152.7153***	-6.9108***	-7.3255***	9.4989***
FDI	316.9987***	-14.1918***	-16.8593***	25.3071***
Open	130.1305***	-5.7621***	-6.0028***	7.3257***
R&D	122.8862***	-4.9485***	-4.8448***	6.6286***
lnTourism	166.2509***	-7.6422***	-8.1479***	10.8014***
Capital	155.8253***	-7.8783***	-7.9921***	9.7981***
Labour	129.4178***	-5.0588***	-5.3178***	7.2571***
Inflation	321.8322***	-14.0706***	-17.1090***	25.7722***
lnIndustry	188.4729***	-8.7974***	-9.5808***	12.9397***

Note: *** p<0.01, ** p<0.05, * p<0.1

2.5 Select the regression model

As shown in Table 6, this study sequentially employs the F-test, LM-test, and Hausman test to determine the most suitable regression model for this panel data.

Firstly, the F-test, displayed in the first column, is used to compare the fixed effects model with the pooled model. The statistic with the value of 284.43 significantly rejects the null hypothesis at the 1% significance level that all individual intercepts are equal to zero, indicating the presence of fixed effects in the model. Therefore, it is necessary to control for unobservable country-specific effects through a fixed effects model. When exploring the effect of FDI inflows on CO_2 emissions, using the pooled OLS model fails to capture the differences in environmental policy, industrialization levels, or energy efficiency across countries. For example, more developed countries within the EU might minimize the negative environmental impacts of FDI due to higher technological standards and stricter environmental regulations, while other countries may experience a significant increase in CO_2 emissions due to lower environmental standards and higher reliance on carbon-intensive energy sources. Compared to pooled regression, the fixed effects model allows for each country to have its own intercept term, effectively controlling for this potential heterogeneity and providing more accurate estimations.

Secondly, the second column shows the results of LM test that can compare the pooled model with the random effects model. The statistic with the value of 2759.34 is also significant at the 1% level of significance, which indicates that the null hypothesis that the variance of all intercept terms equal to zero should be rejected. Therefore, the random effects model is more suitable for this panel data than the pooled model. The random effects model better captures the heterogeneity within (across different time points within the same country) and between groups (between countries) to explore the effects of FDI inflows on CO_2 emissions, which is important for understanding how FDI affects CO_2 emissions in different country contexts.

Lastly, the Hausman test is used to compare the fix effects model with the random effects model, the results of which is shown in the third column. The value of the statistic is 128.04, which is also significant at 1% significance level. This implies that the null hypothesis that individual effects are not correlated with the independent variables should be rejected. Therefore, setting a specific intercept for each country ensures that the estimations are not biased by potential correlations.

Table 6: Select the baseline regression model

(1) FE vs. Pooled (F)	(2) RE vs. Pooled (LM)	(3) FE vs. RE (Hausman)
284.43***	2759.34***	128.04***

Note: *** p<0.01, ** p<0.05, * p<0.1

In conclusion, the individual fixed effects model is preliminarily identified as the optimal choice for this panel data. Moreover, the F-statistic in Table 7 tests the joint significance of the time dummy variables and is significant at the 1% level of significance, suggesting that the time effects should be introduced. As a result, this study uses the two-way fixed effects model as the baseline regression model. By controlling for both time fixed effects and individual fixed effects, this model mitigates the potential endogeneity and reduces omitted variable bias that might arise from neglecting individual-specific factors or common time trends. Therefore, the model can capture the actual impact of the core explanatory variable on the dependent variable more accurately.

Table 7: Test for time fixed effects

F (20, 512)
27.73***

Note: *** p<0.01, ** p<0.05, * p<0.1

2.6 Test assumptions

The existence of serial correlation, heteroscedasticity and cross-sectional dependence could bias the findings and affect policy formulation. Therefore, this study sequentially tested these three assumptions, which is shown in the Table 8.

Firstly, classic linear panel model usually assume that stochastic disturbance terms are serially uncorrelated, but this assumption is often violated. In practice, the dynamic impact of the economic variable is often distributed during several time periods, leading to serial correlation in the stochastic disturbance terms (Baltagi, 2009). In economic and environmental models, the inertia in economic activities and policy implementation, and the persistence of environmental impacts such as the time-lagged nature of CO_2 emissions, can also cause serial correlation in the data. If serial correlation is not identified and addressed, it will result in biased standard errors, thereby affecting the validity of significance tests and the accuracy of confidence intervals. For the fixed effects model, this study employs the Wooldridge-Drucker test, as proposed by Wooldridge (2010), to examines serial correlation in the panel data. As shown in the first column, the statistical value of the test is 109.771, which rejects the null hypothesis at the 1% significance level and indicates that the model's stochastic disturbance term is autocorrelated in the time series. This suggests that CO_2 emissions are influenced not only by current levels of FDI inflows but also by previous levels of FDI inflows.

Secondly, the presence of heteroscedasticity colours the white noise, thereby lowering the estimation efficiency and influencing the accuracy of hypothesis testing and the prediction capacity of the model (Bhattacharyya and Ghosh, 2022). This study uses the Modified Wald test to test for heteroskedasticity for the model. As shown in the second column, the statistical value of the test is 1447.53 and rejects the null hypothesis of homoscedasticity at the 1% level of significance. This suggests that variances of the stochastic disturbance terms differ across sample points, likely due to the differences in environmental policy stringency and technological development among EU countries. Specifically, for countries with looser environmental policies or less advanced technology, FDI inflows might impose a greater environmental burden, leading to greater challenges in reducing CO_2 emissions. In contrast, countries with stricter environmental regulations and more modern green technologies might not experience significant increases in CO_2 emissions from FDI inflows, because they can control the potential environmental impacts of FDI inflows more effectively. Therefore, for different EU countries, the variances of the stochastic disturbance terms are no longer constant but different from each other.

Lastly, if there is cross-sectional dependence, it will invalidate the standard covariance matrix of the model estimates. This leads to biased standard errors and a significant reduction in estimation efficiency (Phillips and Sul, 2003). Therefore, identifying and addressing cross-sectional dependence is important for improving the accuracy of panel data model estimates and the effectiveness of policy analysis. In this study, Pesaran's (2004) CD test is employed because it is specifically designed for short panels. As shown in the third column, the statistical value of the test is -1.337, and the null hypothesis cannot be rejected at the 1%

significance level, indicating that residuals are not correlated across the EU countries. This may be due to the differences in the enforcement strength and priorities of environmental protection among different countries. Firstly, although the EU has a unified environmental policy framework, the enforcement strength of environmental policies differs among member states. For example, Germany, Denmark and the Netherlands have more efficient environmental enforcement mechanisms and pay more attention to environmental impact assessments and compliance checks when introducing FDI (Rivera and Oh, 2013). Secondly, although all EU countries has promised to reduce CO_2 emissions, different member states prioritise environmental protection differently. For instance, countries such as Sweden are more concerned with long-term environmental sustainability (Lidskog and Elander, 2012), so they are more likely to introduce green technologies and projects. Therefore, FDI inflows have a less impact on CO_2 emissions in these countries. However, countries such as Poland emphasise short-term economic development and industrialisation (Piatkowski, 2018). They prefer projects that quickly bring economic benefits, even if these projects largely increase CO_2 emissions. Therefore, these differences will lead to the impact of FDI on CO_2 emissions to show unique characteristics in different countries, thereby reducing the correlation of residuals across countries.

Table 8: Test assumptions

(1) serial correlation	(2) heteroskedasticity	(3) cross-sectional dependence
109.771***	1447.53***	-1.337

Note: *** p<0.01, ** p<0.05, * p<0.1

In conclusion, this panel data only exhibits serial correlation, heteroscedasticity. To improve the credibility of the results, cluster robust standard error is employed in this study to address the issues of serial correlation and heteroskedasticity.

3. Empirical Results

3.1 Baseline regression

The two-way fixed effects model and clustered robust standard errors are employed in this study to examine the impact of FDI on CO_2 emissions, with the regression results presented in Table 9.

Hypothesis 1 is strongly supported by empirical evidence. The coefficient of FDI is significant and positive at the 1% level of significance, suggesting that more FDI inflows to EU countries contributes to more CO_2 emissions. This finding is consistent with the pollution haven hypothesis and the scale effect hypothesis. Moreover, the coefficient of FDI is approximately 0.0003839, revealing that, when controlling for other variables, CO_2 emissions increase by 0.03839% in average following an increase in FDI inflows by one unit. The within-group R-square of this model is 0.9972, suggesting that the explanatory variable have a relatively high explanatory capacity on the dependent variable.

From the perspective of the pollution haven hypothesis, although the EU has attempted to reduce CO_2 emissions through unified policies, the inconsistency in the implementation of environmental protection policies among member states, particularly in attracting FDI with different environmental standards, has led to FDI to flow into regions with lower environmental requirements. Therefore, even if some regions have reduced their CO_2 emissions, the overall CO_2 emissions of the EU still experience a rising trend due to the geographical reorganisation of industries. Specifically, highly economically developed countries such as France and Germany have more stringent environmental enforcement standards and higher level of technology (Bluffstone and Sterner, 2006), which makes them more effective in controlling CO_2 emissions. Also, higher levels of economic development usually imply stronger financial capacities, which not only enable the private sector to invest in long-term R&D of environmental technologies, but also allow governments to promote the application of green technologies and the implementation of environmental management measures through incentives such as tax breaks and subsidies. However, countries with lower compliance costs and looser environmental regulations become destinations for FDI of high-pollution industries, such as Romania and Bulgaria (Spatareanu, 2007). In these less developed countries in the EU, most of policies are primarily focused on promoting economic growth and attracting foreign investment, with environmental protection often not being a priority. This has led to delays in environmental legislation and enforcement. In addition, although these countries have started to adopt some unified environmental standards after joining the EU, the investment in capital and technology necessary for upgrading traditional energy infrastructure remains insufficient because of their relatively weak economic foundations. These factors slow the transition from reliance on high-carbon energy sources to the adoption of greener technologies and caused the significant increase in CO_2 emissions. Therefore, this situation contributes to an overall upward trend in CO_2 emissions of the EU, despite the general policy framework aiming to reduce emissions and enhance environmental standards.

In the framework of the scale effect hypothesis, FDI inflows can promote economic growth of EU but causes the increase of CO_2 emissions because of rapid expansion of production scale, the significant increases in the scale and frequency of transport activities, and reliance on traditional production technologies and energy.

Firstly, the inflow of foreign investment brings large amounts of capital and advanced technology to the host countries, aiming to achieve economies of scale by increasing output. Specifically, the capital is used to build factories and purchase machinery. And the technology transfer enhances the host country's industrial production efficiency and competitive advantages, thereby increasing production activities. Moreover, when a region attracts foreign investment in a certain field, related suppliers, distributors and service providers will gradually converge in this area, forming industrial clusters (Giblin and Ryan, 2012). This clustering effect provides new business opportunities for host country's firms and further accelerates the expansion of production scales. In the EU, this phenomenon is common in the automotive and mechanical industries because they have lower production costs than other regions (Zorpas and Inglezakis, 2012). Therefore, foreign enterprises prefer to establish production bases of these sectors in some EU countries. However, this rapid increase of production activities often fails to coincide with lagging environmental measures. According to the scale effect hypothesis, with the expansion of production scale, if there are no immediate pollution control measures, it will lead to exacerbated environmental impacts of output per unit. Although the EU countries have established frameworks for environmental protection, there is a lag in the implementation of environmental measures, which cannot control the emission of pollutants effectively (Giljum et al., 2005).

Secondly, according to the theory of scale effects, the scale of transport of raw materials and finished products increases due to the increase in production activities caused by FDI. The transportation sector accounts for one-fourth of carbon emissions within the EU, making it the second-largest source of emissions following the sector of energy production (Streimikiene, Baležentis and Baležentienė, 2013). The investment of foreign enterprises in the EU leads to the development of transnational supply chains and more frequent freight transport, particularly within the transport networks linking developed economies in Western Europe with emerging markets in Eastern Europe, thereby increasing CO_2 emissions from the transportation sector. Specifically, with the increase of foreign investments in the manufacturing sector in CEE countries, these countries have become important production hubs for Western European companies (Jürgens and Krzywdzinski, 2009). This not only improves industrial output of CEE countries but also increases the demand for transporting goods throughout the EU. For example, components for the automotive industry are produced and assembled in several countries, and then finished products are transported to other markets for sale. This decentralized production network requires an efficient logistics system, thus increasing the frequency and distance of freight transport and significantly raising overall CO_2 emissions of the EU. Moreover, the freight transport of the EU relies mainly on roads and railways, with road transport accounting for a greater proportion (Otsuka et al., 2017). However, road transport consumes the most transport energy in the EU. Over the past two decades, the ratio of road transport in the overall transport energy consumption has slightly increased but reached 95% in 2020, with railway transport ranking second in transport energy consumption in the same year within the EU (Domagała and Kadłubek, 2022). As FDI-driven industrial activities largely increase, the EU's industrial base expands rapidly, which increases the reliance on road transport. Especially in Eastern Europe where the rail networks are relatively underdeveloped, leading to a heavier dependence on road transport. As a result, high carbon-intensity modes of transport have placed significant pressure on the environment, further increasing CO_2 emissions.

Finally, according to the scale effect hypothesis, although more environmentally friendly and low-carbon production technologies are available, foreign enterprises in order to get more economic benefits and market share usually choose the high-energy-consuming technologies that can immediately have economic returns at the expense of environmental quality. This results in the rise in CO_2 emissions during industrial expansion within the EU, particularly in highly polluting industries such as energy, chemical and heavy industries. In addition, particularly for the new member states from CEE, the majority of their energy infrastructure is inherited from the socialist era, which primarily relies on coal and oil exploited locally or imported from the Soviet Union (Bouzarovski, 2009). Upgrading these infrastructures requires large amounts of fiscal inputs and time. Therefore, these countries continue to rely on their existing fossil fuel-based energy systems during industrial expansion, which further exaggerates the overall CO_2 emissions.

In addition, although some policy design of the EU allows for flexibility, it further leads to inconsistencies in implementation of member states. In 2005, the EU ETS launched by the EU reveals the decentralisation of its operation. The European Commission is responsible for setting the basic structure and rules of the system, while member states determine their emission caps and allocate quotas, and set up relevant monitoring and reporting agencies according to their own capacities and objectives (Kruger, Oates and Pizer, 2007). However, the gap between the unified policy formulation and the actual implementation of different EU countries has weakened the overall effect of environmental policies to some extent, making the goal of reducing CO_2 emissions challenging to achieve.

Moreover, as an economically integrated region, the EU has a unified market and lower trade barriers (Schiff and Winters, 2003), which reduces legal and administrative barriers to cross-border business activities and provides conducive operating environment and market expansion opportunities for FDI. However, the accelerated flow of FDI leads to investments concentrating in carbon-intensive sectors, such as manufacturing and infrastructure development (Ortiz, Cadarso and López, 2020), resulting in environmental degradation.

Some control variables are significant at the 1% significance level, the insignificance of the other control variables is possibly due to the heterogeneity in the sample distribution (Warner and Rountree, 1997). When these heterogeneous effects are incorporated into the regression analysis for the sample, the different impacts of these control variables in different subgroups may cancel out or blend, resulting in a smoothing of these variables' effects in the regression model. Therefore, these control variables may not be statistically significant in the sample analysis. Furthermore, the introduction of control variables primarily aims to reduce bias within the model, thereby helping researchers to identify the causality between core explanatory and dependent variables more accurately. Control variables themselves are not the focus of the research and often do not provide structural explanations. And even if they are effective control variables, they may be potentially associated with unobserved factors (Tchetgen, 2013). In this case, the effects of control variables might not only reflect their impact on the dependent variable but also include the influence of other unobserved factors. Therefore, the statistical significance of control variables may not represent their true impact on the dependent variable, and their marginal effects could be ignored in most empirical research because of the inability of providing explanations (Carsrud and Brännback, 2015).

Table 9: Baseline regression

	$lnCO_2$
FDI	0.0003839***
	(0.0001172)
Open	0.0552667
	(0.0374133)
R&D	0.0675074***
	(0.0141423)
lnTourism	0.043101
	(0.0275658)
Capital	-0.0001183
	(0.001407)
Labour	0.0040385
	(0.0033177)
Inflation	0.0057704***
	(0.0015751)
lnIndustry	0.132738***
	(0.036652)
_cons	6.21038***
	(0.7239714)
Time	Yes
Individual	Yes
N	567
R-squared	0.9972

Note: *** p<0.01, ** p<0.05, * p<0.1

3.2 Endogeneity issue

The endogeneity issue refers to a situation when one or more explanatory variables in a model are correlated with the error term, causing OLS estimates inconsistent and thereby weakening the reliability of causality inference.

Endogeneity arises mainly from reverse causality, omitted variable bias, measurement errors and sample selection bias. In this study, the main causes of endogeneity are the first two. Firstly, when investigating the effects of FDI inflows on CO_2 emissions within the EU, CO_2 emissions may in turn affect their ability to attract FDI (Yüksel et al., 2020), which reveals the reverse causality. Specifically, foreign investors consider potential risks and costs related to CO_2 emissions when selecting investment locations, including possible carbon taxes, environmental compliance costs and future policy changes. These factors are based on an assessment of the destination countries' CO_2 emissions levels and environmental policy framework. If an EU member state has low levels of CO_2 emissions, indicating its effective environmental management and sustainable development practices, it will enhance its capacity to attract more FDI. For example, foreign investors of clean and renewable energy sectors prefer to invest in these countries with better environmental performance in order to improve their green image and market competitiveness by the strict local standards. In contrast, if an EU member state has high levels of CO_2 emissions, implying more lenient or poorly enforced environmental policies, it will only attract some FDI seeking for lower environmental compliance costs, such as traditional manufacturing. Secondly, including all conceivable potential variables into the model may lead to overfitting within the sample, making the conclusions practically meaningless. Also, in empirical research, researchers often unable to cover all the variables that could influence the dependent variable (Collot and Hemauer, 2020), at which point the effects of unincorporated variables are erroneously attributed to the variables included in the model.

This research employs the GMM proposed by Arellano and Bond (1991), which is commonly used to address endogeneity issues in panel data. GMM uses lagged terms as instruments, satisfying all the moment conditions as comprehensively as possible in order to produce robust estimators. Firstly, GMM has an advantage over the instrumental variable approach. GMM increases the number of valid instrumental variables with the extension of the panel data's time dimension, which improves the efficiency of the estimations (Kinoshita and Campos, 2004). In addition, since difference GMM controls for time-invariant individual effects by differencing the data, it may lose long-term information and fixed characteristics between individuals, which could weaken the explanatory power of variables. However, system GMM, by combining level and difference equations, mitigates the information loss and potential measurement errors caused by using only differenced data. Therefore, GMM allows for a comprehensive consideration of the dynamic changes in time series and heterogeneity among individuals, capturing more information on intrinsic characteristics and long-term trends, thus enhancing the model's adaptability and explanatory power to the data structure.

Finally, this study chooses for two-step system GMM over one-step system GMM. One-step system GMM often involves first-order difference transformation of the data. When subtracting past values from current values, the missing recent values of variables will lead to large loss of observations. In particular, this data loss can have a serious negative impact on small samples, significantly influencing the statistical power and reliability of the estimates. However, the two-step system GMM employs "forward orthogonal deviations", implying that the model does not simply subtract past values of a variable from current value. Instead, the two-step system GMM adjusts by subtracting the mean of all future available observations of that specific variable (Ullah, Akhtar and Zaefarian, 2018). Specifically, In the first step, the two-step system GMM uses a consistent but suboptimal weighting matrix (typically an identity matrix or simple diagonal weights) to estimate model parameters. In the second step, it uses the residuals from the first step to re-estimate an optimal weighting matrix and then re-estimates the model parameters using this optimised matrix. This optimal weighting matrix based on the first-step residuals takes into account the heteroskedasticity and autocorrelation among the variables, thereby enhancing the estimates efficiency. Therefore, Arellano and Bover (1995) recommend using the two-step system GMM model for balanced panel data. In summary, this study adopts the two-step system GMM to address the endogeneity issue, because it provides higher data utilisation efficiency, improves statistical efficiency and consistency of estimations, and enhances the overall performance of the model through broader use of instrumental variables and error term management.

Given that the two-step system GMM addresses endogeneity issue by incorporating lagged values and conducting internal transformations, the results obtained from the GMM could be different compared to those obtained from the fixed-effects regression analysis. To begin with, the AR test is a test for autocorrelation, which examines whether the first-order and second-order autocorrelation exist in the differenced residuals. The purpose is to guarantee the consistency of the GMM estimation. As shown in Table 10, the AR (1) statistics is significant at the 1% significance level, which suggests that the first-order difference series are correlated. The AR (2) statistics shows a p-value above 0.1, indicating the absence of second-order difference series correlation. This typically indicates that this GMM has overcame the endogeneity issue and the model specification is appropriate. Furthermore, the Hansen test, which is more robust than the Sargan test for overidentification. The hypothesis of Hansen test is that all instrumental variables are exogenous. The p-value greater than 0.1 suggests that the overidentification limitation imposed by the excluded instruments are not significant, confirming the validity of the instruments. And the coefficient of FDI is significantly positive at the 5% significance level. As a result, it can be concluded that, after controlling for endogeneity, FDI inflows still makes a significant positive contribution to CO_2 emissions between 2000 and 2020 within the EU. And the coefficient of FDI is approximately 0.0005109, revealing that, when controlling for other variables, CO_2 emissions increase 0.05109% in average following an increase in FDI inflows by one unit.

Table 10: Two-step system GMM

	$lnCO_2$
$L.lnCO_2$	1.142937***
	(0.0528839)
FDI	0.0005109**
	(0.0002487)
Open	0.0902721
	(.0677168)
R&D	-0.0378448
	(0.0540364)
lnTourism	0.0677452**
	(0.0292689)
Capital	0.0049282*
	(0.0027359)
Labour	0.0023434
	(0.0076512)
Inflation	-0.0001662
	(0.0036034)
lnIndustry	-0.1147677***

	(0.0366066)
_cons	-0.5875748
	(1.011588)
N	540
AR (1)	0.001
AR (2)	0.134
Hansen	0.294

Note: *** p<0.01, ** p<0.05, * p<0.1

3.3 Robustness test

Robustness tests help to verify whether the main findings hold for different sample subsets and model settings, or when using different measurement methods and estimation techniques. By demonstrating that research conclusions are consistent in different scenarios, it can prove that the results are not incidental or limited to specific conditions, but have broad applicability.

The study period is from 2000 to 2020. However, with the global spread of COVID-19 in 2020, EU member states implemented a series of movement restrictions and lockdown measures to reduce contagion, which significantly reduced or even halted industrial activities in most of the EU countries. During the lockdown period, the reduction of factory operations and business activities directly decreased energy demand. Particularly, the consumption of fossil fuels in the heavy industry reduced, which is one of the primary sources of CO_2 emissions. Additionally, transport is also a main contributor to the increased CO_2 emissions of the EU. The decline in tourism and commuting demand led to a significant decrease in the consumption of gasoline and aviation fuel, thereby significantly reducing CO_2 emissions. Furthermore, the economic uncertainty triggered by the pandemic negatively impacted the confidence of foreign investors. Faced with declining income and unstable market demand, foreign investors preferred to retain cash to cope with ongoing operational challenges rather than making new investments. Consequently, the EU, as one of the major global economies, experienced a significant reduction in FDI inflows (Moosa and Merza, 2022), which reflected not the investment trends under normal economic conditions but the unconventional factors specific to the pandemic. As a result, CO_2 emissions in 2020 experienced atypical changes (Hepburn et al., 2020). Although this reduction in CO_2 emissions is beneficial for environmental protection, it does not reflect the normal relationship between FDI inflows and CO_2 emissions. In conclusion, the data of 2020 is largely impacted by the pandemic. In order to maintain data consistency and comparability, this study reconstructs the model excluding data of 2020. This helps to exclude the interference of major events such as the pandemic, obtaining a more precise assessment of the impact of FDI inflows on CO_2 emissions.

As shown in Table 11, after excluding the data of 2020, the coefficient of FDI remains significant and positive at the 1% significance level, revealing that FDI inflows still significantly and positively contribute to CO_2 emissions within the EU. In addition, the coefficient of FDI increases from 0.0003839 to 0.0004529, suggesting a slight rise in the effects of FDI inflows on CO_2 emissions. This may indicate that the pandemic in 2020 had some inhibitory effects on FDI inflows of the EU, leading to a slight statistical reduction in its contribution to CO_2 emissions.

Table 11: Robustness test: Removal of major incident interference

	$lnCO_2$
FDI	0.0004529***
	(0.0000946)
Open	0.0445649
	(0.0392972)
R&D	0.0693442***
	(0.0139129)
lnTourism	0.0393471*
	(0.022309)
Capital	0.0001114
	(0.0014482)
Labour	0.0050575
	(0.0034909)
Inflation	0.0050542***
	(0.0013462)
lnIndustry	0.1348447***

	(0.0359132)
_cons	6.203958***
	(0.6728948)
Time	Yes
Individual	Yes
N	540
R-squared	0.9976

Note: *** p<0.01, ** p<0.05, * p<0.1

3.4 Moderated Regression

When the relationship between two quantitative variables x and y varies according to the value of a third variable z, the variable z is referred to as a moderator variable (Haldar et al., 1992; Kahl and Darrow, 1984). In moderated regression analysis, the moderator variable z is combined with the exogenous variable x through multiplication to create an interaction term xz. The presence of a moderating effect can be determined by assessing the significance of the regression coefficient of the interaction term, and the influence direction of the moderating effect can be determined by the positive or negative sign of the interaction term regression coefficients (Aguinis, 2004). Moreover, when the mean of the variables forming a polynomial is much larger than their standard deviation, it can lead to the high correlation between the polynomial and the original variables (Livingston, 2004). This will cause multicollinearity and potentially lead to the distortion of regression models and unreliable predictions. In this study, the means of two moderator variables are 24.34 and 4.215, both of which are much larger than the standard deviations of 1.631 and 0.0981, respectively. Therefore, both moderator variables were centred in this study before introducing the regression model.

In order to deeply explore the mechanism of the impact of FDI inflows on CO_2 emissions, this study incorporates the moderator variables of institutional quality and economic growth, and their interaction terms with FDI, into the regression model. This method aims to evaluate the differences in the effects of FDI inflows on CO_2 emissions under various levels of institutional quality and economic growth. It not only provides a new theoretical perspective to understand the complex interactions between FDI inflows and pollution emissions but also offers empirical evidence for making more effective and efficient environmental policies.

Columns (1) and (2) of Table 12 show the moderating effects of institutional quality to the impact of FDI inflows on CO_2 emissions within the EU. In column (1), the first moderator variable (lnInstQuality) and its interaction term with FDI (c.cFDI#c.clnInstQuality) are introduced to the baseline regression model. The coefficient of the interaction term is significantly negative at the 5% significance level, rejecting the null hypothesis and indicating that institutional quality mitigates the positive impact of FDI inflows on CO_2 emissions between 2000 and 2020 in the EU. In order to address potential endogeneity issues, the two-step system GMM method is employed in column (2). The p-value for the AR (2) statistic being greater than 0.1 proves no autocorrelation issues, and the p-value of the Hansen test being larger than 0.1 indicates that the instruments utilised in the GMM are valid and there is no problem of over-identification. Therefore, the coefficient of the interaction term remains significantly negative at the 5% level of significance, which proves the robustness of the previous finding and is consistent with Hypothesis 2.

During the period from 2000 to 2020, the EU has effectively improved institutional quality by formulating stricter environmental policies and regulations, enhancing transparency, and raising public environmental awareness. The combined effect of these measures influenced the process of foreign firms operating in EU countries, which significantly weakened the contribution of FDI inflows to CO_2 emissions.

Firstly, high institutional quality is usually accompanied by stringent environmental regulations and strong enforcement. This compels foreign enterprises to comply with strict environmental standards during their investment processes, thereby limiting pollution emissions. The EU has already set strict carbon emission targets and standards through a series of regulations such as The EU's 2030 climate and energy framework, which requires enterprises to adopt environmentally friendly production technologies and processes (Oberthür, 2019). In addition, the European Environment Agency and environmental regulatory agencies of member states ensure that firms comply with environmental regulations through frequent environmental audits and severe penalties (Welford, 2014).

Secondly, high institutional quality usually implies higher transparency and more robust accountability mechanisms. In the EU, the process of formulating environmental policies is highly transparent and involves the participation of a wide range of stakeholders including enterprises, governments, non-governmental organisations and the public. For example, extensive public consultations and stakeholder participation were conducted during the formulation of The European Green Deal (Khadim and van Eijken, 2022). Additionally, the EU has established comprehensive environmental information disclosure systems. Through the European Environment Agency and the environmental monitoring systems of member states, corporate carbon emission data are made public in real time, exposing the environmental performance of companies to the scrutiny of both the public and regulatory bodies (Camilleri, 2015). This mechanism compels foreign investors to comply more consciously with environmental regulations, thereby reducing CO_2 emissions.

Lastly, high institutional quality can raise environmental protection awareness and encourage public participation. EU member states vigorously promoted environmental education, disseminating environmental protection knowledge in order to raise public environmental awareness. For instance, many countries in the EU have incorporated environmental education into primary and secondary school curricula, encouraged volunteer environmental activities and community environmental projects (Chalkley, Haigh and Higgitt, 2010). This led foreign enterprises to pay more attention to environmental protection during investment and production activities in order to maintain their social image and market competition. Moreover, the high-quality institutional framework of the EU ensures the legal foundation and channels for public participation. This enables the public and non-governmental organisations to monitor and report irregular and illegal environmental behaviours of enterprises through various means, thereby exerting social pressure on companies and prompting them to adopt more environmentally friendly production methods. Foreign investors, aiming to improve their reputation and market position, are more inclined to comply with environmental regulations and reduce CO_2 emissions.

Columns (3) and (4) of Table 12 illustrate the moderating effects of economic growth to the impact of FDI inflows on CO_2 emissions in the EU. In column (3), the second moderator variable (lnGDP) and its interaction term with FDI (c.FDI#c.clnGDP) are introduced into the baseline regression model. The coefficient of the interaction term is significantly negative at the 10% significance level, which rejects the null hypothesis and reveals that economic growth weakens the positive impact of FDI inflows on CO_2 emissions over the period from 2000 to 2020 in the EU. Similarly, as shown in column (4), this study adopts the two-step system GMM method in order to acquire more reliable and accurate estimates. The AR (2) statistic with the p-value greater than 0.1 and the Hansen test with the p-value greater than 0.1 suggest that there are no issues of autocorrelation and over-identification in the GMM, respectively. Therefore, the coefficient of the interaction term remains significantly negative at the 5% significance level, which indicates the robustness of the previous finding and is in line with Hypothesis 3.

During the period from 2000 to 2020, economic growth effectively mitigated the positive effects of FDI inflows on CO_2 emissions through technological innovation, optimisation of industrial structure and increased investment in environmental protection.

Firstly, economic growth usually brings capital, technology and talent that are necessary components for technological innovation to the society. This provides an important guarantee for achieving the goal of sustainable development. During the study period, economic growth brought the EU with sufficient funds and expertise for the R&D and promotion of clean energy technologies. Many foreign enterprises adopted these advanced and environmentally friendly technologies, thus reducing CO_2 emissions during their production activities. For example, the EU has achieved significant technological breakthroughs in the renewable energy fields such as wind power and solar in recent years (Мельник et al., 2020), which have not only improved the efficiency of renewable energy utilisation but also significantly reduced power generation costs. This made clean energy more economically competitive than fossil fuels, so an increasing number of companies were willing to use them. When foreign companies enter into the EU market, adopting these efficient and cost-effective clean energy technologies not only help these companies to comply with stringent environmental regulations, but also increases their productivity and competitiveness in the market, thereby reducing polluting emissions.

Secondly, economic growth can promote the structural transformation of economies from heavy industries to service and technology-intensive industries. In the EU, with economic growth, the service and high-tech industries that have relatively low CO_2 emissions accounts for an increasing proportion of the economic structure, the ratio of FDI in high-pollution industries also decreases (Ortega-Argilés et al., 2010). For instance, the rise of high-value-added sectors such as information technology, financial services and R&D services has reduced economy’s reliance on traditional manufacturing. In addition, economic growth can provide opportunities for the green industries' development. In recent years, foreign enterprises entering into the EU market are more inclined to invest in green industries with sustainable development prospects (Veugelers, 2020), thereby lowering overall CO_2 emissions.

Lastly, economic growth usually enables governments to pay more attention to the formulation of environmental policies and provide financial subsidies, which encourages enterprises to make environmental investments. For example, with economic growth, an increasing number of governments within the EU offer tax reductions and financial subsidies to enterprises that adopt low-carbon technologies and energy-efficient equipment (Polzin and Sanders, 2020), thereby incentivizing companies to reduce CO_2 emissions. In addition, governments and enterprises of the EU have invested large amounts of funds in building environmental protection facilities such as sewage treatment, exhaust gas treatment and solid waste management (Kosek et al., 2020), thereby reducing the negative influence of production activities on the environmental quality.

Table 12: Moderated Regression

	(1) lnCO₂	(2) lnCO₂	(3) lnCO₂	(4) lnCO₂
L.lnCO₂		0.9485892***		1.083143***
		(0.0475525)		(0.0524174)
FDI	0.000477***	0.0002005***	0.0003279**	0.0002398**
	(0.0001082)	(0.0000577)	(0.000132)	(0.0001112)
lnInstQuality	-0.0388297	-0.8552894**		
	(0.0596358)	(0.3540048)		
c.cFDI#c.clnInstQuality	-0.0085754**	-0.0092829**		
	(0.0043256)	(0.0040849)		
lnGDP			0.0928794	0.0054359
			(0.0943443)	(0.0281023)
c.FDI#c.clnGDP			-0.0014639*	-0.0010115**
			(0.000839)	(0.0004547)
Open	0.0539979	-0.0291894	0.0558887	0.0507966
	(0.0385071)	(0.0263819)	(0.0425818)	(0.0465964)
R&D	0.0682507***	-0.0064958	0.0657915***	-0.0946353**
	(0.0140512)	(0.0415858)	(0.0148904)	(0.0454006)
lnTourism	0.0492575**	0.01946	0.0401026	0.0429518***
	(0.0246448)	(0.0166785)	(0.0256067)	(0.0163586)
Capital	-0.0003586	0.002826	-0.0005508	0.0002639
	(0.0014338)	(0.0023472)	(0.0013578)	(0.0029461)
Labour	0.0041377	-0.0100842**	0.0043636	0.0002361
	(0.0033528)	(0.0039277)	(0.002827)	(0.0114404)
Inflation	0.0059273***	0.0038433	0.0056143***	-0.004391
	(0.0015887)	(0.0029107)	(0.0016298)	(0.0054734)
lnIndustry	0.1347271***	0.0087957	0.1060316**	-0.0802132*
	(0.0367562)	(0.0401912)	(0.0491734)	(0.0423917)
_cons	6.186665***	4.048524**	4.475115**	-0.0006841
	(0.7571035)	(1.57009)	(1.781438)	(0.8698105)
N	567	540	567	540
R-squared	0.9972		0.9972	
AR (1)		0.000		0.000
AR (2)		0.119		0.249
Hansen		0.464		0.573

Note: *** p<0.01, ** p<0.05, * p<0.1

3.5 Further discussion

Prior to this section, the core explanatory variable in this study was production-based CO_2 emissions, which is also the primary focus of most scholars in the environmental field. Specifically, the production-based accounting principle calculates the overall generation of CO_2 emissions during the production activities within a region or a country. This method focuses on emissions at the production end, regardless of the final consumption destination of the products. It is mainly used for the allocation of CO_2 emissions responsibilities and the establishment of emissions trading systems at the regional or national level (Peters, 2008). Although this approach has the advantages of the direct management and control of CO_2 emissions during the production process, it ignores the effects of consumption behaviour on CO_2 emissions, potentially resulting in a biased understanding and assumption of environmental responsibility in different sectors and countries. However, the consumption-based accounting principle calculates CO_2 emissions based on consumer responsibility. This method calculates the CO_2 emissions from all services and goods consumed by businesses and residents within a country or region, including the emissions from imported services and goods while excluding those from exports (Wiedmann, 2009). Even if consumers do not directly produce CO_2 emissions, they are responsible for the emissions generated from the production of the products that they purchase. Therefore, this method focuses on the carbon footprint at the consumption end, reflecting the impact of a nation's consumption behaviour on global CO_2 emissions. In summary, these two principles calculate CO_2 emissions from different perspectives. When calculating national CO_2 emissions, the international trade usually results in the countries' consumption-based CO_2 emissions differing from its production-based CO_2 emissions.

Although the production-based accounting principle can cover emissions on a global scale without being limited by the participation of individual countries and provides more options for emission reduction (Peters and Hertwich, 2008), considering only production-based CO_2 emissions in research has some limitations.

Firstly, focusing only on production-based CO_2 emissions ignores the issue of carbon leakage, which is a major criticism raised by some scholars (Fan et al., 2016; Su and Ang, 2014). Carbon leakage is the increase of emissions outside a region because of the implementation of stringent emission reduction policies within that region (Weber, 2008). Specifically, stringent environmental policies usually lead to the relocation of high-pollution enterprises to regions with looser regulations. It results in no net reduction, or even an increase, in global CO_2 emissions. Only examining production-side emissions cannot identify and address this cross-border transfer of CO_2 emissions. However, the consumption-based accounting principle can effectively address this limitation by including the CO_2 emissions of all consumed goods in the total emissions of the consuming country, regardless of where these goods are produced. This means that even if high-pollution enterprises relocate production to regions with lax regulations, the consuming country still accounts for the CO_2 emissions of the imported high-carbon products, thereby eliminating the incentive for carbon leakage.

Secondly, considering only production-based CO_2 emissions ignores global supply chains' complexity. In the modern economy, the production processes for goods and services often span several countries and regions. As a result, a country's production activities may rely on raw materials and intermediate products from other countries. This transnational production network complicates the allocation of carbon emission responsibilities and their impacts. Solely relying on the calculation of production-based CO_2 emissions cannot accurately reflect the carbon footprint across the entire supply chain (Lenzen et al., 2007), nor can it fully assess the actual contribution of a country to global CO_2 emissions. Particularly in the context of highly developed international trade, developed countries may import high-carbon products, shifting the carbon emission responsibility of the production process to developing countries, thus making their own carbon emission statistics look more favourable. By adopting the consumption-based accounting principle, CO_2 emissions can be comprehensively tracked across the entire supply chain, including raw material extraction, production processes and transportation stages (Andrew, Davis and Peters, 2013). Especially in international trade, the consumption-based accounting principle achieves a comprehensive accounting of the carbon footprint across supply chains by detailed recording to CO_2 emissions of imported products.

Thirdly, the production-based accounting principle cannot fully reflect the actual environmental impact of consumption behaviour, especially in regions or countries that largely rely on imports. For instance, although a country may have low production-based CO_2 emissions, its impact on the global environment remains significant due to the import of large quantities of high-carbon products. Consequently, the production-based accounting principle may underestimate the country's actual CO_2 emissions (Tukker et al., 2016). In contrast, under the framework of the consumption-based accounting principle, countries that largely rely on imports must also take responsibility for the high-carbon products they consume, thereby revealing their true impact on the global environment.

Fourth, the production-based accounting principle may lead to an unfair distribution of environmental responsibility, because some consumer countries import high-carbon products and shift the emission responsibility to producer countries, thus evading their own environmental responsibilities (Peters, Davis and Andrew, 2012). This unfair distribution mechanism can also lead to a series of negative effects. Producer countries may face greater economic burden and more pressure to reduce emissions because they need to invest in clean technologies and environmental measures to meet international emission reduction targets. However, consumer countries, not directly taking these emission responsibilities, may lack sufficient motivation to change their consumption patterns and promote domestic low-carbon technologies. Furthermore, this unfair distribution of responsibilities can cause disputes in international environmental negotiations, making the global effort to combat climate change more complex and challenging (Peters et al., 2011). In contrast, the consumption-based accounting principle ensures a fair distribution of carbon emission responsibilities. Consumer countries will have more motivation to promote domestic low-carbon technology development and take measures to reduce the import of high-carbon products, thereby leading to real reductions in global CO_2 emissions. In addition, the application of the consumption-based accounting principle can decrease conflicts during international environmental negotiations because it provides a fairer and more transparent carbon emission accounting mechanism.

Lastly, the production-based accounting principle may lead to policy biases, overlooking the emission reduction potential on the consumption side. If policymakers focus only on controlling CO_2 emissions during the production process, they may neglect the emission reduction effects achieved by changing consumption habits and promoting the use of low-carbon products. For example, policies based on production-based accounting principle may primarily encourage enterprises to invest in clean technologies and process improvements to reduce CO_2 emissions in the production process. However, without simultaneously considering the impact of the consumption side, these efforts may only achieve limited success because the emission reduction potential on the consumption side is substantial. By encouraging consumers to choose low-carbon products, raising public environmental awareness and promoting sustainable consumption, countries or regions can achieve significant reductions in CO_2 emissions (Barrett et al., 2013). For instance, labelling the carbon footprint, providing subsidies for low-carbon products and promoting green procurement initiatives can effectively steer market demand towards more environmentally friendly options. This can incentivise companies to take environmental impacts into account at the production and design stages, leading to wider and deeper CO_2 emission reductions.

Therefore, exploring the impact of FDI inflows on consumption-based CO_2 emissions can help governments to formulate more comprehensive and effective environmental policies. This approach not only captures the impact of global supply chains and consumption behaviours on CO_2 emissions more accurately, but also offers a more comprehensive and fairer perspective on environmental responsibility sharing, thus promoting international cooperation and the implementation of CO_2 emission reduction strategies.

As shown in column (1) of Table 13, this study established a two-way fixed effects model with consumption-based CO_2 emissions as the dependent variable and FDI inflows as the core explanatory variable. The coefficient of FDI is significant and negative at the 1% level of significance, suggesting that FDI inflows significantly reduced the consumption-based CO_2 emissions in the EU between 2000 and 2020. Additionally, the coefficient of FDI is approximately -0.0006332, implying that, when controlling for other variables, consumption-based CO_2 emissions decrease by 0.06332% in average following an increase in FDI inflows by one unit. The within-group R-squared of the model is 0.9938, suggesting a relatively high goodness-of-fit of the model.

In order to further address potential endogeneity issues and provide more reliable estimation results, this study employs the two-step system GMM. As shown in column (2) of Table 13, the AR (1) statistics is significant at the 1% significance level, which indicates the presence of first-order difference series correlation. The AR (2) statistic with the p-value greater than 0.1 indicates that second-order differenced series are not correlated. In addition, the p-value of the Hansen test is larger than 0.1, suggesting that there are no over-identification problems with the instrumental variables. And the coefficient of FDI is significantly negative at the 5% significance level. Therefore, FDI inflows still have a significantly negative impact on consumption-based CO_2 emissions after effectively addressing endogeneity issues. This ensures the reliability and robustness of the previous results.

Over the period from 2000 to 2020, FDI inflows can significantly and negatively contribute to the consumption-based CO_2 emissions within the EU. This is mainly because FDI inflows can introduce advanced low-carbon technologies and green consumer products, increase the popularity and purchase of high-standard and low-carbon products, and replace high-carbon imports with locally produced goods.

Firstly, FDI inflows usually bring advanced low-carbon technologies and green consumer products to the EU. According to the consumption-based accounting principle, the generation of CO_2 emissions during these green products' consumption are included in the total emissions of the consuming country. Compared to traditional high-carbon products, these green products have higher energy efficiency and lower CO_2 emissions during use, significantly reducing consumers' carbon footprints and thereby lowering overall consumption-based CO_2 emissions. During the period from 2000 to 2020, the EU has attracted large amounts of FDI from technologically advanced countries. These foreign enterprises introduced the latest production technologies of the products such as electric vehicles and energy-efficient appliances, which not only reduces the CO_2 emissions of the products during their use, but also enhances the competitiveness of these products in the markets (Rennings, 2000). In addition, foreign enterprises can improve the quality and penetration rate of green products in the EU market through technology transfer and innovation. The popularity of green products leads more consumers to choose low-carbon products, thereby reducing consumption-based CO2 emissions. For instance, companies like Tesla established production bases in the EU, manufacturing and selling electric vehicles, which have significant low-carbon advantages over traditional internal combustion engine vehicles (Hawkins et al., 2012). Tesla introduced advanced electric vehicle manufacturing technology to the EU market, providing efficient low-carbon products and using advertisements and other media to guide consumers to choose these low-carbon vehicles. By purchasing and driving these electric vehicles, consumers significantly reduce their carbon footprints because electric vehicles generate far less CO_2 emissions during use compared to traditional petrol vehicles. Furthermore, the widespread adoption of these green products in the EU makes the public pay more attention to the environmentally friendly products, further increasing market demand for low-carbon products (Sovacool and Hirsh, 2009), significantly reducing the EU's consumption-based CO_2 emissions.

Secondly, the FDI inflows to the EU implies that foreign firms need to comply with the environmental regulations and standards of the EU. The EU's environmental regulations and standards are relatively strict in the world (Jacoby and Meunier, 2013), which regulate the energy efficiency, emissions and environmental performance of products, and require foreign enterprises to produce and sell more environmentally-friendly products. As a result, these high-standard products generate less CO_2 emissions during consumption. In 2019, the European Green Deal was launched by the European Commission, which aimed to transform the EU to the first climate-neutral region in the world by 2050 (European Commission, 2020). It includes action plans of key areas such as clean energy, circular economy, building standards, transport and the Farm to Fork strategy, all designed to increase resource efficiency and reduce pollution (European Commission, 2020). For instance, the European Green Deal encourages organic farming by reducing the use of fertilisers and chemical pesticides. Instead of using synthetic chemicals, organic agriculture depends on natural methods such as biological control, composting and crop rotation. These methods reduce air, water and soil pollution, improve the agricultural ecosystem and ultimately produce organic food with a low carbon footprint. After that, organic food in the EU market is often labelled with a carbon footprint tag to help consumers identify more environmentally-friendly products (Rondoni and Grasso, 2021). This not only has raised environmental awareness of the public but also effectively reduced consumption-based CO_2 emissions. In addition, in the field of household appliances of the EU, foreign enterprises are required to sell appliances such as refrigerators and washing machines that comply with the EU's stringent energy efficiency standards (González-Torres et al., 2023). The adoption of these high-efficiency appliances not only reduces each household's carbon footprint but also encourages enterprises to improve their products' environmental standards in order to improve competitive. This further promotes the popularity and purchase of low-carbon household appliances in the EU market, thereby significantly reducing CO_2 emissions at the consumption end.

Lastly, the technological innovations and production capacity enhancements brought by FDI have enabled the EU to produce low-carbon products in place of high-carbon products that previously had to be imported. These locally produced products generate relatively lower CO_2 emissions during consumption. By reducing the import of high-carbon products and increasing the local production and consumption of low-carbon products, the overall carbon footprint of the EU has decreased. Between 2000 and 2020, the foreign enterprises in the EU adopted advanced low-carbon technologies to produce goods locally, thereby replacing high-carbon products that would have been imported from other countries (Fragkiadakis, Fragkos and Paroussos, 2020). For instance, foreign enterprises that invested in manufacturing bases in Germany used advanced technologies to produce photovoltaic components and wind power equipment (Wüstenhagen and Menichetti, 2012). Such environmentally friendly products that would have otherwise to be imported from other countries, have been effectively replaced by locally produced alternatives. This not only reduced the CO_2 emissions associated with importing high-carbon products but also met the local market's demand for low-carbon products. This shift significantly decreased the EU's reliance on high-carbon imported products and consumers' carbon footprints by providing more environmentally friendly local products. Therefore, this substitution has lowered the consumption-based CO_2 emissions in the EU, thus promoting regional green economic development.

Table 13: The impact of FDI on consumption-based CO_2 emissions

	(1) lnCO_2_2	(2) lnCO_2_2
L.lnCO_2_2		0.87571***
		(0.0971373)
FDI	-0.0006332***	-0.0002468**
	(0.0002162)	(0.0001224)
Open	0.1879822***	-0.1037929**
	(0.0613732)	(0.0522341)
R&D	0.0159832	0.0068698
	(0.0214726)	(0.0457005)
lnTourism	0.0558831*	0.0886599***
	(0.0319063)	(0.0306736)
Capital	0.0099608***	0.0089946***
	(0.0026684)	(0.0027181)
Labour	0.0358937***	0.0003534
	(0.0039304)	(0.0065777)
Inflation	-0.0023095	0.0045874
	(0.0023952)	(0.0052091)
lnIndustry	-0.0133619	-0.043225

	(0.0465542)	(0.0585234)
_cons	14.5705***	1.199223
	(0.9762794)	(1.206096)
N	567	540
R-squared	0.9938	
AR (1)		0.005
AR (2)		0.958
Hansen		0.401

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Conclusion

This study systematically reviews the literature through theoretical analysis and empirical research, including three hypotheses concerning FDI inflows and CO_2 emissions (the pollution haven hypothesis, the scale effect hypothesis and the pollution halo hypothesis), the relationship between institutional quality and air quality, and the effects of economic growth on pollution emissions. Subsequently, this study analysed the data characteristics from several aspects and finally determine the two-way fixed effects model as the baseline regression model. Using a sample of 27 EU countries between 2000 and 2020, this study finds that FDI inflows have a significantly positive contribution to CO_2 emissions. Additionally, by introducing interaction terms, it is revealed that both institutional quality and economic growth weaken the impact of FDI inflows on CO_2 emissions. Finally, this study replaces the dependent variable from production-based CO_2 emissions to consumption-based CO_2 emissions and the result shows that FDI inflows contribute to the reduction of consumption-based CO_2 emissions significantly.

Based on the key findings in this study, the corresponding policy implications are proposed. Firstly, governments need to strengthen environmental regulations and set stricter emission standards especially for the high-pollution industries, in order to ensure that foreign enterprises must control production-based CO_2 emissions while pursuing economic benefits. Additionally, the EU should continue to revise and improve the EU ETS, including expanding the range of sectors it covers and increasing the proportion of auctioned emission allowances. Therefore, this market mechanism can more effectively reduce the cost of emission reductions and improve energy efficiency. Secondly, institutional quality can be further improved through lower levels of corruption, stricter environmental regulation and higher levels of public participation, thereby weakening the negative environmental impact of FDI inflows. Further strengthening accountability in the environmental sector and investing more in independent external scrutiny can reduce the abuse of public office for private gain, thus ensuring that environmental funds are used wisely to achieve the goal of sustainable development. And the regulatory agencies could increase the frequency and scope of environmental monitoring in order to ensure real-time and accurate tracking of companies' emissions. Also, policymakers can establish a more transparent environmental information disclosure system to ensure that the public access the emissions data and encourage public scrutiny and participation. Thirdly, further incentives for consumer spending and business investment can boost economic growth, thereby mitigating the negative effects of FDI inflows on air quality. Governments could stimulate consumption by issuing certain cash subsidies or consumption vouchers to increase the disposable income and real purchasing power of the public. Financial institutions can also provide more personalised consumer credit products to meet the different consumption needs of the residents. In addition, the government could provide financial support and policy incentives such as preferential tax measures to encourage foreign enterprises to invest in green technology research and innovation. Finally, the joint efforts from consumers and producers can further reduce the consumption-based CO_2 emission. Governments can guide the public to choose the low-carbon products and services by increasing publicity of these products and providing subsidies for green consumption. In addition, the government can improve the green product certification system, thereby encouraging foreign enterprises to provide more environmentally friendly products and services.

This study only examined the moderating effects of institutional quality and economic growth. For the future research, scholars could not only expand the selection of moderator variables, but also further explore the mediating effects by drawing on the research of Wang et al. (2021) and Naz et al. (2018). In addition, this study only explores the impact of FDI inflows on environmental quality. However, both inflows and outflows of FDI significantly affect the environment. FDI inflows often bring local pollution control technologies and expertise (Popp, 2011), but it can also increase production activities in high-pollution industries (Singhania and Saini, 2021). And the outflows of FDI can relocate highly polluting industries to other countries, thus reducing the environmental pressures in the home country (Manderson and Kneller, 2011). Therefore, future research could analyse the effects of two-way FDI on CO_2 emissions in order to gain a comprehensive understanding of the impacts of capital flows on global and domestic environments.

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