

Article

Green Taxation, Trade Liberalization and Natural Resource Utilization

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Abstract

Environmental protection is an essential path to achieving high-quality economic development, and green tax policies are an effective means of achieving environmental protection. This study categorizes green tax policies into environmental protection-oriented green tax policies, resource-oriented green tax policies, and guidance-oriented green tax policies based on the nature of the tax. The fixed-effect model, the system GMM model and the continuous DID model are used to explore the causal relationship between the overall green tax policy, the classified green tax policy and the use of natural resources. The spatial Durbin model is used to explore the spatial spillover effect of the green tax policy and the regional heterogeneity in the east, central, west and northeast of China. Finally, the role of trade openness in the relationship between the green tax policy and natural resource use is explored. The research results show that (1) the green tax policy has a positive effect on natural resource use, but the green tax policy in the previous period has no promoting effect, and the natural resource use in the previous period has a positive impact on the current period. Among them, there is no causal relationship between the resource-occupying green tax and natural resource use. (2) All three types of green tax policies studied in this paper have spatial spillover effects, but the spillover effects of the three types of green tax policies are relatively small in the eastern region. The spillover effects of the three types of green tax policies in the central region are significantly negative. In the western region, only the guiding green tax policy has a spillover effect. In the northeastern region, the environmental protection green tax policy and the resource-based green tax policy are significantly negative, while the guiding green tax spillover effect is significantly positive. (3) In the mechanism test, the guiding green tax policy has an impact on natural resource utilization through trade openness, while the environmental protection green tax policy and the resource-based green tax policy cannot affect natural resource utilization through the level of trade openness. Finally, based on the research conclusions, policy recommendations are proposed from the perspectives of policy timeliness, tax structure adjustment, and trade network optimization to maximize economic benefits.

Keywords: green tax policy; trade openness; natural resource utilization; spatial spillover effects



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1. Introduction

The green economy is a trend in global economic development today. China has made resource conservation and environmental protection a fundamental national policy and

is actively working to build a beautiful China [1,2]. However, China has long adopted a relatively extensive production method, resulting in serious resource waste, land degradation, water pollution, and other problems [3,4]. Environmental pollution usually has high negative externalities and diffusion, which inhibits the development of the green economy [5]. For this reason, the report of the 20th National Congress of the Communist Party of China also clearly pointed out that the development of the green economy requires the coordinated development of ecology and the economy as the core to achieve the unity of low carbon emissions and economic growth [6]. In recent years, China has also successively issued relevant policy documents to encourage the development of the green economy, such as the “Opinions of the Central Committee of the Communist Party of China and the State Council on Accelerating the Comprehensive Green Transformation of Economic and Social Development” and “Opinions on Playing the Role of Green Finance in Serving the Construction of a Beautiful China”. In the development process of the green economy, the green tax system is an extremely important link. The purpose of green taxation is to give full play to the regulatory role of green taxation and coordinate the relationship between economic development, environmental protection, and resource utilization [7]. Therefore, in order to deeply explore the actual role of green tax policies, this study divides green taxes into three major categories, namely environmental protection green tax policies, resource occupation green tax policies and guidance green tax policies.

China’s green tax policy can be subdivided based on the Coase theorem and Pigovian tax. The core idea of the Coase theorem is to solve externality problems through the definition of property rights and market negotiations. Pigovian tax emphasizes taxing negative externalities and subsidizing positive externalities [8]. Under the guidance of the Coase theorem and Pigou taxation, combined with the evolution history of green tax policies, it is not difficult to find that the government has shifted from rigid intervention and semi-rigid intervention to flexible intervention. The changes in these three types of intervention methods also reflect the changes in the boundaries of the different roles of the government and the market. Rigid intervention is the internalization of environmental external costs through legal coercion, and is also a concentrated expression of the government’s “command-and-control” model. Environmental protection tax best embodies the characteristics of rigid intervention. This tax requires direct taxation on the emission of air pollutants, solid waste and other pollutants, and it is difficult to reflect the role of market mechanisms in government intervention. Therefore, the first category of green tax policies is environmental protection tax policies, which include sewage fees and environmental protection taxes. Semi-rigid intervention combines market incentives and government regulation. Under the green tax policy system, resource taxes have different tax rates by category and region. Urban land use tax transfers use rights through transaction contracts through the market. To this end, the second category of green tax policies is subdivided into resource occupation tax policies, which include resource tax, urban land use tax, and cultivated land occupation tax. Flexible intervention refers to stimulating the motivation of enterprises to reduce emissions independently through non-mandatory means such as tax incentives and industry guidance, embodying the concept of co-governance in which market spontaneity is the mainstay and government intervention is supplementary. The “voluntary negotiation” logic of the Coase Theorem suggests that reducing transaction costs is an effective way to promote cooperation between businesses and the government [9]. The consumption tax exempts new energy vehicles from purchase tax, resulting in a shortage of new energy companies in the market; the value-added tax encourages companies to voluntarily upgrade by reducing the cost of using clean technology. Based on this, green tax policies are further subdivided into a third category: guiding tax policies, which include value-added tax, corporate income tax, vehicle and vessel tax, deed tax, urban

construction tax, and consumption tax (The classification system of this research has a clear operational basis in the report structure of the “China Tax Yearbook”. The data of environmental protection-oriented taxes are fully reflected in the report on the income situation of environmental protection taxes by region and tax category across the country. The data of resource occupation-oriented taxes, such as the resource tax, can be obtained from the report on the income situation of resource taxes by region and tax category across the country, and its statistical dimensions closely revolve around the behaviors of resource exploitation and occupation. The policy effects of guiding-oriented taxes, although scattered among multiple main tax types, have the same policy goals under different statistical standards. For instance, the data in the chapter on the income situation of consumption taxes by region and enterprise type across the country directly reflects the suppression of high-energy consumption, while reports such as the income situation of enterprise income taxes by province and type provide the possibility for tax preferences for industries such as environmental protection, energy conservation, and new energy. Therefore, the physical separation based on the official yearbook reports is a direct proof of the operability of the classification method of this research. It indicates that on the theoretical basis of dividing the three types of taxes, they also correspond to different data sets in the official statistical system.).

Furthermore, China’s green economic development faces multiple challenges, particularly the long-standing problem of inefficient natural resource utilization. This inefficient utilization not only exacerbates ecological and environmental pressures but also makes the “natural resource curse” effect more pronounced in some regions of China [10,11]. Currently, building a resource-conserving economic system has become a strategic priority. This requires regulating resource utilization through green tax policies and, more importantly, driving improvements in resource utilization efficiency through technological innovation [12]. Furthermore, with the increasing momentum of globalization, trade openness offers new avenues for breaking through bottlenecks in resource utilization. High levels of trade openness accelerate the cross-border transfer of low-pollution production technologies through technological spillovers, specifically the import of environmentally friendly equipment and the introduction of low-carbon patented technologies, thus enabling China’s manufacturing industry to break free from its path dependence on primary resource-intensive processes. Competitive pressures in the international market and green trade barriers also incentivize companies to enhance product competitiveness by improving resource efficiency. However, the optimizing effect of trade openness on natural resource utilization can be more effectively mitigated when local institutional innovation, strengthened environmental regulations, and import and export processes form a synergistic mechanism, truly achieving a dynamic balance between an open economy and green development. To this end, this paper explores the impact of green tax policies on natural resource utilization using methods such as system GMM and continuous DID. The paper demonstrates that different levels of green taxation have different effects on natural resource utilization, further clarifying the mechanism of action of the green tax system. This study also explores the spillover effects of green tax policies in eastern, central, western, and north-eastern China (According to the “Opinions of the CPC Central Committee and the State Council on Promoting the Rise of the Central Region” and the “Implementation Opinions of the State Council on Several Policies and Measures for the Development of the Western Region,” China’s economic regions are divided into four major regions: the East, the Central, the West, and the Northeast. The East includes Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan. The Central includes Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan. The West includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia,

and Xinjiang. The Northeast includes Liaoning, Jilin, and Heilongjiang.), as shown in Figure 1 below. Empirical results indicate that spillover effects vary across regions. Furthermore, we find that trade openness plays a partial mediating role in the mechanism of green tax policies, thus providing a new avenue for improving the efficiency of natural resource utilization.

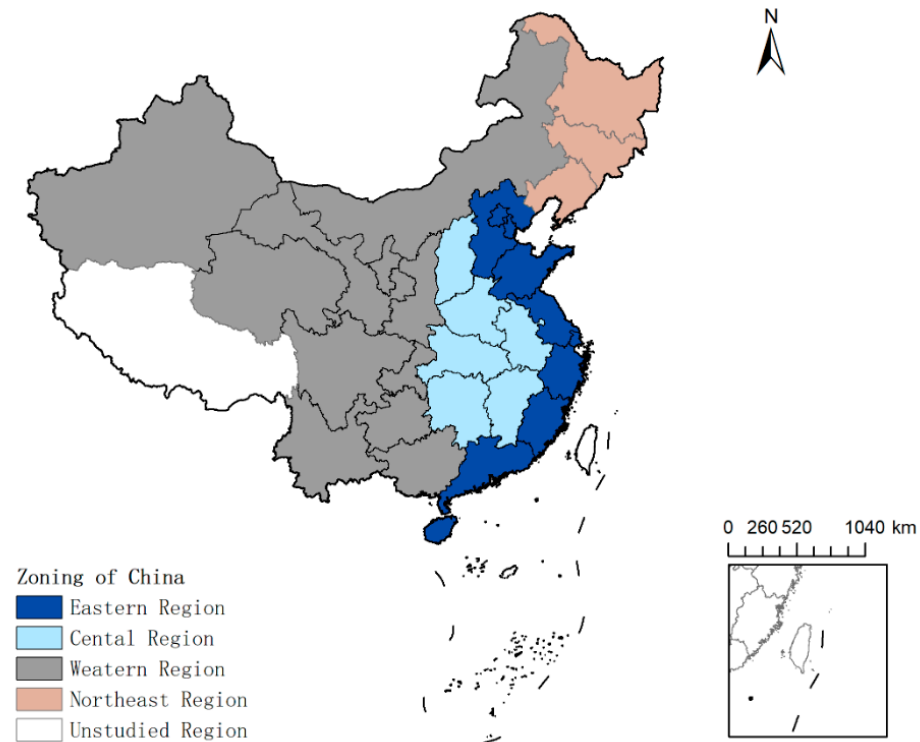


Figure 1. Regional distribution of eastern, central, western, and northeastern China (This map is based on a standard map of national administrative division vector data, with approval number GS(2024)0650 and downloaded from the China National Geographic Information Platform. The base map remains unchanged.).

The remainder of this paper, including Section 2, provides a review of research on this topic. Section 3 presents the theoretical analysis and research hypotheses. The model setting, variable interpretation, and data for this study are presented in Section 4. Section 5 reports the empirical results. Section 6 presents the main conclusions and policy implications.

2. Literature Review

2.1. Research on the Relationship Between Green Tax Policy and Trade Openness

The connotation of green tax policy is a prerequisite for exploring its effectiveness. Green tax policy aims to protect the environment and, through a combination of economic constraints and positive incentives, achieves a coordinated regulation of resource utilization and social and environmental pollution through multiple tax types [13]. Green tax policy levies taxes on energy consumption and energy inputs for household energy use, using tax revenue to reduce distortionary taxes, thereby achieving environmental improvements and enhancing redistributive efficiency [14,15]. Although scholars have yet to reach a unified definition of green tax policy, existing scholars generally agree that China has established a comprehensive green tax system with environmental protection taxes as the core, resource taxes, consumption taxes, and vehicle purchase taxes as key components, and value-added taxes, deed taxes, farmland occupation taxes, corporate income taxes, and vehicle and vessel taxes as supplementary components.

Regarding the impact of green tax policies on trade openness, the core controversy in existing research centers on whether environmental regulation can achieve synergy with trade openness. Different scholars, based on their own research perspectives and empirical logic, have reached different conclusions. Scholars, exemplified by the “synergy theory,” believe that green tax policies can be an important tool for balancing trade development and environmental protection, drawing on the perspectives of environmental cost internalization and policy adaptability. China’s current environmental tax system, due to its narrow coverage and low collection standards, fails to fully transform environmental costs into internal constraints for businesses, ultimately leading to increased trade friction and inefficient resource utilization [16,17]. Therefore, these scholars explicitly advocate for the internalization of environmental costs through strengthening green tax measures, such as pollution discharge fees, thereby promoting the coordinated development of trade and the environment. Yang primarily validates this logic from an international comparative perspective, arguing that trade openness and the degree of cross-border pollution together constitute key variables in setting environmental tax rates. When cross-border pollution risks are low, countries with high trade openness are more motivated to raise environmental tax rates. This is because these countries can use strict green taxation to select high-value-added, low-pollution industries and maintain their trade competitive advantage [18]. This conclusion directly supports the positive interaction between green taxation and trade openness.

Nevertheless, scholars of the conflict theory, as opposed to the synergy theory, directly challenge the aforementioned synergy view by revealing policy contradictions at the international level. Empirical research based on agricultural trade has found that when environmental standards and green tax intensity differ significantly across countries, the “pollution haven” effect can significantly weaken the policy effectiveness of green taxes, distort trade patterns, and ultimately defeat the environmental protection objectives of green tax policies [19]. Lai’s cross-border pollution model further validates this phenomenon. In the absence of international coordination, countries may lower green tax standards to maintain trade competitiveness, attracting foreign investment and industry. This creates a dilemma: “whoever imposes stricter taxes first loses their trade advantage first.” This makes it difficult for a single country’s green tax policy to achieve its intended goals through trade liberalization [20]. Böhringer, using a general equilibrium model simulation at the policy implementation level, found that when transboundary pollution problems are prominent, some countries may even need to subsidize highly polluting imports to comply with multilateral trade agreements and avoid trade retaliation [21].

To sum up, the relationship between green taxation and trade openness remains inconclusive. The reason why the “synergy theory” and “conflict theory” have been in a stalemate in existing research is that most discussions are still confined to theoretical deductions or the examination of a single tax type, such as environmental taxes, lacking empirical tests from the perspective of the overall green tax policy system on their complex interactions with trade openness. Different types of green taxes, such as restrictive environmental taxes and incentive-driven guiding taxes, may have entirely different impact mechanisms on trade openness, but existing research has insufficiently examined these distinctions. Therefore, this paper categorizes green tax policies into three types: environmental protection, resource occupation, and guiding, aiming to transcend the binary debate of either-or and empirically test the differentiated performances of different types of green tax policies in the context of trade openness from a more refined structural perspective, providing new evidence to resolve the aforementioned academic disputes.

Researchers such as Huang, Huo and others unanimously believe that trade opening has a positive impact on environmental policy. Trade liberalization and fiscal decentraliza-

tion are policy leverages to achieve green growth through the development of renewable energy, thus reflecting the effect of green tax policy [22]. Financial development, trade openness and FDI as predictors, analyze the impact through the automatic regression distribution lag method. Financial development, trade opening and foreign direct investment have been found to have made positive contributions to promoting environmental sustainability [23]. But more researchers prefer that trade openness has negative impacts on the environment. Wan and others have constructed a trade model between the two countries and found that when there is no environmental policy, countries may not benefit from trade opening up, and pollution tax can help trade liberalization to achieve welfare improvement [24]. Hu pointed out that without environmental policy support, the impact of trade opening on the environment is questionable. The impact of the multi-purpose use of trade openness on traditional energy can lead to environmental damage. Integrating trade opening into the global carbon tax system will increase the impact of carbon tax on carbon dioxide emission reduction by 33% [25]. Li constructs a three-stage dynamic game model, believing that trade opening will lead to an increase in environmental tax and import tax [26]. Trade openness may allow cheap imported goods to crowd out the domestic market, weakening the guiding effect of green tax policies on consumer behavior [27].

These studies collectively reveal the complex and multifaceted impacts of trade openness on green tax policies under different scenarios. Thus, academic research has reached no consensus on the relationship between green tax policies and trade openness. Most studies have not explored the relationship between green tax policies and trade openness from the perspective of green tax policies, focusing instead on specific tax types. This paper, based on a tax-by-tax perspective, examines the role of trade openness in green tax policies as a whole, providing an opportunity for this study.

2.2. Research on the Relationship Between Trade Openness and Natural Resource Utilization

Regarding the impact of trade openness on the utilization of natural resources, there are also significant differences among scholars. The core of the debate lies in whether trade openness optimizes global resource allocation and promotes resource utilization efficiency through technology spillovers (the “promotion” view), or whether it exacerbates resource consumption and the “resource curse” effect (the “repression” view), or whether there exists a more complex nonlinear relationship between the two.

Those who advocate the “promotion theory” emphasize the positive aspects of trade openness. They point out that trade openness can effectively mitigate the negative impact of energy endowment on the efficiency of green resource utilization [28]. Cheng and Zhang found, from the perspective of energy utilization structure, that under the guidance of appropriate policies, trade openness can optimize resource allocation, promote technological progress, and thus enhance resource utilization efficiency, ultimately promoting sustainable development [29]. Trade openness can also optimize resource utilization structure, indirectly improving resource utilization efficiency and laying the foundation for sustainable development [30]. From a technical perspective, green trade facilitates the exchange of clean fuels and technologies, while innovations in hydropower development efficiency improve resource utilization efficiency, ultimately promoting economic growth in ASEAN countries [31]. Thus, researchers have explored the relationship between trade openness and natural resource utilization from different perspectives, but all agree that trade openness directly promotes resource utilization. However, not all scholars support this view.

In contrast, the “restraint theory” proponents have identified the potential risks and conditional nature of trade liberalization. Their research indicates that, given the current volatile global market situation, trade barriers have a severely adverse impact on high-

income and highly trade-oriented economies [32]. Under the impact of renewable energy and trade policies in RCEP countries, resources like coal could become a trade advantage for RCEP countries, while oil dependence could inhibit trade development due to the “resource curse [33].” Furthermore, Zheng Yongjie’s research has found that the technological spillover effects brought about by trade openness do not occur automatically. Their effectiveness depends on the absorptive capacity of the host country. If the local technological level is insufficient, it may not be able to effectively enhance resource utilization [34]. Resource rents and trade openness have quantile-heterogeneous environmental effects. At low levels, resource rents exacerbate pollution, while at high levels, green technologies are needed to offset their effects [35]. Existing scholars have explored the relationship between trade openness and natural resource utilization from the perspectives of energy structure, technological progress, and trade barriers, but the fundamental path of trade openness’s impact on natural resource utilization efficiency remains undetermined.

Overall, the impact of trade openness on the utilization of natural resources is not a simple linear promotion or inhibition, but is regulated by multiple factors such as the stage of development, resource endowment, technological level, and policy environment. However, most existing studies mainly examine the direct relationship between the two from a static perspective, generally ignoring the time lag of policy effects and the possibility of trade openness as an intermediate mechanism. Most literature regards trade openness as a given external condition or control variable, rather than a dynamic transmission path. An important breakthrough of this paper lies in not only capturing the time lag effect of policies through a dynamic panel model, but also testing trade openness in the “green taxation policy–trade openness–natural resource utilization” mediating path, aiming to reveal the indirect mechanism by which trade openness affects resource utilization, thereby providing a mechanism-based explanation for the above debate.

2.3. Research on the Relationship Between Green Taxation and Natural Resource Utilization

Although the goal of green taxation policies is directly aimed at resource conservation and environmental protection, the actual effect of these policies on the utilization of natural resources remains controversial in empirical studies. The focus of these studies lies in whether the policy effect of green taxation is generally positive, or whether it has significant conditional heterogeneity and spatial complexity.

Some scholars hold the “positive promotion” viewpoint. The research of this group of scholars mainly focuses on the reform effects of specific tax types. For instance, they believe that green taxation can significantly enhance the efficiency of natural resource utilization through cost constraints and incentive guidance. Currently, China’s green taxation system has shortcomings such as narrow tax coverage and insufficient preferential policies, which are the key obstacles restricting the improvement of resource utilization efficiency. Therefore, they explicitly advocate that reforms such as expanding the scope of resource tax collection and innovating the form of consumption tax collection should be carried out to strengthen the regulatory role of green taxation on the utilization of natural resources [36,37]. Qian, Yang, and other researchers used multi-period DID and PSM-DID methods to focus on the impact of specific tax categories, such as resource taxes and environmental taxes, on water and mineral resource utilization. Their results showed that pilot water resource tax reforms can significantly reduce water waste, while effective mineral resource tax management can achieve sustainable mineral resource utilization [38,39]. This provides micro-level empirical support for the “positive effects of green taxation.” Cheng’s research complements this conclusion from the perspective of optimizing the energy structure, arguing that increasing the environmental tax rate can directly incentivize businesses

to shift to clean energy alternatives and promote green infrastructure investment, thereby improving natural resource efficiency from the energy consumption side [40].

However, scholars advocating for “heterogeneous effects” challenge the universality of the “positive promotion theory” by revealing the conditionality of policy effects. Some studies indicate that the positive effects of green taxes are not absolute but rather constrained by multiple factors [41]. Some scholars, through dynamic panel data analysis, have found significant instability in the role of environmental taxes in promoting renewable energy substitution. Specifically, in regions with lower technological levels, environmental taxes may simply increase corporate compliance costs without promoting energy substitution [42]. The positive effects of environmental tax policies only become apparent when regional green innovation capacity reaches a threshold [43]. Ma’s research shows that in some economies, environmental taxes even show a significant negative correlation with natural resource utilization efficiency: When an economy is in the early stages of industrialization and its industrial structure is dominated by high-energy-consuming industries, environmental taxes may force companies to reduce production to avoid the tax burden, which in turn leads to a decrease in resource allocation efficiency. This negative correlation will gradually weaken as economies advance in development and policy synergy increases [44]. This conclusion directly undermines the single-minded perception that “green taxation inevitably optimizes resource utilization.”

A more critical controversy arises from scholars who support the “regional heterogeneity theory,” further enriching the debate through cross-national and cross-regional comparative studies. A study comparing the effects of resource taxation in Russia and South Africa found that Russia significantly enhanced its ability to curb regional carbon emissions and indirectly improved resource utilization efficiency through taxes related to natural resource development [45]. However, South Africa’s mineral resource tax policy failed to achieve similar results. Instead, it exacerbated pollution emissions due to the expansion of mineral trade. This suggests that the compatibility of environmental regulation methods with resource endowments directly influences the effectiveness of tax policies in regulating resource utilization. Research in China has shown that when neighboring provinces form a coordinated environmental policy mechanism, green taxation can effectively reduce regional resource dependence. However, if there is a “race to the bottom” policy among provinces, the tax’s effect on optimizing resource utilization is weakened. Furthermore, in the unique context of developing countries, blindly raising green taxes could force vulnerable economies to take on highly polluting industries [46,47].

The above research indicates that the assessment of the effectiveness of green taxation policies must go beyond a single dimension and be placed within a dynamic, spatial and multi-type comprehensive analysis framework. The shortcomings of the existing research lie in:

First, there is a confusion of concepts, with green taxation often being equated with environmental taxation, while the complete policy system including incentives and constraints is overlooked. green tax policies encompass a wider range of topics, extending beyond environmental taxes to include other functional taxes. Existing research has focused primarily on environmental taxes, lacking sufficient exploration of the effects of these other taxes. Most studies confuse the concepts of green tax policies with individual taxes. This study, however, deconstructs the connotations of green tax policies from three perspectives, integrating multiple tax types. From the perspective of the nature of the tax, it analyzes the inherent impacts of different types of green taxes on natural resources, thereby providing a more comprehensive exploration of the intrinsic pathways between green tax policies and natural resources. Second, the perspective is static, with less consideration given to the dynamic lag effects of policies. most studies use static panel models to explore

the relationship between green tax policies and natural resource utilization. However, due to the time lag inherent in these policies, these effects are not immediately apparent. Therefore, dynamic models are more realistic. To this end, this study constructs a system GMM dynamic panel model, comprehensively considering the lag in the effects of green tax policies to make the research more relevant to social reality. Third, the research has a single dimension and lacks systematic examination of the spatial spillover effect, as well as insufficient in-depth discussion on the heterogeneity among different regions in China (such as eastern, central, western, and northeastern regions). This study addresses these research deficiencies. Firstly, starting from the nature of tax types, a comprehensive green tax policy framework including environmental protection type, resource occupation type, and guidance type was constructed; then, using the System GMM and spatial Durbin models, both the dynamic effect and spatial spillover effect of the policy were captured simultaneously; finally, through regional heterogeneity analysis, the complex and diverse effects of green tax policies in different regions of China were revealed, thereby providing evidence from China for the “heterogeneous complex theory”.

3. Theoretical Framework

In the process of market transactions, private traders only focus on how to maximize their profits. For resource-intensive enterprises, this process is usually based on sacrificing social interests, resulting in problems such as excess output and idle resources in society. This phenomenon is also called negative externalities [48]. Green tax policies are environmental policy tools based on Pigouvian externality theory [49]. A Pigovian tax is a regulatory measure used by the government to maximize social welfare at the expense of deadweight losses through tax intervention when negative market externalities cannot be internalized through free negotiation.

A specific green tax policy places the tax cost directly on resource-intensive enterprises. To avoid taxes, enterprises reduce energy-intensive and polluting output and adjust their production practices [50]. However, at this point, as prices are transmitted across the supply chain, costs across the entire production system rise, making it difficult for the industry to operate smoothly [51]. Under tax controls, enterprises can rationally avoid taxes through factor substitution, allowing them to achieve excess output while increasing unit resource output. However, while tax policy controls directly impact private costs, enterprises also need time to absorb the impact of these policies. Large-scale investments by resource-intensive enterprises may result in shutdowns and production reductions for renovations, failing to promote improved natural resource utilization efficiency. Green tax technology innovation and implementation require time.

The Pigovian tax mechanism primarily serves to induce enterprises to make intertemporal green investments. These investments generate path-dependencies in green technology and equipment, physical capital, management experience and knowledge capital, and efficient development trajectories [52]. The fundamental purpose of Pigovian taxes is to correct market failures caused by negative externalities, and environmentally friendly green taxes are a typical application of Pigovian tax externality internalization. Pigou believes that the marginal pollution cost of each pollutant emitted should be levied [53]. When the government levies environmentally friendly green taxes, the private costs for resource-based companies will include both their own costs and the environmental taxes. To maximize profits, companies have a strong economic incentive to invest in pollution treatment facilities. With regard to resource-intensive green taxes, the marginal costs of resource consumption include the costs of resource scarcity, the costs of ecological damage, and the social welfare losses caused by resource waste [54]. From the perspective of tax shifting mechanisms, the ultimate effectiveness of resource-intensive green taxes (RGTs)

may be directly influenced by market structure. In markets with inelastic demand for resource products, companies can shift the tax burden to consumers by raising product prices, thereby weakening the tax's incentive effect. However, if resource-intensive companies find it difficult to fully shift the burden of environmental taxes, this can effectively squeeze profit margins, forcing them to absorb the costs through improved resource efficiency. Secondly, at the level of corporate behavioral responses, RGTs can either guide companies to achieve efficiency gains through technological innovation or force them to relocate high-energy-consuming operations to areas with weaker resource-intensive environmental taxes, offsetting local resource optimization effects by cross-regional resource shifts. Finally, policy linkage is a key factor. If RGT revenue fails to form a closed loop with incentives for green technology innovation, companies may be discouraged from long-term green investment due to increased compliance costs. However, if tax revenue is directed toward technology R&D subsidies or innovation tax credits, it can effectively transform cost constraints into an internal driving force for efficiency improvement. In terms of guiding green taxation, the positive and negative incentives of Pigouvian taxes are fully demonstrated. By providing income tax credits for investments in environmentally friendly equipment and exempting new energy vehicles from purchase tax, these policies compensate for positive externalities in the market and reduce private costs. Conversely, higher consumption taxes are imposed on high-energy-consuming consumer goods, encouraging consumers to purchase fewer of them. Thus, under the intervention of green taxation, both consumer and producer behavior will spontaneously evolve toward the socially desirable green and environmentally friendly direction. Based on the above analysis, the following hypotheses are proposed:

Hypothesis 1. *Green tax policies promote increased natural resource utilization, but previous green tax policies do not.*

Hypothesis 2. *Natural resource utilization in the previous period can promote current utilization.*

Hypothesis 3. *Environmental protection tax policies, resource-intensive tax policies, and guiding tax policies have a positive impact on natural resource utilization.*

The spatial spillover effect of green taxation on natural resource utilization stems from the spatial interaction mechanism of new economic geography. Its essence is the “knowledge spillover” theory of Marshall’s industrial district theory, revealing the phenomenon of economic factor flows breaking through administrative boundary barriers [55]. Whether it is environmental protection, resource occupation or guidance green tax policies, the source of the local green tax policies is the implementation of local green tax policies. Therefore, Pigou tax is the primary driving force for the spatial spillover of green tax policies. However, the adjustment behavior of local enterprises will not be limited to administrative boundaries. The three major paths of Marshall’s knowledge spillover theory can fully explain how the local adjustment behavior caused by Pigou Tax can achieve spatial spillover effect. In terms of industrial linkage and migration, in the face of the province’s higher environmental protection and resource occupation tax costs, resource-dependent enterprises directly choose industries to flow across regions in order to choose low-tax areas, which has also changed the industrial structure of neighboring provinces [56]. In terms of knowledge and technology diffusion, local enterprises have a demonstration effect in order to update technical talents and management experience in response to policy requirements, and are seeking free-ride speculation by neighboring provinces. In terms of learning systems and policies, an effective green tax policy in one province will be regarded as a learning model by other provinces, forming a spillover effect of institutional knowledge, and ultimately affecting the natural resource utilization effect of each province. Therefore, this is not only

a confirmation of the influence of Pigot's space, but also a successful expansion of the application scenarios of Marshall's spillover theory from traditional industrial agglomeration research to the fields of environmental regulation and green development.

Environmentally protective green tax policies are the most direct form of Pigouvian taxes, targeting typical public goods. Environmental governance measures in one province often generate positive externalities, such as improved air quality and cleaner rivers. However, these spillovers limit the incentive for policy spillovers. Neighboring provinces can enjoy the benefits of environmental improvements without incurring governance costs. This is true across regions, so it's not difficult to infer that the overall spillover effects of environmentally protective green tax policies are relatively weak. Resource-intensive green tax policies target natural resources like minerals and land. The internalization of these negative externalities directly alters the market prices of resource-based end products. The eastern and northeastern regions, with their developed economies or strong industrial bases, are at a higher stage of the Environmental Kuznets Curve (EKC). Consequently, resource demand is relatively high. Local green tax regulations can create a significant demand shock, forcing businesses to seek production resources in neighboring provinces, disrupting their equilibrium of low prices and high energy consumption [57]. In contrast, the western region is a resource-exporting region, where improvements in natural resource utilization efficiency rely more heavily on local policies. Its responsiveness to external price signals is relatively weak, resulting in less significant spillover effects. Guidance-based green tax policies can be viewed as soft Pigouvian taxes, incentivizing businesses to adopt green production through tax incentives. Although such green tax policies exhibit Marshallian technology diffusion and institutional learning spillovers, these technological spillovers may not be affected by the EKC stage. Advanced production technologies are always attractive regardless of the stage of neighboring provinces, so the spillover effects of guidance-based green tax policies are likely to be more universal [58]. This study combines this theory with policy intervention, providing theoretical and empirical support for policy-driven EKC inflection points, moving EKC theory from passive observation to active intervention. Based on the above, the following hypotheses are proposed:

Hypothesis 4. *Green tax policies have spatial spillover effects on natural resource utilization.*

Hypothesis 5. *Environmental protection-based tax policies have weak spillover effects, resource-intensive tax policies have stronger spillover effects in the eastern and northeastern regions, and guidance-based tax policies have stronger spillover effects.*

A Pigouvian tax requires the internalization of costs, forcing changes in production behavior. This is the root of all these effects. However, the weak Porter hypothesis argues that environmental regulations can provide end-of-life treatment for businesses, leading them to passively purchase equipment to reduce compliance costs. This type of innovation is often defensive. Strong Porter falsely indicates that environmental regulation can produce fundamental innovations that develop completely clean production tools and can also form innovation compensation, which is called proactive innovation [59]. Trade opening is an amplifier of the green tax environment regulation effect. Trade opening determines whether the innovative achievements of enterprises can form comparative advantages by being amplified by the international market.

In terms of environmental protection green taxation, the emergence of externalities mainly triggers the weak Porter effect, and direct Pigou tax forces enterprises to avoid high taxes through terminal governance. The technical capital formed by this terminal governance is difficult to reduce unit production costs and cannot tradeable goods with comparative advantages [60]. High-intensity environmental protection tax policies provide

enterprises with more alternatives. Neither industrial transfer nor resource outflow can solve the negative externalities, nor can it be improved by promoting trade opening up. In terms of resource-occupying green taxation, increasing resource prices can theoretically guide enterprise process reform and improve resource utilization efficiency, which is also a reflection of the weak Porter theory. However, under the conditions of opening trade, enterprises can directly import cheap primary resources and semi-finished products to replace the resource needs of the region. In order to pursue short and fast tax avoidance effects, enterprises will curb their independent motivation and find it difficult to promote the sustained utilization of natural resources in the region. Inductive green taxation is a concentrated manifestation of the strong Porter hypothesis. This type of green tax policy does not directly penalize negative externalities but instead encourages positive externalities, guiding enterprises to undertake fundamental product and process innovation [61]. Technological improvements directly reduce unit product input costs, creating a comparative advantage over other countries' products in an open trade environment. Furthermore, open trade provides opportunities for enterprises to export their technologies and products, thereby earning excess profits through innovation compensation [62]. This positive incentive strengthens enterprises' innovative investment. Technological innovation is key to improving resource utilization. Trade openness, as a mediating condition for green taxation, provides a path for natural resource utilization. Based on the above, the following hypotheses are proposed:

Hypothesis 6. *Trade openness mediates the impact of inductive green taxation policies on natural resource utilization only. It has no mediating effect on environmental protection green taxation policies or resource-intensive green taxation policies.*

4. Research Design

4.1. Model Specification

4.1.1. Baseline Regression Model

This paper uses interprovincial dynamic panel data to examine how green taxation affects natural resource utilization. The baseline regression model is as follows:

$$\ln NRE_{it} = a + \sum_{j=1}^M \lambda_j \ln NRE_{i,t-j} + \beta_1 \ln GT_{it} + \beta_2 \ln GT_{it-1} + n_1 \ln IS_{it} + n_2 \ln CUIG_{it} + n_3 \ln URB_{it} + n_4 \ln FILR_{it} + u_i + u_t + \varepsilon_{it} \quad (1)$$

where i represents China's 30 provinces, t represents the year, NRE represents the natural resource utilization rate, $NRE_{i,t-j}$ represents the lagged order of the natural resource utilization rate, and M is the maximum lagged order. GT_{it} represents green tax, and GT_{it-1} represents the green tax lagged by one period. where IS , $CUIG$, URB , and $FILR$ are control variables. u_i represents the regional fixed effect, u_t represents the time fixed effect, and ε_{it} represents the disturbance error term.

Model (1) in this study may face two endogeneity problems. The first is the two-way causality. While green tax policies (GT) may affect natural resource utilization (NRE), policymakers in regions with rich or scarce natural resource endowments may also formulate green tax policies of different intensities. That is, there is a possibility that NRE affects GT . Secondly, omitted variable bias. Although we control for a range of variables, there may still be unobservable factors that influence both GT and NRE , such as regional environmental governance commitment and public environmental awareness.

To effectively address this endogeneity issue, this study employs the system GMM estimation method proposed by Blundell and Bond [63]. This method combines level equations and difference equations and uses higher-order lags of the explanatory and

dependent variables as instrumental variables for their current values. For the difference equations used to eliminate individual fixed effects u_i , this study uses level variables, such as GT_{it-1} and earlier lags, as instrumental variables for the difference variable ΔGT_{it-1} . For the level equations, we use first-order differences in variables, such as ΔGT_{it-1} , as instrumental variables for the level variable GT_{it-1} . Thus, the system GMM effectively handles dynamic panel models and potential endogeneity issues of explanatory variables.

4.1.2. Continuous DID Model for Different Tax Types

China first systematically proposed a green tax policy in an official policy document in September 2015, marked by the release of the “Overall Plan for Ecological Civilization System Reform” (hereinafter referred to as the “Plan”) by the Central Committee of the Communist Party of China and the State Council. Although this is the first systematic proposal, many taxes under the green tax system, such as resource tax, farmland occupation tax, and vehicle and vessel tax, were levied before 2015. Therefore, this study uses 2015 as the time point for exogenous policies and adopts a quasi-natural experiment strategy for identification. However, given that the Plan is a national policy, it’s not possible to simply construct a control and experimental group based on whether or not a province received a policy shock. Furthermore, the initial conditions for implementing green tax policies vary across provinces, making it impossible to categorize provinces into experimental and control groups based on whether or not they were impacted. To further explore the effectiveness of green tax policy implementation, this study divides green tax policies into three tiers: environmental protection tax (*ENT*); resource-based green tax (*RGT*), consisting of resource tax, urban land use tax, and cultivated land occupation tax; and inductive green tax (*IGT*), consisting of value-added tax (for specific industries or products), corporate income tax (preferential policies), vehicle and vessel tax, deed tax (for specific uses), urban maintenance and construction tax, and consumption tax. Based on this, this study adopts a continuous difference-in-differences approach, treating categorized tax revenue as a continuous variable to reflect the impact of green tax policies on each region. The following model is constructed:

$$\ln NRE_{it} = a_0 + a_1 Nid_{sj,it} + a_2 Control_{it} + u_i + \gamma_t + \varepsilon_{it}, j = 1, 2, 3 \quad (2)$$

In the above formula, when $j = 1, 2$, and 3 , Nid_{s1} , Nid_{s2} , and Nid_{s3} , respectively, represent the green tax policy dummy variables ($ENT_{it} \times Post_{it}$, $ENT_{it} \times Post_{it}$, $ENT_{it} \times Post_{it}$); $Post_{it}$ represents the policy time point dummy variable; $Controls_{it}$ represents the control variable; u_i and γ_t represent the province fixed effect and the time fixed effect, respectively; and ε_{it} represents the random error term.

4.1.3. Spatial Spillover Effect Model

This paper uses the spatial Durbin model to explore the spillover effect of green taxation on natural resource utilization through LM and LR tests. The model is as follows:

$$\begin{aligned} \ln NRE_{it} = & a_0 + \rho \omega_{it} \ln NRE_{it} + a_1 \ln GT_{it} \\ & + \sum \beta_j Control_{it} + \delta_j \omega_{it} Control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \end{aligned} \quad (3)$$

To further explore the role of green taxation, this study explores its impact in the eastern, central, western, and northeastern regions from three levels: environmental protection tax, resource-based green tax, and guiding green tax:

$$\ln NRE_{it} = a_0 + \rho \omega_{it} \ln NRE_{it} + a_1 \ln X_{it} + \sum \beta_j Control_{it} + \delta_j \omega_{it} Control_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (4)$$

$$\ln NRE_{rit} = a_0 + \rho_{rit} \omega_{rit} \ln NRE_{rit} + \sum_{k=1}^k \beta_{r,k} X_{r,k,rit} + \gamma_r Z_{rit} + \varepsilon_{rit} \quad (5)$$

In Formulas (4) and (5), X contains ENT , RGT , and IGT ; r corresponds to the eastern, central, western, and northwestern regions, respectively; w is the spatial weight matrix; and ρ_r is the spatial spillover effect coefficient of region r . $X_{r,k}$ is the k th core explanatory variable of region r (e.g., environmental protection tax, resource-based green tax, and inductive green tax). Z_r is the set of control variables for region r , while $\beta_{r,k}$ and γ_r are the regression coefficients of the explanatory and control variables, respectively.

4.1.4. Mediation Effect

Based on the above theoretical analysis, this study constructs a mediation effect model of trade openness to explore the deep-seated pathways through which environmental protection tax, resource-based green tax, and inductive green tax affect natural resources:

$$\begin{aligned} \ln NRE_{it} &= a_0 + \beta_1 \ln M_{it} + \beta_2 \text{Control}_{it} + u_i + \varepsilon_{it} \\ \ln TDC_{it} &= b_0 + \gamma_1 \ln M_{it} + \gamma_2 \text{Control}_{it} + u_i + \varepsilon_{it} \\ \ln NRE_{it} &= c_0 + \rho_1 \ln M_{it} + \rho_2 \ln TDC_{it} + \rho_3 \text{Control}_{it} + u_i + \varepsilon_{it} \end{aligned} \quad (6)$$

In Formula (6), TDC represents trade openness; M includes ENT , RGT , and IGT ; β , γ , and ρ are the coefficients of the core explanatory variables; u_i represents the province fixed effect; and ε_{it} represents the random error term.

4.2. Explanation of Variables

4.2.1. Explained Variables

This study uses the natural resource utilization efficiency (NRE) model developed by Chen Xun to measure changes in natural resources. Due to the different evaluation objectives and regional scopes of resource utilization efficiency, the selected evaluation indicator system also differs [64]. This study comprehensively considers the ratio of each province's GDP to seven indicators: energy consumption, total fixed asset investment, water consumption, construction land area, industrial waste gas emissions, industrial wastewater emissions, and industrial solid waste generation. These indicators represent the economic and ecological benefits of energy, mineral resources, water, and land resources in each region, respectively. The weights of each indicator were determined using principal component analysis.

4.2.2. Explanatory Variables

This study constructs a green tax index system to measure the green tax level in 30 provinces. By drawing on the construction methods of existing studies and combining them with the above-mentioned mechanism analysis, a green tax evaluation index system was constructed, encompassing 10 secondary green tax indicators: environmental protection tax, resource tax, farmland occupation tax, urban maintenance and construction tax, urban land use tax, vehicle and vessel tax, value-added tax, deed tax, corporate income tax, and consumption tax [65]. To scientifically determine the weights of each indicator and synthesize the comprehensive index, this study uses the entropy-weighted TOPSIS model for (In order to eliminate the dimensional influence, first perform standardization processing on the original indicator data. For positive indicators, use Formula (1) to process; for negative indicators, use Formula (2) to process. $Y_{ij} = \frac{X_{ij} - \text{Min}X_{ij}}{\text{Max}X_{ij} - \text{Min}X_{ij}}$ (1) $Y_{ij} = \frac{\text{Max}X_{ij} - X_{ij}}{\text{Max}X_{ij} - \text{Min}X_{ij}}$ (2). Among them, X_{ij} is the original value of the j -th indicator in the Y_{ij} i -th province, is the standardized $\text{Max}X_{ij}$ value, $\text{Min}X_{ij}$ and are the maximum and minimum values of the j -th indicator, respectively. Secondly, the

entropy weight method is used to calculate the indicator weight: Calculate the proportion of the i -th province under the j -th P_{ij} indicator: $P_{ij} = Y_{ij} / \sum_{i=1}^m Y_{ij}$. Calculate the entropy value of the e_j j -th $e_j = -\frac{1}{\ln m} \sum_{i=1}^m P_{ij} \ln P_{ij}$ (if $P_{ij} = 0$, else $\lim_{p \rightarrow 0} p \ln p = 0$) indicator: Calculate the difference coefficient of the j -th g_j indicator: $g_j = 1 - e_j$. The smaller the entropy value, the larger the difference coefficient, indicating that the indicator provides more information and the greater the weight. Calculate W_j weight: $W_j = g_j / \sum_{j=1}^n g_j$. Finally, calculate the comprehensive index based on the TOPSIS method: construct a weighted $Z = (z_{ij})_{m \times n}$ normative. $z_{ij} = W_j \times Y_{ij}$ matrix, where determine the positive Z^+ and negative Z^- ideal solutions. That $Z^+ = (z_1^+, z_2^+, \dots, z_n^+) = (\max z_{i1}, \max z_{i2}, \dots, \max z_{in})$ is, $Z^- = (z_1^-, z_2^-, \dots, z_n^-) = (\min z_{i1}, \min z_{i2}, \dots, \min z_{in})$. Calculate the sum of the distances between each evaluation object and the positive and negative D_i^+ ideal D_i^- solutions: $D_i^+ = \sqrt{\sum_{j=1}^n (z_{ij} - z_j^+)^2}$, $D_i^- = \sqrt{\sum_{j=1}^n (z_{ij} - z_j^-)^2}$. Calculate the relative closeness of each evaluation target to the optimal C_i solution, i.e., the final comprehensive green tax index (GT), where $C_i = D_i^- / (D_i^+ + D_i^-)$. The value range is $[0, 1]$; the closer the value is to 1, the higher the green tax level of the province.) The resulting Green Tax Index (GT) ranges between 0 and 1, with larger values indicating a higher level of green taxation in the province. Similarly, based on the above research in this study, green taxation is divided into three levels: environmental protection green tax, resource occupation green tax and guidance green tax, and the environmental protection green tax index (ENT), resource occupation green tax index (RGT) and guidance green tax index (IGT) are constructed, respectively.

4.2.3. Mediating Variable

This study uses trade openness as a mediating variable. Drawing on existing literature, we use the trade dependence of each province (autonomous region, or municipality) as a measure [66], namely, the proportion of total import and export trade to GDP during the same period.

4.2.4. Control Variables

Income inequality may affect natural resource utilization through consumption structure and resource demand, as shown in Table 1 below. Research indicates that income inequality is positively correlated with deforestation and water consumption [67], necessitating the independent impact of income inequality on natural resources. The relationship between financial development and resources and the environment has been widely discussed in studies of the Environmental Kuznets Curve [68]. Controlling for the loan rates of financial institutions can isolate the impact of financial policies on resource utilization. Industrial structure is one of the core control variables in environmental economics research [69]. When analyzing the relationship between trade and the environment, it is especially important to eliminate the interference of industrial structure. The inverted U-shaped relationship between urbanization and carbon emissions and resource consumption has been widely verified [70]. Controlling for urbanization levels can avoid confounding the relationship between green taxation and resources. Based on this, the control variables selected for this study include the urban–rural income gap, the loan rates of financial institutions, the social industrial structure, and the urbanization level.

Table 1. Variable Names and Calculations.

Variable Symbols		Describe	Calculation Formula
Explained variable	<i>NRE</i>	Natural resource utilization efficiency	Evaluation indicators of natural resource utilization efficiency
	<i>GT</i>	Green tax policy	Green Tax Index
Explanatory variables	<i>ENT</i>	Environmental protection green taxation	Environmental Protection Green Tax Index
	<i>RGT</i>	Resource-intensive green taxation	Resource-intensive green tax index
	<i>IGT</i>	Guiding green taxation	Guiding Green Tax Index
Mediating variables	<i>TDC</i>	Trade Dependence	The proportion of total import and export trade to GDP in the same period
	<i>IS</i>	Industrial Structure	Value added of the tertiary industry\value added of the secondary industry
Control variables	<i>FILR</i>	Loans from financial institutions	Financial institutions' loan balances in RMB and foreign currencies\GDP
	<i>CUIG</i>	Urban–rural income gap	Per capita disposable income of urban residents\Per capita disposable income of rural residents
	<i>URB</i>	Urbanization level	Urban permanent population\permanent population

4.3. Data Sources

All tax data related to green taxation in this study are sourced from the China Tax Yearbook, which was edited and published by China Taxation Press from 2011 to 2023, focusing on total tax revenue, structure, and tax types. Natural resource utilization data are derived from two sources: first, the environment and resources chapter of the China Statistical Yearbook, compiled by the National Bureau of Statistics of the People's Republic of China from 2011 to 2023. The chapter numbers vary slightly between years. Second, the solid waste, natural ecology, and environmental investment chapters of the China Environmental Statistical Yearbook, jointly edited by the National Bureau of Statistics and the Ministry of Ecology and Environment. The chapter numbers vary slightly between years. Missing data are supplemented by searching for missing data in the corresponding provincial statistical yearbooks. The control variable, industrial structure, is derived from the regional GDP accounting section of the China Statistical Yearbook from 2011 to 2023. The level of financial development is derived from the China Financial Yearbook published by the People's Bank of China and financial data released by provincial branches. Data on urban and rural residents' income and social consumption levels are sourced from the chapters on people's livelihood and national economic accounting in the China Statistical Yearbook. Population data related to urbanization levels are sourced from the 2011–2023 China Population and Employment Statistical Yearbook published by China Statistics Press and provincial statistical yearbooks. In addition, to eliminate dimensionality effects and mitigate potential heteroskedasticity, core continuous variables such as green tax revenue, natural resource utilization efficiency, and trade openness were logarithmized. For small amounts of missing annual data for individual provinces, this study used linear interpolation to fill in the gaps. In addition, all the empirical content in this paper was completed using the Stata 16.0 software. Descriptive statistical analysis is shown in Table 2.

Table 2. Descriptive Analysis.

Variable	Mean	sd	Min	Max
<i>NRE</i>	1.0334	0.7856	0.2304	7.1314
<i>GT</i>	0.1666	0.1209	0.0043	0.5937
<i>ENT</i>	0.2850	0.1620	0.0035	0.3150
<i>RGT</i>	0.3520	0.3380	0.0012	0.2080
<i>IGT</i>	0.4430	0.2310	0.0008	0.1750
<i>TDC</i>	0.2655	0.2871	0.0076	1.5482
<i>IS</i>	1.3536	0.7450	0.5271	5.2829
<i>FILR</i>	1.5105	0.4428	0.6706	2.7741
<i>CUIG</i>	2.5468	0.3789	1.8266	3.6716
<i>URB</i>	0.6012	0.1206	0.3504	0.8958

As shown in the table above, the mean *NRE* is 1.0334, but its standard deviation reaches 0.7856, with a wide range of extreme values. This indicates significant differences in resource utilization across regions, potentially indicating uneven resource endowments or uneven utilization efficiency. The mean *GT* is only 0.1666, with a standard deviation of 0.1209. Combined with the extremely low values, this reflects the overall weak implementation of green tax policies, with some regions even approaching non-existence, indicating significant deficiencies in policy coverage and effectiveness. The low mean *TDC* is 0.2655, with a standard deviation of 0.2871 and a wide range of extreme values. This highlights the polarization of regional trade openness, with a few regions showing high levels of openness, while most remain at relatively low levels. Among the other variables, *IS* and *FILR* show some fluctuation or variation, but the overall dispersion is relatively manageable. Overall, the dispersion characteristics and numerical levels of key variables reveal imbalances and room for development in resource utilization, policy implementation, and trade openness, providing intuitive data clues for future research.

5. Results and Discussion

5.1. Baseline Regression Results

As shown in Table 3, this section uses fixed-effects and system GMM methods to explore the causal relationship between green tax policies and natural resource utilization. In model (1), the green tax index coefficient is 0.283, which is significantly positive at the 1% level, indicating that the current green tax policy directly improves the current natural resource utilization rate, which is consistent with the Pigouvian tax correction of negative externalities and scale economy mechanism presented in the theoretical analysis. In model (2), its coefficient is 0.198, which is significantly positive at the 1% level, but the lagged green tax coefficient is not significant. The realization of the Pigouvian tax governance effect requires providing time guarantees for enterprises. Although the reduction in private and social costs provides a shortcut to expanding the government's Pigouvian tax revenue, technological changes require a cross-cycle process, and the adjustment of resource use and management experience requires continuous learning, which leads to the existence of time lag in green tax policies. Therefore, Hypothesis 1 is confirmed. In model (3), its coefficient is significantly positive at the 5% level, and the lagged green tax coefficient is significantly negative at the 1% level. This study further examines the effectiveness and robustness of the evaluation model. The Arellano-Bond autocorrelation test shows that the error term after first-order difference has a first-order autocorrelation of $AR(1) = 0.001$, while the second-order autocorrelation test is insignificant, $AR(2) = 0.458$, indicating that the model setting is reasonable and there is no serious serial correlation problem. In terms of over-identification test, the *p*-value of the Sargan test is 0.101, which fails to reject the null

hypothesis that “all instrumental variables are exogenous”, indicating that the instrumental variables are generally effective; the p -value of the Hansen test is 1.000, which does not reject the null hypothesis, but due to the large number of instrumental variables, its test power may be weakened. To this end, this study also conducted a Difference-in-Hansen test, and the results showed that the exogeneity of the instrumental variable subset was not rejected ($p = 0.372$), further supporting the rationality of the instrumental variables. In summary, the system GMM model is effective in controlling endogeneity and dynamic bias, and the estimation results have a good statistical basis. In addition, we use robust standard errors in the regression to control heteroskedasticity, further enhancing the reliability of the results. Except for the lagged natural resource utilization rate, which is 1.125, indicating that the previous period’s natural resource utilization rate has a strong inertia effect on the current periods. The current green tax policy is designed to correct negative externalities and encourage enterprises to use resources more efficiently. However, to reduce private production costs, enterprises need to adjust their production scale. Short-term changes in the capital-labor ratio will have a certain inhibitory effect on their production activities. In other words, natural resource utilization is subject to dynamic changes during the policy pulse process. Hypothesis 2 is confirmed. Overall, green taxation has a strong positive effect on natural resource utilization efficiency, but the lagged terms vary across models, reflecting the varying duration of the green policy’s effects.

Table 3. Baseline regression results of green tax policy on natural resource utilization.

	(1)	(2)	(3)
	FE Without Lag Term	FE with Lag Term	GMM
<i>GT</i>	0.283 *** (0.056)	0.198 *** (0.068)	0.230 *** (0.094)
<i>L.GT</i>		−0.077 (0.068)	−0.233 *** (0.085)
<i>L.NRE</i>		0.911 *** (0.062)	1.125 *** (0.092)
<i>L2. NRE</i>		−0.107 (0.065)	−0.091 (0.061)
<i>IS</i>	0.363 *** (0.082)	−0.056 (0.068)	0.023 (0.068)
<i>CUIG</i>	0.002 (0.131)	−0.088 (0.090)	0.019 (0.024)
<i>URB</i>	−1.211 ** (0.564)	−0.489 (0.440)	0.065 (0.189)
<i>FILR</i>	−0.163 ** (0.072)	0.039 (0.052)	−0.032 (0.023)
<i>cons</i>	1.312 ** (0.620)	0.695 (0.473)	−0.038 (0.098)
AR (1)			0.001
AR (2)			0.458
Sargan test			0.101
Hansen test			1.000
Difference-in-Hansen test			0.372

Note: ** $p < 0.05$; *** $p < 0.01$.

5.2. Continuous DID by Tax Type

To ensure the reliability of the continuous difference-in-difference model estimation results, we first conducted a parallel trend test for the three types of green tax policies. The results are shown in Figure 2 (environmental protection), Figure 3 (guidance), and Figure 4 (resource occupation). The parallel trend hypothesis requires that before the policy

shock, the development trends of natural resource utilization efficiency in provinces with different treatment intensities should not show systematic differences. In other words, the estimated coefficients in each period before the policy shock should not be statistically significantly different from zero. The test results show that all three types of green tax policies generally meet the parallel trend hypothesis. Specifically, for environmental protection green taxes (*ENT*), the confidence intervals for the coefficients in each period before policy implementation (pre4 to pre1) all include zero, and the estimated values fluctuate slightly around zero. This indicates that before the 2015 policy was introduced, regions with different environmental protection tax intensities had comparable trends in natural resource utilization efficiency. For the inductive (*IGT*) and resource-requiring green taxes (*RGT*), although some of the pre-policy point estimates deviate slightly, their 95% confidence intervals cover zero throughout the entire pre-policy period, indicating that these deviations are not statistically significant, and therefore the parallel trend hypothesis remains valid.

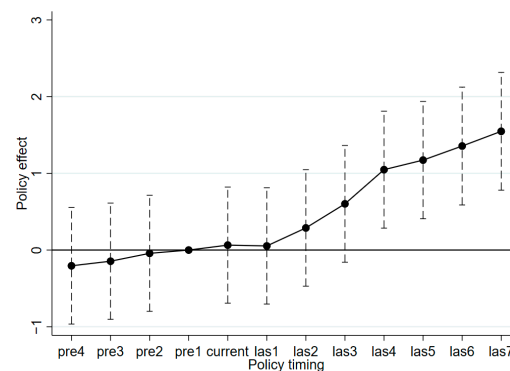


Figure 2. *ENT* Parallel Trend Test.

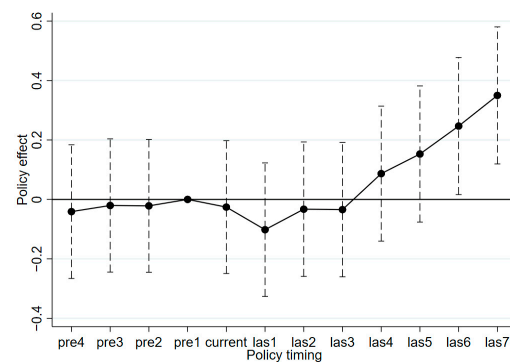


Figure 3. *RGT* Parallel Trend Test.

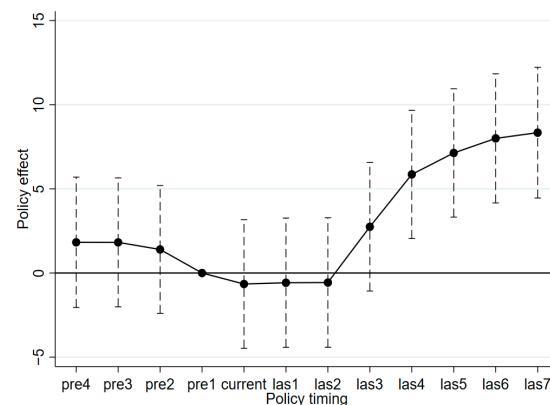


Figure 4. *IGT* Parallel Trend Test.

To further explore the relationship between different types of green tax policies—environmentally protective, resource-requiring, and inductive—and natural resource utilization, this study uses the continuous DID method and constructs an intensity variable to further analyze the causal relationship between green tax policies and natural resource utilization. As shown in the model in Table 4 below, the *ENT* coefficient is 0.80 and significantly greater than zero, indicating that the implementation of green tax policies has significantly increased the level of natural resource utilization. As a direct application of Pigouvian tax theory, environmentally protective green tax policies can directly change private costs for enterprises, guiding them toward social costs, achieving a balance between marginal social benefits and marginal social costs, and ultimately promoting enterprises to improve the efficiency of natural resource utilization. The *RGT* coefficient is 0.075 and is not significant, indicating that resource-intensive green tax policies have not effectively promoted the improvement of natural resource utilization efficiency at the current stage. From the perspective of tax shifting mechanisms, demand for resource products such as minerals and energy is often inelastic. When *RGT* increases resource usage costs, companies tend to pass the tax burden on to downstream consumers or end markets by raising product prices. This directly undermines the “Pigouvian tax” function of *RGT*, which is intended to incentivize companies to improve resource efficiency by internalizing costs. At the level of corporate behavioral responses, empirical results show that resource-based companies are more inclined to adjust their factor input structure through short-term measures such as industrial relocation and cost reduction and efficiency improvement, shifting high-energy-consuming operations to regions with lower green tax intensity, rather than engaging in long-term green technology innovation. The lack of a policy linkage mechanism further weakens the effectiveness of *RGT*. If *RGT* revenue fails to form a closed loop with incentive policies such as green technology R&D subsidies and innovation tax credits, companies will only face increased compliance costs and lack the internal motivation to transform and upgrade. However, the *IGT* coefficient is significant at 2.981. Guiding green taxation fully demonstrates the dual incentive and constraint effects of Pigouvian taxes. Tax and investment incentives encourage businesses to upgrade capital factors, compensating for positive externalities. Advanced development equipment can reduce unit labor time and increase unit output. Thus, Hypothesis 3 is not fully supported. *ENT* has a “constraint and forcing” effect, *IGT* has an “incentive and guiding” effect, and *RGT* cannot promote the utilization of natural resources.

Table 4. Continuous DID Results of Categorized Green Tax Policies on Natural Resource Utilization.

	(1) <i>ENT</i>	(2) <i>RGT</i>	(3) <i>IGT</i>
did	0.802 *** (0.181)	0.075 (0.056)	2.981 *** (0.959)
<i>IS</i>	0.241 *** (0.093)	0.263 *** (0.098)	0.183 * (0.096)
<i>FILR</i>	−0.325 *** (0.070)	−0.368 *** (0.071)	−0.300 *** (0.074)
<i>CUIG</i>	0.845 *** (0.160)	0.705 *** (0.162)	0.608 *** (0.164)
<i>URB</i>	−0.984 * (0.550)	−1.427 ** (0.596)	−1.663 *** (0.579)
cons	−1.655 *** (0.614)	−0.984 (0.634)	−0.678 (0.632)
N	360	360	360

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

To further verify the robustness of the continuous DID results and eliminate the influence of unobservable factors or randomness on the conclusions, this study conducted a placebo test. Specifically, we created three fictitious policy periods in 2012, 2011, and 2010 and reran the continuous DID model based on these fictitious policy periods.

The test results are shown in Table 5. When the policy impact of the environmental protection green tax (*ENT*) is fictitiously set to 2012 (*did_{ENT}*), the policy impact of the resource-based green tax (*RGT*) is fictitiously set to 2011 (*did_{RGT}*), and the policy impact of the inductive green tax (*IGT*) is fictitiously set to 2010 (*did_{IGT}*). The estimated coefficients of the core explanatory variables all become very small and statistically insignificant, with coefficients of 0.105, 0.098, and -0.244 , respectively. For the environmental protection tax (*ENT*) and inductive green tax (*IGT*), placebo tests show that they significantly promote natural resource utilization only at the actual policy time point of 2015. The effect disappears at the fictitious policy time point, strongly confirming the policy effectiveness of *ENT* and *IGT*. For the resource-based green tax (*RGT*), the main regression finds its coefficient is insignificant, indicating that the policy has failed to effectively improve natural resource utilization. A placebo test confirms that the coefficient on *RGT* is insignificant even at the fictitious policy time point. This suggests that the ineffectiveness of the main regression results for resource-intensive green tax policies is not accidental but a robust empirical fact. This eliminates the possibility that the conclusions in this section are due to accidental model specification, thereby confirming the robustness of the continuous DID main regression's conclusion that the *RGT* policy has a limited effect.

Table 5. Continuous DID Placebo Test Results of the Categorized Green Tax Policy on Natural Resource Utilization.

	(1)	(2)	(3)
<i>did_{ENT}</i>	0.105 (0.091)		
<i>did_{RGT}</i>		0.098 (0.151)	
<i>did_{IGT}</i>			-0.244 (0.269)
<i>IS</i>	0.238 ** (0.096)	0.267 *** (0.097)	0.250 ** (0.097)
<i>FILR</i>	-0.388 *** (0.071)	-0.367 *** (0.071)	-0.380 *** (0.071)
<i>CUIG</i>	0.707 *** (0.162)	0.674 *** (0.163)	0.711 *** (0.162)
<i>URB</i>	-1.016 * (0.580)	-0.926 (0.576)	-1.190 ** (0.565)
N	360	360	360

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

5.3. Spatial Spillover Effects

Before constructing the spatial econometric model, this study conducted Lagrange, likelihood ratio, and Hausman tests. The results are summarized in Table 6. The test results show that the LM statistics for both the spatial error model and the spatial lag model are highly significant at the 1% level. This result rejects the null hypothesis of the absence of both spatial error correlation and spatial lag correlation, indicating that spatial effects do exist. More importantly, the robust LM test is also highly significant, suggesting that the spatial Durbin model (SDM) may be the most appropriate specification. This model includes spatial lags of both the explained variable (*NRE*) and the explanatory variable (*GT*), allowing it to capture more complex spatial influence paths. To ultimately confirm the

applicability of the SDM, this study conducted a likelihood ratio test to examine whether the SDM could potentially degenerate into an SLM or SEM. The LR test results all returned p -values of 0.000, strongly rejecting the null hypothesis of model degeneration. This means that forcibly using an SLM or SEM would result in model specification errors, leading to biased estimation results. In summary, both the LM test and the LR test point to the same conclusion: the spatial Durbin model (SDM) is the optimal choice for this study. Combined with the results of the Hausman test (p significantly less than 0.01), this suggests that a fixed-effect model is appropriate. Therefore, this study chose a fixed-effects spatial Durbin model to explore the direct effects and spatial spillover effects of green tax policies, ensuring the accuracy and reliability of the estimation results.

Table 6. Spillover Effect Results of Green Tax Policy.

	(1) Main	(2) Wx	(3) Spatial	(5) Direct	(6) Indirect	(7) Total
<i>GT</i>	0.216 *** (9.91)	0.123 *** (2.65)		0.255 *** (9.95)	0.458 *** (5.17)	0.714 *** (6.65)
<i>IS</i>	0.539 *** (12.32)	0.035 (0.34)		0.587 *** (13.01)	0.612 *** (2.75)	1.199 *** (4.75)
<i>FILR</i>	−0.082 (−1.57)	−0.019 (−0.21)		−0.121 (−1.30)	−0.208 (−0.62)	(−0.86)
<i>CUIG</i>	0.075 (1.46)	−0.041 (−0.42)		0.077 (1.14)	−0.014 (−0.07)	0.063 (0.24)
<i>URB</i>	−1.901 *** (9.50)	−1.301 *** (−2.81)		−0.581 (6.55)	1.237 (−0.61)	(1.08)
overflow effect (ρ)			0.520 *** (9.38)			
Observations	360	360	360	360	360	360
R-squared	0.597	0.597	0.597	0.597	0.597	0.597
LM Test	Spatial Error	0.000		0.0002		
	Spatial Lag:	0.000	LR Test	0.0000		
Robust LM Test	Spatial Error	0.000				
	Spatial Lag:	0.021	Husman	0.0000		

Notes: *** $p < 0.01$.

Table 6 shows that green tax policies have spatial spillover effects on natural resource utilization. The direct, indirect, and total effects of green tax policies are all positive and significant. The indirect effect is greater than the direct effect, and the significance of the direct effect indicates that the Pigouvian tax of green tax policies directly changes the cost–benefit structure of resource-based enterprises. Maintaining existing marginal returns requires technological growth, and technological change drives improvements in natural resource utilization. The indirect effect surpassing the direct effect is a concentrated manifestation of Marshall’s theory of knowledge and technology diffusion and institutional learning. Industrial technological advancements in a province have a demonstration effect on neighboring provinces. These provinces can provide incentives for industrial relocation, technology replication, and policy learning to improve natural resource utilization, ultimately allowing the indirect effect of green taxation to surpass the local direct effect. The ρ value indicates that natural resource utilization among adjacent provinces is strongly spatially connected. Policy effects can be transmitted through geographical or economic connections. Therefore, it is not difficult to see that green tax policies have spatial spillover characteristics, confirming Hypothesis 4.

Table 7 shows that different types of green taxes have significant impacts on natural resource utilization and all exhibit significant spatial spillover effects. The weak spillover

effect of *ENT* confirms the “free-rider” effect brought about by its public good nature: while environmental governance investments by a province can improve regional environmental quality, neighboring provinces can share the benefits without paying for governance costs, which in turn weakens their inherent motivation to proactively improve resource efficiency, resulting in limited direct spillover effects. *RGT* also has strong spatial spillover effects. Higher resource taxes in a province trigger a surge in resource demand and price fluctuations in neighboring provinces. Industrial linkage and migration under Marshallian knowledge spillovers force neighboring provinces to break through the “low-price, high-energy consumption” equilibrium. Furthermore, due to regional differences in resource endowments and technological absorptive capacity, the central and western regions have higher resource carrying capacity but weaker intensive technologies, and weaker institutional and policy learning capabilities. This main effect is offset by regional heterogeneity. The spillover effects of *IGT* are attributed to the knowledge diffusion and policy learning of Marshallian knowledge spillovers. When economically developed regions form green industry clusters through tax incentives, neighboring provinces can not only attract industrial relocation by imitating these preferential policies, but also leverage technological spillovers to reduce the costs of green innovation. This “incentive compatibility” mechanism allows guiding policies to not only improve efficiency in their own provinces but also significantly drive efficiency improvements in neighboring provinces through factor mobility and institutional learning. Overall, *ENT* has a stronger local effect, while *IGT* exerts greater cross-regional synergy. Therefore, policy design should be tailored to the characteristics of different tax types.

Table 7. Spillover Effect Results of Green Tax Policies by Region.

	1	2	3
<i>ENT</i>	0.122 *** (5.72)		
<i>RGT</i>		0.269 * (1.77)	
<i>IGT</i>			0.772 *** (8.51)
<i>FILR</i>	0.517 *** (11.33)	0.529 *** (10.79)	0.517 *** (11.33)
<i>CUIG</i>	−0.292 * (−4.96)	0.326 *** (−6.35)	−0.248 *** (−5.27)
<i>URB</i>	0.341 ** (2.37)	0.072 (1.27)	0.059 (1.10)
<i>IS</i>	−0.141 (−0.26)	2.411 *** (11.37)	1.984 *** (9.60)
overflow effect (ρ)	0.344 *** (5.48)	0.584 *** (11.80)	0.486 *** (8.03)
sigma2_e	0.012 *** (13.24)	0.053 *** (12.92)	0.046 *** (13.04)
Observations	360	360	360
R2	0.329	0.683	0.646
Number of ID	30	30	30

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

As shown in the regional regressions in Table 8, green tax policies have strong spatial spillover effects, with heterogeneous differences in direction and intensity. In the eastern region, the local effect of *RGT* is the largest, reaching 0.813. However, the lack of spatial spillovers confirms that while high resource taxes in the eastern region force local enterprises to reduce their resource dependence, neighboring provinces, with their greater

emphasis on information-based services, have mitigated resource demand shocks. Given the high degree of economic integration in the eastern region, it is possible that policy competition within the region offsets the cross-regional spillovers from green taxes. The weak positive effect of *ENT* reflects the Pigouvian tax's effectiveness in addressing local negative externalities, but it is unlikely to trigger Marshallese knowledge spillovers, thus lacking spillover effects. In addition, *IGT* exhibits a significant negative spillover of -1.116 . While green tax policies can generate positive incentives in the eastern region, tax incentives can also easily create barriers to green technology. When neighboring provinces blindly imitate the policy's effects, they suffer from "policy hollowing out" due to a lack of supporting factors such as skilled workers and supply chains. This leads to policy distortions that drive up production costs and reduce the efficiency of natural resource utilization. Environmental protection taxes (*ENT*) have insignificant spillover effects. Based on the public goods theory of pure Pigovian taxes, *ENT* internalizes costs to address local pollution, and the resulting environmental benefits are typically non-excludable and non-rivalrous. The positive externalities created by strengthening environmental governance in one eastern province are quickly "free-ridden" by neighboring provinces, weakening the urgency for neighboring provincial governments to proactively learn from or strengthen their local *ENT* policies, thereby hindering the spillover of *ENT* policy knowledge. The lack of significant spillover effects from resource-based taxes (*RGT*) is closely related to the upgrading of the eastern region's industrial structure after crossing the inflection point of the Environmental Kuznets Curve. Faced with rising tax costs, local enterprises are more inclined to respond through technological upgrades and industrial restructuring rather than relocating high-energy-consuming industries to surrounding areas. This weakens the "industrial linkage and migration" path in Marshall's spillover theory in the eastern region.

Table 8. Regional Spillover Effect Results of Green Taxes by Region.

	Eastern Region			Central Region			Western Region			Northeastern Region		
	1	2	3	1	2	3	1	2	3	1	2	3
<i>ENT</i>	0.008 *** (3.10)			0.016 *** (2.91)			0.044 *** (4.51)			−0.069 ** (−3.94)		
<i>RGT</i>		0.813 *** (3.24)			0.025 (0.13)			3.478 *** (−8.63)			−0.481 * (−1.75)	
<i>IGT</i>			0.049 (0.44)			−2.119 * (−1.81)			2.737 *** (3.02)			5.477 ** (2.12)
<i>Controls</i>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Overflow Effect (ρ)	0.084 (0.67)	0.002 (0.02)	−1.116 *** (−7.85)	−0.513 * (−1.9)	−0.444 * (−1.65)	−0.592 ** (−2.27)	−0.063 (−0.29)	0.130 (0.61)	0.445 *** (3.61)	−0.741 *** (−4.24)	0.400 *** (3.29)	0.307 ** (2.32)
sigma2_e	0.006 *** (7.74)	0.007 *** (7.75)	0.003 *** (7.28)	0.003 *** (5.71)	0.004 *** (5.80)	0.002 *** (5.71)	0.006 *** (8.12)	0.045 *** (8.14)	0.011 *** (8.00)	0.001 *** (4.06)	0.006 *** (4.07)	0.008 *** (4.14)
Observations	120	120	120	72	72	72	132	132	132	36	36	36
R2	0.53	0.556	0.619	0.22	0.321	0.363	0.001	0.066	0.218	0.065	0.318	0.53
Number of ID	10	10	10	6	6	6	11	11	11	3	3	3

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

In the central region, inductive green taxes (*IGT*) exhibit extremely negative spatial spillover effects. Based on the weak Porter hypothesis and the pollution haven theory, when central provinces promote local industrial upgrading through *IGT* tools such as value-added tax exemptions and corporate income tax incentives, high-energy-consuming enterprises struggle to achieve compliant production through technological transformation due to the lack of a comprehensive green industrial chain within the region. At this point, companies are more inclined to follow the passive tax avoidance approach of the weak Porter hypothesis, shifting highly polluting production capacity to neighboring provinces with looser environmental regulations and lower green tax intensity, turning these regions into "pollution havens." This industrial relocation directly expands the pollution stage of the Environmental Kuznets Curve (EKC), ultimately resulting in negative spatial

spillovers from the *IGT* policy. Further examining the spillover results of environmental green taxes (*ENT*) and resource-based green taxes (*RGT*), both also exhibit significant negative spatial spillovers. On the one hand, *ENT* in central China forces businesses to internalize environmental costs by directly levying pollution taxes. However, due to the region's still-dominant heavy industry structure, businesses lack the funding and technical reserves for green technology innovation, forcing them to relocate polluting equipment and production capacity outside the province. On the other hand, *RGT* constrains corporate resource consumption by increasing resource extraction and occupation costs. However, as important national energy and raw material supply bases, resource-based businesses in central provinces face the dual pressures of maintaining production and reducing costs. Consequently, they are more inclined to relocate high-energy-consuming extraction processes to neighboring provinces with lower resource tax standards, resulting in excessive depletion of natural resource utilization efficiency in these provinces.

The empirical results from the western region show the typical characteristics of “strong local effects and weak spatial spillovers.” First, environmental protection taxes (*ENT*) have significant local effects, but insignificant spatial spillovers. This verifies that *ENT*, as a public property of pure Pigou tax, has easy to be “free-ride” by neighboring provinces. In addition, the western region is vast and the inter-provincial economic ties are weak, and the industrial linkage path in Marshall's spillover is blocked, making it difficult for knowledge and technology to spread across provinces. Secondly, although resource occupancy tax (*RGT*) has the greatest local effect, its spatial overflow is also not significant. All provinces are mainly resource-based industries, with similar *RGT* policies, forming homogeneous competition. Enterprises tend to make adaptive adjustments locally rather than cross-provincial migration. Finally, guided taxation (*IGT*) is the only policy in the western region that generates significant positive spatial spillovers. Its mechanism of action is in line with the “strong Porter hypothesis” and Marshall's “knowledge and technology diffusion” path. Through fundamental green innovations in incentives for tax incentives, *IGT* helps the western region to form advanced management experience and production technology and has strong replicability. Even among provinces with different levels of economic development, this technological demonstration effect can break through geographical barriers and be imitated and learned by neighboring provinces, resulting in positive cross-regional spillover.

The green tax policies in the Northeast region show a complex two-way overflow characteristic of “local incentives and neighboring siphons”. First, environmental protection taxes (*ENT*) have significantly negative local effects and spatial spillovers. *ENT* directly constrains local polluting behavior by internalizing costs. However, as a traditional industrial base, enterprises in Northeast China face high compliance costs and may choose to reduce production or relocate high-polluting operations to regions with more relaxed environmental regulations. This leads to reduced local resource utilization efficiency and negative spillovers to neighboring provinces. Second, resource-use taxes (*RGT*) exhibit negative local effects but positive spillovers. Increasing resource taxes increases the burden on local resource-based enterprises and suppresses their production efficiency. However, this also drives up regional resource product prices, prompting enterprises in neighboring provinces to seek intensive substitution or technological innovation to reduce dependence, thereby indirectly improving their resource utilization efficiency. Finally, the significant local and spillover effects of inductive taxation (*IGT*) are the result of the combined effects of soft Pigouvian taxation and the “strong Porter hypothesis.” *IGT* incentivizes green technology innovation through tax incentives, forming local green industry clusters and generating Marshallian knowledge spillovers. This mechanism not only optimizes local resource utilization but also provides a replicable green transformation path for the entire

region, achieving positive spillovers from local innovation and regional synergy. Hence, Hypothesis 5 is confirmed.

5.4. Mechanism Test

Based on the theoretical analysis above, this section explores whether trade openness can mediate the impact of three green tax policies on natural resource utilization, namely, environmental protection green taxation, resource-intensive green taxation, and guidance-oriented green taxation. Based on strong and weak Porter theories, green taxation guides enterprises to increase innovation investment by restructuring the relative prices of regional production factors. Trade opening further strengthens this mechanism by reducing cross-border transaction barriers and information costs, it forces low-tax-related enterprises to break the “low environmental cost dependence” path, and instead compress resource consumption and improve total factor productivity through clean technology innovation to maintain export competitiveness. As shown in Table 9, trade opening is a key intermediary mechanism for green taxation to affect the efficiency of natural resource utilization, but the degree of trade opening plays a different role in the impact of green taxation on the efficiency of natural resource utilization.

Table 9. Results of Testing the Intermediary Mechanism of Trade Openness.

	NRE			TDC			NRE			TDC
	1	2	3	1	2	3	1	2	3	1
ENT	0.146 *** (0.027)			−0.123 *** (0.042)			0.148 *** (0.027)			−44.160 (63.677)
RGT		0.137 (0.171)			0.513 ** (0.260)			0.149 (0.172)		−26.182 (24.873)
IGT			0.870 *** (0.115)			1.515 *** (0.234)			0.519 *** (0.107)	−32.904 (188.915)
TDC			0.011 (0.035)			−0.024 (0.037)	0.011 (0.035)	−0.024 (0.037)	0.232 *** (0.023)	
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	−1.051 * (0.625)	0.289 (0.608)	−1.521 *** (0.234)	1.327 (0.984)	0.397 (0.922)	−3.547 *** (0.477)	−1.065 * (0.628)	0.299 (0.608)	−0.700 *** (0.222)	
Observations	360	360	360	360	360	360	360	360	360	360
R2	0.189	0.115	0.674	0.086	0.072	0.572	0.19	0.116	0.747	

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

Based on the corresponding analysis of theoretical mechanisms and empirical results, this study found that trade opening does not play a mediating role in the influence of natural resource utilization in environmental protection and resource occupation green taxation, but there is a significant mediating effect in guiding green taxation, and its internal logic is highly consistent with theoretical assumptions. First, the environmental protection and resource occupation green taxes are essentially used as Pigou taxes to internalize costs by punishing negative externalities. This mainly triggers the “weak baud effect”. In order to avoid high taxes, enterprises tend to adopt passive innovations in replacing imported equipment with cheap equipment, which are cost-centric rather than profit-focused. Under the conditions of opening trade, the disadvantage of increasing operating costs is amplified, and enterprises cannot form tradable goods with comparative advantages, and may even weaken their international competitiveness due to rising costs. Therefore, trade opening cannot become an “amplifier” to improve the efficiency of natural resource utilization, but may instead catalyze resource outflow or industrial transfer, so the mediation effect is not significant. Secondly, guided green tax positive incentives reward positive external behaviors, which fits the “strong Porter hypothesis”, inspires enterprises to actively innovate, reduce resource investment and production costs per unit product, and thus form an “innovation compensation” effect within the enterprise. At this time,

trade opening can truly reflect the role of intermediary, and the reduction in costs will enable the company's green products to have non-price comparative advantages in the international market. Trade opening provides a broad export market for such advantageous products, allowing them to obtain excess profits and feedback and strengthen the company's innovation investment. In addition, the mechanism testing method of this study cannot determine whether there is a two-way causal relationship between various types of green tax policies and trade opening. For this purpose, a simultaneous equation model (SEM) system is used to test the two-way causal relationship between three types of green taxation and trade opening. As shown in the last column of the table, the estimated results for the reverse path from trade openness to green taxation all failed the significance test. Specifically, the feedback coefficient for environmental protection-oriented green taxation is -44.160 , with a significant p -value of 0.488 ; for resource-oriented green taxation, it is -26.182 , with a significant p -value of 0.293 ; and for guidance-oriented green taxation, it is -32.904 , with a significant p -value of 0.862 . This finding indicates that trade openness does not significantly affect the intensity of green tax policies, and there is no reverse causal relationship between various types of green tax policies and trade openness, thus validating the validity of our mediation model. Therefore, the conclusion that trade openness amplifies the benefits of guidance-oriented green policies and, as a mediating effect, drives the growth of natural resource utilization is relatively robust. Hence, Hypothesis 6 is confirmed.

5.5. Robustness Tests

To ensure the reliability of the baseline regression results, this study conducted the following robustness tests. As shown in Table 10 below, replacing the measurement method of the core explanatory variables. Here, we abandon the original index construction method and recalculate the green tax index using principal component analysis. This dimensionality reduction measurement method can eliminate collinearity between indicators and extract the most representative common factors. The results, as shown in the first column of the table below, show that the coefficient of the newly constructed green tax index is still significantly positive at the 1% level and is similar in magnitude to that of the baseline regression, indicating that the conclusions of this study are not sensitive to the variable measurement method. Adding control variables. To prevent omitted variable bias, we add a variable that may affect natural resource utilization but was not previously controlled for, namely, social consumption level, to the baseline model. The results shown in column 2 of the table below show that even after controlling for this variable, the core coefficient of green tax policy, 0.192 , remains significant, indicating that this study's results are not affected by this potential omitted variable. Between 2016 and 2018, my country implemented the environmental protection fee-to-tax policy. To mitigate the impact of this major tax reform on the estimation of the green tax policy's effects, this study further excluded the sample data from 2017 and 2018 in a robustness test and re-regressed the remaining samples using a high-dimensional fixed-effect model to examine the robustness of the green tax policy's impact on natural resource utilization efficiency. The results, shown in column 3 of the table below, show that the coefficient of green tax policy (GT) is 0.299 , positive at the 5% significance level, indicating that even after excluding the interference of the structural policy shock of the fee-to-tax reform, green tax policy still has a significant promoting effect on natural resource utilization efficiency. This result further confirms the reliability of the baseline regression conclusion.

Table 10. Robustness and Endogeneity Tests.

Variables	(1) Replacing Explanatory Variables	(2) Adding Control Variables	(3) High-Dimensional Fixed Effects	(4) First-Stage GT	(5) Second-Stage NRE
<i>GT</i>		0.192 *** (9.14)	0.299 ** (2.14)		0.153 *** (0.00)
<i>L.GT</i>				0.946 *** (0.00)	
Green Taxation After The Main Component	0.257 *** (7.31)				
<i>IS</i>	0.552 *** (12.08)	0.461 *** (10.68)	0.340 (1.42)	−0.032 * (0.09)	0.531 *** (0.00)
<i>FILR</i>	−0.173 *** (−3.31)	0.089 (−2.93)	−0.210 * (−1.73)	−0.117 *** (0.00)	−0.392 *** (0.00)
<i>CUIG</i>	0.102 * (1.88)	0.121 ** (2.45)	−0.019 (−0.06)	0.077 *** (0.00)	0.079 (0.22)
<i>URB</i>	2.229 *** (11.00)	2.055 *** (10.76)	−1.071 (−0.67)	0.370 *** (0.00)	2.789 *** (0.00)
Social consumption level		1.371 *** (5.88)			
ρ	0.588 *** (11.51)	0.580 *** (11.05)			
LM statistic				7.020 *** (0.0081)	
K-P rk LM statistic				194.629	
sigma2_e	0.047 *** (12.87)	0.038 *** (12.88)			
Observations	360	360	300	360	360
R2	0.551	0.541	0.922	0.988	0.657

Notes: * $p < 0.1$, ** $p < 0.05$; *** $p < 0.01$.

To address the potential endogeneity between green tax policy and natural resource utilization, this study uses a two-stage least squares instrumental variable test. The instrumental variable selected is the lagged one-period value of each province's green tax policy (*L.GT*). The lagged one-period value of the green tax policy satisfies the requirement of being correlated with the current green tax but unaffected by the current error term. The results of the unidentification test in Table 9 show that the LM statistic significantly rejects the null hypothesis of unidentification, indicating that the instrumental variable is not unidentifiable. The F-value of the instrumental variable test is 194.629, which is greater than the critical value (16.38) at the 10% level, indicating that there is no weak instrumental variable problem. The first-stage regression instrumental variable *L.GT* is highly correlated with current green tax revenue (*GT*), strongly demonstrating the strength of the instrumental variable. The second-stage results show that, after controlling for endogeneity, green tax policies still have a significant positive impact on natural resource utilization. This means that for every 1% increase in green tax revenue, resource utilization increases by approximately 15.3%. This test confirms that green tax policies are an effective causal driver of improving resource utilization efficiency, rather than a simple correlation.

6. Conclusions and Discussion

6.1. Research Conclusions

This study uses fixed-effect and system GMM models and examines the spatial spillover effects of different types of green tax policies, the regional differences in spatial spillover effects, and the mediating effect of trade openness on the differences in green tax policies among different types. The following conclusions are drawn:

First, the current promotion effect of green tax policies on natural resource utilization efficiency is significantly robust. The fixed-effect model also validates the effectiveness of Pigouvian tax theory in environmental governance, and the GMM model constructed in this study further confirms the reliability of this conclusion. However, this study also found significant temporal heterogeneity in green tax policies. In the fixed-effect model with a lagged term, the one-period lagged green tax coefficient is insignificant, suggesting that the sustainability of policy effects may face obstacles. However, the one-period lagged

coefficient in the GMM model is significantly negative, reflecting that when companies need to restructure production processes or upgrade equipment, short-term output reductions may lead to a temporary decline in resource utilization efficiency. Furthermore, the one-period lagged natural resource utilization coefficient is as high as 1.125, indicating a strong inertia effect in resource utilization patterns. However, the two-period lagged coefficient is insignificant, indicating that this inertia largely dissipates after two years, which is consistent with the typical 2–3-year update cycle of industrial technology.

Secondly, the significant positive effect of environmental protection taxes of 0.802 confirms the transmission path of production function theory. By increasing resource factor prices, environmental protection taxes encourage companies to proactively reduce their natural resource inputs while maintaining output, thereby optimizing the allocation of capital and labor factors. The non-significant coefficient of 0.075 for resource-demand taxes reveals the heterogeneity of factor substitution elasticity. Guided taxation demonstrated a multiplier effect with a significant coefficient of 2.981. By building a transmission chain of “differentiated tax rates–tax incentives–market response,” dual incentives are created on both the business and consumer sides to achieve Pareto improvements.

Third, green tax policies as a whole have significant spatial spillover effects, with their indirect effects significantly exceeding their direct effects, indicating that environmental regulation practices do indeed experience cross-regional transmission. In particular, when the spatial spillover effect reaches 0.520, it suggests significant spatial strategic interaction among provinces, providing empirical evidence for building a cross-regional environmental governance alliance. A study of tax types shows that environmental protection taxes (*ENT*) have significant direct effects but only a spatial spillover of 0.344. This “strong local, weak spillover” characteristic suggests that while environmental governance investments in a province can benefit neighboring provinces through technology diffusion, the spillover effects are partially offset by “free-riding” behavior. The spatial spillover of resource taxes (*RGT*) reaches 0.584. Increases in resource taxes in a province trigger fluctuation in resource prices in neighboring provinces, forcing enterprises to break out of the “low-price, high-energy consumption” equilibrium. Instructional taxes (*IGT*) have a spillover effect of 0.486. Analysis of regional heterogeneity reveals structural differences in spatial spillover effects: The eastern region has the largest *RGT* local effect (0.813), but the spillover effects of the *ENT*, *RGT*, and *IGT* are relatively small, indicating that green tax policies are buffered by market mechanisms, generating a lock-in effect at the inflection point of the Environmental Kuznets Curve. The *ENT*, *RGT*, and *IGT* in the central region all exhibit strong negative spillovers, indicating a “pollution haven” effect in industrial transfer. In the western region, the *ENT*, *RGT*, and *IGT* all exhibit strong local effects, but only the *IGT* exhibits spillover effects. Spillover effects in the northeastern region are more complex. The *ENT*’s local and spillover effects are both significantly negative. The *RGT* exhibits a negative local effect and positive spillover effects, and only the *IGT* exhibits both positive local and spillover effects.

Fourth, this study found that neither environmentally friendly green taxes nor resource-intensive green taxes can influence natural resource utilization efficiency through trade openness. Trade openness can only further influence natural resource utilization efficiency through guiding green tax policies. Resource-intensive taxes may cause enterprises to pass on cost pressures through industrial transfers, leading to a negative erosion of the policy’s effectiveness through trade openness. Guided taxation leverages international trade networks to create a chain reaction, fostering comparative advantages in clean industries through strengthened tax incentives and preferential policies and achieving synergistic benefits between environmental regulation and trade openness.

6.2. Countermeasures and Discussion

Based on the above conclusions, this study proposes the following policy recommendations: First, implement precise regulation based on policy timeliness and the functional differences between tax types. This study confirms that green tax policies have significant time lags and tax heterogeneity. Therefore, government policy design must be wary of falling into the trap of a “one size fits all” model. In terms of policy lags and short-term fluctuations, establish a dynamic monitoring and response mechanism for the effects of green tax policies, and set up a policy buffer observation period of 1–2 years for green tax policies. During this policy buffer period, temporary tax deductions and exemptions will be provided to key resource-based enterprises experiencing short-term operating difficulties to help them survive the painful period and prevent a temporary decline in resource utilization efficiency. At the same time, using the strong inertia conclusion revealed by this study that the one-period natural resource utilization coefficient is as high as 1.125, the continuous improvement of resource utilization efficiency is used as a long-term assessment indicator for local governments to encourage the government to adhere to long-term sustainable policies rather than short-term speculation. Environmental protection tax (*ENT*) has a clear “restraint and forcing” effect, which can guide the government from fixed quota collection to high-intensity emission reduction incentives. For enterprises whose annual reduction in pollutant emission intensity exceeds the industry average, environmental protection tax refunds or preferential tax rates will be implemented, gradually forming a refined incentive mechanism in the industry of “penalties for exceeding standards and rewards for being ahead of the curve”. Resource-based taxes (*RGT*) have no significant causal relationship with natural resource utilization, and enterprises are prone to circumventing costs through industrial relocation. Reform should focus on blocking tax avoidance channels and strengthening local innovation incentives. It is recommended that *RGT* revenue be used to establish a “Local Green Technology Innovation Subsidy Fund for Resource-Based Enterprises” to provide supporting funding for enterprises to purchase water-saving and energy-saving equipment or conduct research and development of recycling technologies, thereby transforming tax costs into innovation drivers rather than pressure for transfer. Research has found that inductive taxes (*IGT*) are the most effective and can strengthen their “incentive and guiding” function. A system linking a green technology and product certification catalog with *IGT* benefits could be implemented. Enterprises that purchase energy-saving equipment included in the catalog should be allowed to enjoy corporate income tax deductions; consumers who purchase new energy vehicles and energy-saving appliances included in the catalog should be given consumption tax exemptions or personal income tax deductions, thereby creating strong guidance on both the supply and demand sides.

Second, a differentiated regional collaborative governance mechanism should be established based on the spatial spillover effects of green taxes. The results of this study’s spatial Durbin model indicate the presence of a spillover effect ($\rho = 0.520$), revealing the crucial role of interprovincial interactions. First, establish a cross-provincial green tax policy coordination platform. With the central government as the main body, green tax and natural resource utilization coordination agencies should be established within the four major regions of eastern, central, western, and northeastern China. This agency should regularly communicate green tax policy adjustment plans among regions to avoid the negative spillover traps of vicious competition or policy hollowing out. Secondly, differentiated regional coordination strategies should be implemented. The eastern region has strong local effects of *RGT* but weak spillovers, and negative spillovers from *IGT*. Green tax revenues from eastern provinces should be used for interprovincial green technology transfer and cooperation. Funding should be provided to environmental protection enterprises in the province to establish branches or provide technical assistance in neighboring provinces

in central and western China, transforming the “siphon effect” into a “diffusion effect.” All three types of taxes in the central region exhibit negative spillovers, posing the risk of creating “pollution havens.” A “green threshold” could be introduced for industrial transfer in the central region, requiring that the receiving enterprises meet the green tax intensity of the sending region, with oversight and implementation by the regional coordination agency. Western and northeastern regions should fully leverage the significant positive spillover effects of *IGT*. These regions are encouraged to jointly apply for national-level green industry coordinated development demonstration zones. Within these demonstration zones, a unified catalog of guiding tax incentives will be implemented to attract the development of industrial chain clusters and amplify the positive spillover effects of *IGT*.

Third, strengthen the synergy between trade openness and inductive green taxation. Trade openness only plays a significant mediating role in inductive green taxation (*IGT*). Create a closed-loop policy for green taxation and trade facilitation. Specifically, for exporting enterprises that accept *IGT* incentives and obtain green certification, customs and commerce departments should grant “green customs clearance” conveniences, such as shortened customs clearance times and reduced inspection rates. At the same time, in international trade negotiations, we can strive for import tariff reductions and exemptions in other countries for products from these green enterprises that utilize natural resources, thus combining domestic incentives with international market access. Regarding environmental protection (*ENT*) and resource-use taxation (*RGT*), we must be wary of the potential for industrial relocation under high trade openness. Strengthen environmental cost assessments for the export of high-energy-consuming and high-emission products, and study and formulate differentiated green tax coverage for export links. At the same time, we must prevent strict domestic environmental regulations from forcing resource-dependent enterprises to transfer pollution through trade channels.

While this study has drawn numerous conclusions, there is still considerable room for further research. First, although this study constructs a green tax intensity index based on ten tax categories, the weightings assigned to each tax category may not fully and accurately reflect their actual environmental regulation intensity. Future research could explore using more refined industry or enterprise-level data to more meticulously measure the effects of green tax policies. Second, the sample coverage is limited. Due to data integrity constraints, this study does not include Tibet, Hong Kong, Macao, and Taiwan. As data becomes more available, they could be incorporated into the analysis to enhance the generalizability of the conclusions. Third, differences in policy implementation are not fully considered. The same green tax policy may have varying collection and enforcement efficiency and enforcement strength across different regions. These implementation gaps could affect the assessment of the green tax policy’s impact on natural resource utilization. Subsequent research could therefore consider these limitations in more detail.

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References

1. Cui, K.; Li, X.; Li, G. What kind of fiscal policies and natural resources efficiency promotes green economic growth? Evidence from regression analysis. *Resour. Policy* **2023**, *85*, 103941. [\[CrossRef\]](#)
2. Ge, T.; Li, C.; Li, J.; Hao, X. Does neighboring green development benefit or suffer from local economic growth targets? Evidence from China. *Econ. Model.* **2023**, *120*, 106149. [\[CrossRef\]](#)
3. Filiou, D.; Kesidou, E.; Wu, L. Are smart cities green? The role of environmental and digital policies for eco-innovation in China. *World Dev.* **2023**, *165*, 106212. [\[CrossRef\]](#)
4. Yu, X. An assessment of the green development efficiency of industrial parks in China: Based on non-desired output and non-radial DEA model. *Struct. Change Econ.* **2023**, *66*, 81–88. [\[CrossRef\]](#)
5. Danish; Baloch, M.A.; Mahmood, N.; Zhang, J.W. Effect of natural resources, renewable energy and economic development on CO₂ emissions in BRICS countries. *Sci. Total Environ.* **2019**, *678*, 632–638. [\[CrossRef\]](#)
6. Li, M.; Yu, X. Green economy helps residents transform to green and low-carbon life. *Coop. Econ. Technol.* **2025**, *8*, 4–11. [\[CrossRef\]](#)
7. Ma, H. On the reform and improvement of green taxation in my country. *Dev. Res.* **2009**, *6*, 143–146. [\[CrossRef\]](#)
8. Nerudová, D.; Dobranschi, M. The Impact of Tax Burden Overshifting on the Pigovian Taxation. *Procedia Soc. Behav. Sci.* **2016**, *220*, 302–311. [\[CrossRef\]](#)
9. Dutta, P.K.; Radner, R. Climate payments: A Coase theorem. *J. Econ. Theory* **2025**, *228*, 106032. [\[CrossRef\]](#)
10. Zhang, L.; Zhu, D. Research on the effect of green taxation on improving resource productivity. *Stat. Decis.* **2012**, *14*, 105–108. [\[CrossRef\]](#)
11. Loganathan, N.; Mursitama, T.N.; Pillai, L.L.K.; Khan, A.; Taha, R. The effects of total factor of productivity, natural resources and green taxation on CO₂ emissions in Malaysia. *Environ. Sci. Pollut. Res. Int.* **2020**, *27*, 45121–45132. [\[CrossRef\]](#) [\[PubMed\]](#)
12. Jóźwik, B.; Sarigül, S.S.; Topcu, B.A.; Çetin, M.; Doğan, M. Trade Openness, Economic Growth, Capital, and Financial Globalization: Unveiling Their Impact on Renewable Energy Consumption. *Energies* **2025**, *18*, 1244. [\[CrossRef\]](#)
13. Deng, L.; Chen, B. ‘Carbon Peak, Carbon Neutrality’ goals and the construction of a green tax system. *Tax. Econ. Res.* **2022**, *27*, 1–7. [\[CrossRef\]](#)
14. van der Ploeg, F.; Rezai, A.; Reanos, M.T. Gathering support for green tax reform: Evidence from German household surveys. *Eur. Econ. Rev.* **2022**, *141*, 103966. [\[CrossRef\]](#)
15. De Miguel, C.; Montero, M.; Bajona, C. Intergenerational effects of a green tax reform for a more sustainable social security system. *Energy Econ.* **2015**, *52*, S117–S129. [\[CrossRef\]](#)
16. Huang, X. Research on optimization of environmental tax and fee system for international trade development. *Reform. Strategy* **2016**, *32*, 144–147. [\[CrossRef\]](#)
17. Rehman, M.A.; Abbas, S.; Arshad, Z.; Shahzad, F.; Fareed, Z.; Yan, Y. Green trading mechanisms, carbon taxation, and technology integration: Achieving the carbon neutrality ambition in OECD countries. *Clean Technol. Environ. Policy* **2025**, 1–18. [\[CrossRef\]](#)
18. Yang, H. Carbon emissions control and trade liberalization: Coordinated approaches to Taiwan’s trade and tax policy. *Energy Policy* **2001**, *29*, 725–734. [\[CrossRef\]](#)
19. Sheldon, I. Trade and Environmental Policy: A Race to the Bottom? *J. Agric. Econ.* **2006**, *57*, 365–392. [\[CrossRef\]](#)
20. Lai, Y.-B.; Hu, C.-H. Trade agreements, domestic environmental regulation, and transboundary pollution. *Resour. Energy Econ.* **2008**, *30*, 209–228. [\[CrossRef\]](#)
21. Böhringer, C.; Löschel, A. Computable general equilibrium models for sustainability impact assessment: Status quo and prospects. *Ecol. Econ.* **2006**, *60*, 49–64. [\[CrossRef\]](#)
22. Huang, F. How does trade and fiscal decentralization leads to green growth; role of renewable energy development. *Renew. Energy* **2023**, *214*, 334–341. [\[CrossRef\]](#)
23. Huo, W.; Ullah, M.R.; Zulfiqar, M.; Parveen, S.; Kibria, U. Financial Development, Trade Openness, and Foreign Direct Investment: A Battle Between the Measures of Environmental Sustainability. *Front. Environ. Sci.* **2022**, *10*, 851290. [\[CrossRef\]](#)
24. Wan, R.; Nakada, M.; Takarada, Y. Trade liberalization in environmental goods. *Resour. Energy Econ.* **2018**, *51*, 44–66. [\[CrossRef\]](#)
25. Hu, X.; Pollitt, H.; Pirie, J.; Mercure, J.-F.; Liu, J.; Meng, J.; Tao, S. The impacts of the trade liberalization of environmental goods on power system and CO₂ emissions. *Energy Policy* **2020**, *140*, 111173. [\[CrossRef\]](#)
26. Li, B.; Xing, F.; Yu, M. Upstream Pricing Schemes, Trade Liberalization, Trade and Environmental Policies of Downstream Countries. *Sustainability* **2018**, *10*, 2428. [\[CrossRef\]](#)
27. Sarkodie, S.A. The invisible hand and EKC hypothesis: What are the drivers of environmental degradation and pollution in Africa? *Environ. Sci. Pollut. Res.* **2018**, *25*, 21993–22022. [\[CrossRef\]](#) [\[PubMed\]](#)

28. Wang, P.; Sun, B. The impact of energy endowment and trade openness on resource green utilization efficiency. *J. Dalian Univ. Technol.* **2019**, *40*, 9–16. [\[CrossRef\]](#)
29. Cheng, D.; Zhou, H.; Guo, D.; He, Y. Green Knot: Trade openness and digital commerce contribute to the natural resources. *Resour. Policy* **2024**, *90*, 104579. [\[CrossRef\]](#)
30. Zhang, M.; Zhang, D.; Yang, Y. Green bond and trade openness effects on sustainable business practices in natural resource markets. *Resour. Policy* **2023**, *86*, 104188. [\[CrossRef\]](#)
31. Van Kien, P.; Ou, J.P.; Sadiq, M.; Nguyen, T.T.H.; Huy, P.Q.; Tran, T.K. What role financial inclusion, green trade and natural resources utilization play in ASEAN economic growth: Evidence from post COVID era. *Resour. Policy* **2023**, *85*, 103884. [\[CrossRef\]](#)
32. Liu, Y.; Jiang, R.; Zhang, Y.; Dai, J.; Cheng, J. Mitigating digital trade barriers: Strategies for enhancing national value chains performance. *Int. Rev. Econ. Financ.* **2024**, *95*, 103485. [\[CrossRef\]](#)
33. Zhang, S.; Xi, L.; Gao, J. Impact of natural resource rents on global trade dynamics in RCEP: Economic and geopolitical interdependencies. *Resour. Policy* **2024**, *99*, 105365. [\[CrossRef\]](#)
34. Zheng, Y.; Qi, Z. Resource constraints, trade openness and technological spillovers. *Sci. Res.* **2012**, *30*, 1518–1526. [\[CrossRef\]](#)
35. Ehigiamusoe, K.U.; Dogan, E.; Ramakrishnan, S.; Binsaeed, R.H. How does technological innovation moderate the environmental impacts of economic growth, natural resource rents and trade openness? *J. Environ. Manag.* **2024**, *371*, 123229. [\[CrossRef\]](#) [\[PubMed\]](#)
36. Song, Y.; Hua, X. The role of carbon taxation in promoting a green economy for sustainability: Optimizing natural resource efficiency. *Resour. Policy* **2024**, *91*, 104874. [\[CrossRef\]](#)
37. He, W.; Chen, H. Research on the impact of green taxation on green transformation of manufacturing industry—Based on empirical data of green total factor productivity. *J. Guizhou Bus. Univ.* **2021**, *34*, 56–67. [\[CrossRef\]](#)
38. Qian, S. Ripples of change: Assessing the impact of water resource tax reform pilot on the green growth of China's coastal cities. *J. Sea Res.* **2024**, *198*, 102479. [\[CrossRef\]](#)
39. Yang, Y.; Zhen, D.; Meng, F. Mineral resource management for a sustainable future: Unraveling the role of energy tax in driving green technologies and environmental quality. *Resour. Policy* **2024**, *94*, 105073. [\[CrossRef\]](#)
40. Cheng, Y.; Zhao, G.; Meng, W.; Wang, Q. Resources utilization, taxation and green education: A path to sustainable power generation. *Resour. Policy* **2024**, *88*, 104389. [\[CrossRef\]](#)
41. Yao, S.; Li, T.; Li, Y. Promoting sustainable fossil fuels resources in BRICS countries: Evaluating green policies and driving renewable energy development. *Resour. Policy* **2023**, *85*, 103990. [\[CrossRef\]](#)
42. Ullah, S.; Luo, R.; Nadeem, M.; Cifuentes-Faura, J. Advancing sustainable growth and energy transition in the United States through the lens of green energy innovations, natural resources and environmental policy. *Resour. Policy* **2023**, *85*, 103848. [\[CrossRef\]](#)
43. Obobisa, E.S.; Ahakwa, I. Stimulating the adoption of green technology innovation, clean energy resources, green finance, and environmental taxes: The way to achieve net zero CO₂ emissions in Europe? *Technol. Forecast. Soc. Change* **2024**, *205*, 123489. [\[CrossRef\]](#)
44. Ma, F.; Saleem, H.; Ding, X.; Nazir, S.; Tariq, S. Do natural resource rents, green technological innovation, and renewable energy matter for ecological sustainability? Role of green policies in testing the environmental kuznets curve hypothesis. *Resour. Policy* **2024**, *91*, 104844. [\[CrossRef\]](#)
45. Bozatli, O.; Akca, H. Effectiveness of environmental protection expenditures and resource tax policy in the Netherland's load capacity factor: Do government effectiveness and renewable energy matter? Evidence from Fourier augmented ARDL. *Resour. Policy* **2024**, *92*, 105030. [\[CrossRef\]](#)
46. Ge, T.; Chen, Y. Interregional Environmental Policy Coordination, Natural Resource Endowment, and Green Economic Development: A Quantitative Analysis of China's Policy Tests. *Sustainability* **2025**, *17*, 686. [\[CrossRef\]](#)
47. Qamruzzaman, M.; Karim, S.; Kor, S. Nexus between Innovation–Openness–Natural Resources–Environmental Quality in N-11 Countries: What Is the Role of Environmental Tax? *Sustainability* **2024**, *16*, 3889. [\[CrossRef\]](#)
48. Kanazawa, T.; Fukumoto, Y.; Ushio, T.; Misaka, T. Replicator dynamics with Pigovian subsidy and capitation tax. *Nonlinear Anal. Theory Methods Appl.* **2009**, *71*, e818–e826. [\[CrossRef\]](#)
49. Yadav, M.P.; Pandey, A.; Taghizadeh-Hesary, F.; Arya, V.; Mishra, N. Volatility spillover of green bond with renewable energy and crypto market. *Renew. Energy* **2023**, *212*, 928–939. [\[CrossRef\]](#)
50. Hao, L.N.; Umar, M.; Khan, Z.; Ali, W. Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is? *Sci. Total Environ.* **2021**, *752*, 141853. [\[CrossRef\]](#) [\[PubMed\]](#)
51. Amin, M.; Zhou, S.; Safi, A. The nexus between consumption-based carbon emissions, trade, eco-innovation, and energy productivity: Empirical evidence from N-11 economies. *Environ. Sci. Pollut.* **2022**, *29*, 39239–39248. [\[CrossRef\]](#)
52. Arrow, K.J. The Economic Implications of Learning by Doing. In *Readings in the Theory of Growth*; Hahn, F.H., Ed.; Macmillan: London, UK, 1971; pp. 131–149. [\[CrossRef\]](#)

53. Dai, J.; Ahmed, Z.; Sinha, A.; Pata, U.K.; Alvarado, R. Sustainable green electricity, technological innovation, and ecological footprint: Does democratic accountability moderate the nexus? *Util. Policy* **2023**, *82*, 101541. [\[CrossRef\]](#)
54. Hussain, Z.; Khan, M.K.; Xia, Z. Investigating the role of green transport, environmental taxes and expenditures in mitigating the transport CO₂ emissions. *Transport. Lett.* **2023**, *15*, 439–449. [\[CrossRef\]](#)
55. Liu, L.; Zhou, Y. Study on the double dividend effect and spatial spillover of China's green taxation. *Fisc. Res.* **2024**, *6*, 40–53. [\[CrossRef\]](#)
56. Murphy, J.; Gouldson, A. Environmental policy and industrial innovation: Integrating environment and economy through ecological modernisation. *Geoforum* **2000**, *31*, 33–44. [\[CrossRef\]](#)
57. Kaika, D.; Zervas, E. The Environmental Kuznets Curve (EKC) theory—Part A: Concept, causes and the CO₂ emissions case. *Energy Policy* **2013**, *62*, 1392–1402. [\[CrossRef\]](#)
58. Ullah, S.; Luo, R.; Adebayo, T.S.; Kartal, M.T. Dynamics between environmental taxes and ecological sustainability: Evidence from top-seven green economies by novel quantile approaches. *Sustain* **2023**, *31*, 825–839. [\[CrossRef\]](#)
59. André, F.J.; Ranocchia, C.; Rubio, S.J. Porter Hypothesis vs. Pollution Haven Hypothesis: Can an environmental policy generate a win–win solution? *Energy Econ.* **2025**, *146*, 108477. [\[CrossRef\]](#)
60. Shimomura, K. Factor income function and an oligopolistic Heckscher-Ohlin model of international trade. *Econ. Lett.* **1998**, *61*, 91–100. [\[CrossRef\]](#)
61. Benatti, N.; Groiss, M.; Kelly, P.; Lopez-Garcia, P. Environmental regulation and productivity growth in the euro area: Testing the porter hypothesis. *J. Environ. Econ. Manag.* **2024**, *126*, 102995. [\[CrossRef\]](#)
62. Felbermayr, G.; Peterson, S.; Wanner, J. Trade and the environment, trade policies and environmental policies—How do they interact? *J. Econ. Surv.* **2025**, *39*, 1148–1184. [\[CrossRef\]](#)
63. Blundell, R.; Bond, S. Initial Conditions and Moment Restrictions in Dynamic Panel Data Models. *J. Econom.* **1998**, *87*, 115–143. [\[CrossRef\]](#)
64. Chen, X.; Zhao, F.; Gao, Y. An empirical analysis of the relationship between natural resource utilization efficiency and urbanization in China. *Resour. Sci.* **2013**, *35*, 430–438.
65. Xiao, J.; Xu, L.; Xiao, W. The impact of green taxation on sustainable development—Based on the perspective of tax heterogeneity and threshold effect. *Yunnan Soc. Sci.* **2023**, *5*, 91–100. [\[CrossRef\]](#)
66. Jin, Z. Does trade openness reduce the volatility of the RMB real effective exchange rate—An empirical study based on provincial trade and price level data. *Int. Financ. Res.* **2020**, *12*, 73–83. [\[CrossRef\]](#)
67. Barbier, E.B. Poverty, development, and environment. *Environ. Dev. Econ.* **2010**, *15*, 635–660. [\[CrossRef\]](#)
68. Zhang, H.; Chen, T.; Yu, Y. From finance to sustainability: Understanding the financial development-environment nexus with the environmental Kuznets curve in East-Asia and Pacific economies. *Borsa Istanbul. Rev.* **2023**, *23*, 1448–1457. [\[CrossRef\]](#)
69. Zhao, C.; Lei, Z.; Zhao, X.; Wang, Y. Carbon finance development, industrial structure and green financial instruments. *N. Am. J. Econ. Financ.* **2025**, *78*, 102430. [\[CrossRef\]](#)
70. Amer, E.A.A.A.; Xiuwu, Z.; Meyad, E.M.A.; Alareqi, M.M.; Bather, S.M.; Abdelwahed, A. Urbanization, growth, and carbon footprints: A GCC perspective on sustainable development. *Sustain. Futures* **2025**, *9*, 100631. [\[CrossRef\]](#)

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