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Environmental Taxes and Food Exports: Assessing Trade and Sustainability Dynamics in OECD Countries

Nesrine Gafsi[1]*, Sayef Bakari[2]

[1]Department of Finance, College of Business, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, Saudi Arabia, [2]LIEI, Faculty of Economic Sciences and Management of Tunis, University of Tunis El Manar, Tunisia. *Email: nwgafsi@imamu.edu.sa

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ABSTRACT

This study investigates the impact of environmental taxes on food exports in OECD countries from 1994 to 2022, utilizing advanced econometric techniques, including panel cointegration analysis and panel vector error correction models (Panel VECMs). While environmental taxation aims to mitigate ecological degradation, its trade implications remain debated. The results reveal a positive long-term relationship between environmental taxes and food exports, suggesting that taxation policies incentivize sustainable innovation and enhance export competitiveness. However, short-term effects indicate a temporary decline in food exports following tax increases. The study also identifies a bidirectional causal relationship between environmental taxation and food exports, highlighting the role of regulatory adaptation and market adjustments. These findings provide critical insights for policymakers seeking to balance trade competitiveness and environmental sustainability through well-designed taxation frameworks and international policy coordination.

Keywords: Environmental Taxes, Food Exports, Organization for Economic Co-Operation and Development Countries, Sustainable Trade, Panel Vector Error Correction Model
JEL Classifications: F18, H23, Q56, Q17, C33

1. INTRODUCTION

In response to the increasing severity of environmental challenges, including climate change, resource depletion, and biodiversity loss, governments worldwide are actively implementing a variety of policy measures designed to mitigate these issues. One of the most widely used tools in this regard is the imposition of environmental taxes, which are financial penalties levied on activities that contribute to environmental degradation. These taxes aim to internalize the social costs associated with environmental harm, reduce negative externalities, and incentivize more sustainable practices within industries and consumers (Zhang et al., 2023; Schlegel et al., 2022). By creating financial disincentives for environmentally harmful activities, these taxes encourage businesses to adopt cleaner technologies, shift toward more sustainable production methods, and make resource use more efficient. This policy approach has been embraced by governments across the globe as an essential part of the transition to a more sustainable economy (Böhringer et al., 2023; Martinez, 2023).

While the environmental benefits of these taxes are well-documented, the economic implications, particularly those concerning trade, remain complex and relatively understudied. Environmental taxes, including carbon taxes and product-specific taxes, are often introduced with the dual aim of curbing environmental degradation while also promoting green innovation and sustainability. However, they also raise concerns about their potential effects on international trade, particularly the competitiveness of domestic industries in global markets. As some countries introduce environmental taxes unilaterally, there are fears that these measures may disrupt the competitive landscape, particularly for agricultural exports. In industries such as food production, where cost structures are heavily impacted by external taxes, these policies can place exporters at a significant disadvantage unless implemented in a globally coordinated manner (Beckman et al., 2018; Rivers and Schaufele, 2015).

Several scholars have explored the potential trade-related implications of environmental taxes. For instance, Rivers and Schaufele (2015) evaluate the impact of a carbon tax introduced in British Columbia and find little evidence that it significantly affected agricultural trade. Similarly, Beckman et al. (2018) assess the effects of export taxes on agricultural trade and find that while export taxes do not have widespread effects on international prices, they can influence specific commodities, especially those where the country imposing the tax is a major global exporter. These findings suggest that export taxes, particularly those related to environmental goals, can have a notable impact on global agricultural markets by affecting both the supply-side dynamics and demand-side responses in importing countries (Beckman et al., 2018; Carrere et al., 2022). Additionally, the World Trade Organization (WTO) rules on trade and tariffs are central to the discussion, as many countries may hesitate to implement unilateral environmental taxes due to concerns over compliance with WTO regulations such as national treatment and most-favored-nation principles (Martinez, 2023; Zhang et al., 2023).

The concept of border carbon adjustments (BCA), where countries impose taxes on imports from countries without similar environmental policies, has been proposed as a way to counteract the potential for competitive imbalances. While BCAs may level the playing field by addressing disparities in environmental regulations, their implementation raises legal and economic questions regarding their alignment with international trade agreements (Böhringer et al., 2023). As countries push for greener economies, discussions surrounding BCAs continue to evolve, with some arguing that these adjustments could provide a solution to prevent market distortions caused by environmental tax differences across nations (Martinez, 2023). However, there remains a lack of consensus on the economic feasibility and legal permissibility of such measures in light of the WTO's framework (Carrere et al., 2022; Zhang et al., 2023).

Furthermore, the effect of environmental taxation on trade in food exports is of particular concern. Studies show that environmental taxes may result in short-term disruptions to food exports as companies adjust to new cost structures. For example, Säll (2018) explores the effects of a meat tax in Sweden, finding that although the tax is nearly neutral in its impact on household welfare when measured against expenditures, it could impose a regressive burden on lower-income households, further complicating the broader implications of such taxes. In the context of food exports, the imposition of environmental taxes could lead to increased production costs for food exporters, particularly in countries where agriculture is a major economic sector. These cost increases may lead to a reduction in export competitiveness, especially if trading partners do not implement similar policies (Beckman et al., 2018; Schlegel et al., 2022). This paper investigates the causal relationship between environmental taxes and food exports in OECD countries, with a focus on understanding how these taxes influence trade competitiveness, export performance, and the broader interplay between environmental and economic goals.

The global food sector occupies a pivotal position within the international economy, representing a cornerstone of both economic activity and societal well-being. Food production and exports not only ensure food security and generate substantial employment but also serve as a major driver of GDP growth in many countries (Bakari and Mabrouki, 2017; Bakari and Mabrouki, 2018; Bakari, 2017a; Bakari, 2017b; Bakari, 2018; Bakari, 2016; Othmani et al., 2024; Gafsi and Bakari, 2024; Bakari and Tiba, 2022; Bakari and Tiba, 2020; Bakari and Abdelhafidh, 2018; Bakari and El Weriemmi, 2022; Abdelhafidh and Bakari, 2019; El Weriemmi and Bakari, 2024a; El Weriemmi and Bakari, 2024b; El Weriemmi and Bakari, 2024c). However, the environmental footprint is significant. According to the Food and Agriculture Organization (FAO, 2021), agriculture and related activities account for a considerable share of greenhouse gas emissions, land-use change, water consumption, and pollution. Addressing these environmental challenges has become a priority for policymakers, particularly in advanced economies like those of the OECD, which collectively contribute a significant proportion of global food trade.

Environmental taxes have emerged as a key policy tool in this context, designed to align economic activities with environmental objectives. These taxes are typically imposed on emissions, resource use, or pollution-intensive processes, thereby increasing the cost of environmentally harmful activities. While the theoretical foundations of environmental taxes, grounded in Pigouvian economics (Pigou, 1920), suggest their potential to correct market failures and promote sustainability, their impact on international trade, especially in export-driven sectors like food—raises critical questions. Higher production costs stemming from environmental taxes may erode the price competitiveness of exports, shifting trade flows and altering comparative advantages. At the same time, such policies may drive innovation and efficiency improvements, potentially enhancing competitiveness in the long term (Porter and Van-der-Linde, 1995).

Despite growing academic interest in the intersection of trade and environmental policy, the specific relationship between environmental taxes and food exports remains underexplored. Existing literature has primarily focused on the broader impacts of environmental regulations on trade flows (Costantini and Mazzanti, 2012; Tobey, 1990) or the effectiveness of green taxes in achieving environmental outcomes (Nordhaus, 2019; Ekins and Speck, 2011). However, these studies often overlook the nuanced effects of such policies on specific sectors, such as agriculture and food production, which are particularly sensitive to both environmental and economic policies. This paper aims to fill this research gap by examining the dynamic interplay between environmental taxes and food export performance within the OECD context.

The OECD provides an ideal case study for this investigation, given its member countries' diverse economic structures, environmental policy frameworks, and roles in the global food trade. Comprising

37 nations—including Australia, Austria, Canada, France, Japan, and the United States—this group represents a significant portion of global trade and policy leadership. These countries have implemented a wide range of environmental tax policies over recent decades, creating a rich dataset for empirical analysis. This study spans the period from 1994 to 2022, capturing critical developments in both environmental and trade policy, as well as major shifts in global economic conditions.

To achieve its objectives, this research employs advanced econometric techniques, including panel stationarity tests, panel cointegration analyses, and panel vector error correction models (Panel VECMs). These methods allow for a rigorous examination of both short-term and long-term relationships between environmental taxes and food exports. Key questions include whether environmental taxes adversely affect export performance in the short term, whether they foster innovation and long-term competitiveness, and how these effects vary across different OECD countries. The inclusion of detailed descriptive statistics, stationarity tests, and panel data methodologies ensures a robust analytical framework for addressing these questions.

Preliminary data suggest significant variation in the relationship between environmental taxes and food exports across countries and time periods. For example, countries with well-established environmental policies and higher levels of technological innovation may experience less adverse impacts—or even positive effects—from environmental taxes on their export competitiveness. Conversely, countries who are heavily reliant on resource-intensive food production may face greater challenges. By examining these dynamics, this paper seeks to identify patterns, drivers, and mediating factors that shape the causal relationship between environmental taxes and food exports.

The broader significance of this research lies in its potential to inform policy decisions at the intersection of environmental and economic objectives. As the world moves toward more sustainable models of development, understanding the trade-offs and synergies between environmental taxation and trade performance is essential. For policymakers, the findings of this study will offer insights into how environmental taxes can be designed to minimize negative economic impacts while maximizing environmental benefits. For example, revenue recycling mechanisms, whereby tax revenues are reinvested in green technologies or support measures for affected industries, may play a crucial role in mitigating adverse effects.

This paper contributes to the growing body of literature on sustainable trade by exploring the underexamined relationship between environmental taxes and food exports. By focusing on OECD countries, it provides a comprehensive analysis of the factors that mediate this relationship in a diverse and economically significant group of nations. The findings are expected to deepen our understanding of how environmental policies interact with trade dynamics, offering practical recommendations for achieving a balance between economic growth and environmental sustainability. As global challenges demand integrated policy approaches, this research represents a step toward crafting solutions that align economic and environmental priorities for a more sustainable future.

2. LITERATURE REVIEW: ENVIRONMENTAL TAXES AND FOOD EXPORTS

The interplay between environmental taxes and food exports represents an emerging area of scholarly inquiry, positioned at the nexus of environmental economics, international trade, and agricultural policy. This review synthesizes the existing literature, emphasizing key theoretical frameworks, empirical findings, and unresolved debates. While the majority of studies focus on the general relationship between environmental regulations and trade, fewer address sector-specific impacts, particularly in the context of food exports. This section outlines foundational theories, sector-specific insights, and the methodologies commonly employed in this domain.

2.1. Theoretical Foundations of Environmental Taxes and Trade

The theoretical foundations of environmental taxes and international trade are deeply rooted in Pigouvian economics, where taxes are proposed as tools to internalize the negative externalities arising from polluting activities or resource overuse (Pigou, 1920). These environmental taxes increase the cost of environmentally harmful activities, incentivizing firms to adopt cleaner technologies and reduce emissions. On a macroeconomic scale, such taxes are designed to influence production costs and, consequently, the trade competitiveness of nations. However, their impact on trade, especially exports, remains a contested subject.

From a theoretical perspective, environmental taxes are viewed both as regulatory tools and as drivers of industrial transformation. According to the well-known 'Porter Hypothesis, proposed by Porter and van der Linde (1995), well-designed environmental policies, including taxes, can stimulate innovation and, over time, enhance economic competitiveness. This hypothesis challenges traditional views that associate environmental policies with economic burdens on firms. The central idea is that innovation induced by these policies can enable firms to improve operational efficiency and gain favorable positions in markets increasingly sensitive to environmental performance (Ambec et al., 2013). However, this hypothesis is not without criticism. Some researchers argue that the immediate costs of environmental taxes may outweigh potential long-term benefits, especially in resource-intensive sectors (Greaker, 2003).

The international trade dimension adds complexity to this debate, with theoretical frameworks such as the Heckscher-Ohlin model and comparative advantage theories offering different predictions. These approaches suggest that countries with strict environmental regulations may lose their comparative advantage in pollution-intensive industries (Copeland and Taylor, 2004). Higher costs associated with such regulations could render exports less competitive compared to those from countries with more lenient environmental policies. This phenomenon, often referred to as "carbon leakage," has been explored by researchers like Levinson and Taylor (2008), who emphasize that the relocation of polluting industries to countries with weaker regulations can undermine global environmental gains.

However, recent studies provide a more nuanced perspective, highlighting the potential advantages of innovation and improved resource efficiency. Ederington et al. (2005) argue that in certain sectors, where environmental performance becomes a critical factor for differentiation in international markets, environmental taxes can incentivize investments in advanced technologies. Moreover, empirical analyses, such as those by Costantini and Mazzanti (2012), suggest that stringent environmental policies may, in some cases, enhance export competitiveness, particularly in high-technology industries.

The theoretical foundations of environmental taxes and trade oscillate between opposing views: One emphasizes the risks of competitiveness loss and industrial relocation, and the other highlights opportunities for innovation and market differentiation. This theoretical tension reflects the complex interplay between environmental and economic objectives, field where ongoing research aims to better understand sectoral dynamics and the specific conditions under which such taxes can be optimized.

2.2. Empirical Evidence on Environmental Taxes and Trade Flows

The empirical literature on the relationship between environmental taxes and trade flows presents a complex and mixed picture, reflecting the multifaceted nature of these interactions. One of the earliest empirical contributions in this field is Tobey (1990), who conducted a cross-sectional analysis across various industries to investigate whether stringent environmental regulations significantly affect trade patterns. Tobey's findings revealed limited evidence of competitiveness losses attributable to environmental policies, suggesting that the widely held fears of regulatory-induced declines in export performance may be overstated. His work laid the foundation for subsequent studies that delve deeper into sectoral and context-specific dynamics.

Building on these insights, more recent research has highlighted that the impacts of environmental taxes are not uniform but highly dependent on industry characteristics and the broader policy environment. Costantini and Mazzanti (2012) provided an important contribution by demonstrating that stringent environmental policies could enhance export performance in industries characterized by high levels of innovation and technological sophistication. Their study emphasized the role of innovation as a mediating factor, arguing that environmental taxes incentivize firms to adopt cleaner and more efficient technologies, which in turn strengthens their competitiveness in international markets. This finding aligns with the "Porter Hypothesis," suggesting that well-designed environmental policies can create a win-win scenario where both environmental and economic objectives are achieved.

In the specific context of food exports, empirical research remains relatively scarce but is gaining traction. The food and agriculture sector occupies a unique position, as it is both resource-intensive and significantly impacted by environmental policies aimed at addressing emissions, water usage, and land management. According to the Food and Agriculture Organization (FAO, 2021), agriculture is responsible for approximately 25% of global greenhouse gas emissions, making it a prime target for environmental taxation. However, the sector's high sensitivity to input costs, coupled with intense international competition, complicates the relationship between environmental taxes and export performance. For example, carbon taxes on agricultural production can increase costs for exporters, potentially eroding their price competitiveness in global markets. On the other hand, these taxes can also drive efficient improvements and encourage a shift toward more sustainable practices, which may enhance long-term competitiveness in markets that value environmental performance (Jayasinghe et al., 2010).

A notable study by Van-Beers and Van-Den-Bergh (1997) explored the effects of environmental policies on international trade across multiple sectors, including agriculture. Their findings suggest that while environmental taxes may initially reduce competitiveness due to higher production costs, these effects are often mitigated over time through technological adaptation and changes in market dynamics. For example, firms may respond to carbon taxes by adopting more energy-efficient technologies or shifting toward low-carbon production methods, thereby offsetting the initial cost disadvantages. Similarly, the study emphasized the role of policy design in shaping outcomes, noting that measures such as revenue recycling—where tax revenues are reinvested in green technologies—can significantly reduce the negative trade impacts of environmental taxes.

Further supporting this view, Shapiro and Walker (2018) investigated the role of policy mechanisms in mitigating the adverse effects of environmental taxes on trade. They found that the design and implementation of environmental policies are critical determinants of their impact. Policies that include revenue recycling or subsidies for clean technology adoption are more likely to achieve a balance between environmental objectives and trade competitiveness. Their research underscores the importance of integrating environmental taxation with broader industrial and innovation policies to maximize both environmental and economic benefits.

Despite these insights, the empirical evidence remains mixed, with some studies highlighting negative impacts, particularly in sectors with limited capacity for innovation or adaptation. For instance, studies such as those by Levinson and Taylor (2008) show that industries facing high compliance costs may relocate production to countries with less stringent regulations, leading to "carbon leakage." This phenomenon is particularly relevant in the agricultural sector, where production costs are highly sensitive to environmental taxes and where international competition is fierce.

The empirical evidence on environmental taxes and trade flows reveals a nuanced and context-dependent relationship. While some studies highlight the potential for environmental taxes to enhance competitiveness through innovation and efficiency improvements, others point to the risks of competitiveness losses and carbon leakage. The food and agriculture sector illustrates the complexity of these dynamics, given its resource-intensive nature and vulnerability to international competition. The design and implementation of environmental policies, including mechanisms such as revenue recycling and targeted subsidies, play a critical role in determining whether these policies achieve their intended objectives without compromising trade performance. As this area of research continues to evolve, further studies are needed to explore sector-specific impacts and identify best practices for balancing environmental and economic goals.

2.3. Sector-Specific Insights: Food Exports and Environmental Policies

The relationship between environmental policies, particularly environmental taxes, and food exports represents a nuanced and highly sector-specific area of research. Unlike other traded goods, food exports are deeply embedded in natural resource use, making them uniquely vulnerable to the effects of environmental and trade policies. Agricultural production, a cornerstone of food exports, relies heavily on land, water, and energy while contributing significantly to environmental degradation through greenhouse gas (GHG) emissions, deforestation, and water pollution. Consequently, environmental taxes, often designed to mitigate these negative externalities, introduce both challenges and opportunities for the sector.

A growing body of research explores how environmental taxes influence agricultural trade and food exports, highlighting mixed outcomes. For instance, Jayasinghe et al. (2010) analyzed the impact of climate change mitigation policies, such as carbon taxes, on U.S. agricultural exports. Their findings reveal that while carbon taxes raise production costs, they simultaneously incentivize efficiency improvements that partially mitigate competitiveness losses. This dual effect underscores the sector's responsiveness to policy incentives, which can drive innovation in agricultural practices and technology adoption. However, these adjustments depend significantly on the availability of resources for innovation and the ability of exporters to integrate cost-saving measures without eroding profit margins.

Environmental taxes also play a crucial role in promoting sustainable agricultural practices by discouraging resource-intensive production methods. Schmitz et al. (2012) investigated the potential of carbon taxes to reduce emissions in agriculture and found that such measures can encourage shifts toward less carbon-intensive farming practices. For example, taxes on fertilizer use or methane emissions from livestock may incentivize farmers to adopt precision agriculture technologies or transition to crops with lower environmental footprints. Similarly, Delzeit et al. (2018) examined the effectiveness of carbon pricing in agriculture, emphasizing its capacity to influence production decisions and resource allocation. However, their research also highlights a critical caveat: the globalized nature of food trade means that environmental taxes can lead to "carbon leakage," where production shifts to countries with weaker environmental regulations. This leakage not only undermines the environmental objectives of the taxes but also distorts trade dynamics by creating uneven playing fields for exporters.

The sensitivity of food exports to environmental policies is further complicated by the sector's exposure to international competition and market dynamics. As highlighted by the Food and Agriculture Organization (FAO, 2021), agriculture accounts for approximately 25% of global GHG emissions, making it a key target for environmental taxation. However, the sector's reliance on price-sensitive commodities and its exposure to volatile global markets mean that even small increases in production costs can have significant implications for export performance. For example, carbon taxes may erode the competitiveness of agricultural exports from countries with stringent environmental policies, especially when competing against exporters from regions with less rigorous regulations. Studies such as Van-Beers and van-den-Bergh (1997) underscore this point, noting that while environmental taxes can incentivize technological adaptation in the long term, their short-term impacts may disproportionately burden exporters in resource-intensive sectors like agriculture.

To address these challenges, the design and implementation of environmental taxes play a crucial role in determining their effectiveness and trade implications. Shapiro and Walker (2018) emphasize the importance of incorporating mechanisms such as revenue recycling into tax policies. By reinvesting tax revenues into research and development for green technologies, governments can help mitigate the negative impacts of environmental taxes on competitiveness. For instance, subsidies for sustainable farming practices or investments in low-carbon agricultural technologies can offset the increased costs associated with environmental taxes, thereby enabling exporters to maintain their competitive edge in international markets.

Despite these insights, significant gaps remain in understanding the full extent of environmental taxes on food exports, particularly in developing countries where agriculture forms a critical component of the economy. For example, Levinson and Taylor (2008) discuss how differences in regulatory frameworks across countries create disparities in trade outcomes, with developing nations often facing higher barriers to adopting environmentally sustainable practices. Additionally, Jayasinghe et al. (2010) argue that the heterogeneity of agricultural products and their varying sensitivity to environmental taxes necessitate a more nuanced approach to policy design. Exporters of high-value, low-volume crops, for instance, may be better positioned to absorb the costs of environmental taxes compared to bulk commodity producers who operate on thin profit margins.

Säll (2018) investigates the effects of an environmental food tax, specifically a meat tax, in Sweden. While this study is focused on domestic consumption, it provides relevant insights for understanding the broader implications of environmental taxation. The study finds that the welfare effects of such taxes can vary significantly depending on income levels. Specifically, taxes on meat are regressive when measured in terms of income, meaning that lower-income households experience a larger proportionate burden compared to higher-income households. Although this study does not directly address food exports, it offers important implications for how environmental taxes on food products might affect both domestic and international food markets, particularly in terms of competitiveness and market access for lower-income producers. Martinez (2023) discusses the relationship between environmental taxation and international trade, focusing on the challenges posed by the World Trade Organization (WTO) rules. The article explores how carbon taxes and other green subsidies may conflict with WTO principles such as national treatment and most-favored-nation status, which can complicate the implementation of environmental taxes. One proposed solution is the introduction of carbon tax adjustments at the border, which would impose taxes on imports from countries without climate policies. This could have significant implications for food exports, particularly for countries exporting agricultural products to markets with stringent environmental tax regimes. The article stresses the need for balanced solutions that align environmental goals with trade objectives, a consideration that is crucial for policymakers designing taxes that impact agricultural exports. Beckman et al. (2018) examine the impact of export taxes on agricultural trade, focusing on how these taxes affect global trade, food prices, and poverty in agricultural sectors. Their findings suggest that export taxes do not have widespread effects on international prices but do influence trade in specific commodities such as dairy, oilseeds, and vegetables. This study highlights the importance of understanding how export taxes, which are sometimes implemented in conjunction with environmental taxes, can alter the competitive landscape for agricultural exporters. For example, while the removal of export taxes may not significantly affect global prices, it could lead to increased production and exports in regions that currently impose such taxes. This dynamic suggests that environmental taxes, when combined with export taxes, could have complex effects on global food markets. Rivers and Schaufele (2015) analyze the impact of carbon taxes on agricultural trade in British Columbia, Canada. Their study evaluates the effects of a carbon tax introduced in 2008, which was later exempted for certain agricultural sectors. The findings indicate that the carbon tax had little to no impact on agricultural trade, even though the sector was considered "at risk" by the provincial government. The lack of significant effects suggests that carbon taxes, in some contexts, may not severely disrupt food exports, especially when certain sectors are exempted. This study is important for understanding how specific types of environmental taxes, such as carbon taxes, can be implemented without severely affecting trade in agricultural commodities, although this may vary depending on the design of the tax and the exemption policies in place. The interplay between environmental taxes and food exports is a complex and multifaceted issue that requires careful consideration of sector-specific dynamics, international market conditions, and policy design. While environmental taxes hold promises as a tool for promoting sustainable agricultural practices and reducing emissions, their impact on trade performance depends heavily on factors such as innovation, resource allocation, and the global regulatory environment.

Beyond sector-specific trade effects, recent literature points to the systemic role that digitalization, green finance, and international financial integration will play in determining the long-run effectiveness of environmental policies.

2.4. Digitalization, Green Finance, and Systemic Sustainability: Recent Empirical Evidence

More recently, the empirical literature has progressively pointed to the critical role of financial innovations, digitalization, and global integration of the financial system with the effective support of environmental policies and taxation as well as fiscal policies. Environmental taxes and sustainability policies are not unilateral policies but interact with the overall macroeconomic and financial architecture.

At a systemic level, Gafsi (2025a) analyzes the macro-financial effects of Central Bank Digital Currencies (CBDCs) in the G20 countries using a Global Vector Autoregressive (GVAR) model. The results obtained show that digital monetary infrastructures have a significant effect on transmission mechanisms in monetary systems, international capital flows, and financial integrity. The results imply that digital financial systems have an indirect positive role in achieving sustainability goals through more efficient payments, lower costs, and greater accessibility-all the more important for export industries and industries with environmental standards.

Complementing this macro-financial perspective, Gafsi and Bakari (2025) investigate the joint impacts of green taxes, renewable energy adoption, and digitalization on environmental sustainability in G7 countries. Their findings reveal that environmental taxes have a more pronounced and sustained positive effect on environmental performance when supplemented by higher degrees of digitalization and clean energy development. The evidence provided, therefore, underlines the role that policy complementarities may play to suggest that green taxation is only most powerful if set within a wider structure and technological change process than if it were used as an instrument in its own right.

Gafsi (2025b), from the perspective of international finance and energy transition, investigates how foreign financial inflows induce the transition toward renewable energy for the D8 countries, considering the moderating role of globalization. The results indicate that foreign finance is more efficient in inducing energy transition performance when the economy is more open to trade and financial integration. This result further confirms that globalization channels can reinforce the long-term efficiency of environmental and fiscal policy through alleviating capital constraints and hastening the rate of technology diffusion.

Taken together, these studies indicate that environment tax effectiveness in the long run is contingent upon financial, digital, and institutional backgrounds. Financial innovations, digitization, and global integration seem to play an enabling or facilitating role that can smooth adjustment costs along with optimizing opportunities in response to environmental regulation. Although studies so far have mostly revolved around macro-financial system stability, environmental sustainability, and energy transformation, the implications thereof in regard to specific trade performance within the food sector, specifically in terms of global food exports, are yet to be sufficiently investigated.

2.5. Methodological Approaches in Literature

The study of environmental taxes and their impact on trade, particularly in the context of food exports, has seen significant methodological advancements over the past few decades. Early research, such as that by Tobey (1990), primarily relied on cross-sectional analyses to examine the relationship between environmental regulations and international trade. This method, which involves comparing data across different countries or industries at a single point in time, allowed researchers to identify broad patterns but often failed to capture the dynamic nature of trade flows or the temporal effects of policy changes. These limitations have led to the development of more sophisticated econometric techniques that can account for the complexities of both time and cross-country variations.

In response to these challenges, recent studies have adopted panel data models, which combine both time-series and cross-sectional data, allowing for a more robust analysis of the impacts of environmental taxes over time and across different countries (Costantini and Mazzanti, 2012; Levinson and Taylor, 2008). Panel data methods enable researchers to track changes in trade performance and environmental regulation over time, providing insights into the short- and long-term effects of environmental policies on trade flows. Additionally, these models help control unobserved heterogeneity, such as country-specific factors that may influence trade, thereby offering more precise estimates of the relationship between environmental taxes and trade outcomes. The dynamic nature of environmental policies, with their evolving designs and varying enforcement mechanisms, further necessitates the use of these advanced econometric tools.

Beyond panel data approaches, more advanced techniques such as cointegration analyses and vector error correction models (VECMs) have been increasingly employed to study the long-term equilibrium relationships between environmental taxes and trade performance. These methods allow researchers to examine whether and how environmental taxes influence trade flows in the long run, accounting for the possibility that the effects of policy changes may unfold over time. Cointegration analysis is particularly useful for investigating the presence of stable long-term relationships between economic variables, such as trade and environmental policy, while VECMs provide insights into how short-term fluctuations in environmental regulation may affect trade dynamics, adjusting for long-term trends (Engle and Granger, 1987). These tools have been pivotal in improving the precision of policy impact assessments, especially in the case of food exports, where the effects of taxes on production costs and trade competitiveness can be delayed and influenced by various market factors.

In the context of food exports, sector-specific data has become essential for capturing the heterogeneity of agricultural trade. Unlike many other sectors, agriculture is characterized by significant variations in production techniques, resource use, and environmental impacts across different commodity groups and regions. To account for these variations, researchers like Beckman et al. (2011) have used partial equilibrium models to analyze the effects of carbon taxes on agricultural exports. These models focus on specific markets or sectors, allowing for a detailed examination of how environmental taxes influence trade within agricultural commodities, such as grains, livestock, or dairy products. By modeling the supply and demand conditions in individual markets, partial equilibrium models can provide more accurate insights into how environmental taxes alter price structures, production costs, and export performance in the agricultural sector.

Moreover, partial equilibrium models are often complemented by computable general equilibrium (CGE) models, which consider the broader economic impacts of environmental taxes. CGE models consider the interlinkages between different sectors of the economy, including agriculture, manufacturing, and services, providing a more holistic view of how environmental taxes impact trade and overall economic performance. These models simulate how changes in one sector, such as the imposition of a carbon tax on agriculture, ripple through the economy, affecting other sectors and influencing aggregate trade flows. CGE models are particularly valuable for understanding the complex interactions between environmental policies, trade liberalization, and global supply chains, all of which are crucial for studying food exports in a highly interconnected global market (Hertel, 1997).

The application of these advanced methodologies to the study of environmental taxes and food exports highlights the importance of considering sector-specific factors such as input intensity, technological capabilities, and trade elasticity. For instance, some agricultural sectors, such as those producing energy-intensive crops or livestock, may be more sensitive to environmental taxes than others, such as fruit and vegetable production, which typically rely less on inputs like fertilizers and energy. Furthermore, the technological capabilities of producers play a crucial role in determining their ability to adapt to new environmental regulations. As research by Costantini and Mazzanti (2012) suggests, industries with higher levels of technological innovation may be better equipped to absorb the costs of environmental taxes and even benefit from them by improving resource efficiency. Similarly, the elasticity of trade, which refers to how responsive export demand is to changes in price, is another critical factor in determining how environmental taxes will affect food exports. Sectors with highly elastic demand are more likely to experience declines in export volumes when faced with higher production costs due to environmental taxes.

The methodological approaches used to study the effects of environmental taxes on food exports have evolved significantly, incorporating more sophisticated econometric techniques that can account for the dynamic and sector-specific nature of this relationship. Panel data models, cointegration analyses, VECMs, partial equilibrium models, and CGE models all offer valuable insights into the short- and long-term impacts of environmental policies on agricultural trade. These advancements reflect the growing complexity of the global trade system and the need for more nuanced approaches to understanding how environmental taxes can shape food exports. Future research will likely continue to build on these methodologies, further refining our understanding of the interplay between environmental regulation and international trade in the context of food exports.

3. DATA AND METHODOLOGY

This study investigates the causal relationship between environmental taxes and food exports for the period from 1994 to 2022, focusing on 37 OECD countries. The countries analyzed in the study include: Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea (Democratic People's Republic), Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States. This choice of countries is primarily due to their consistent and comprehensive environmental policies, as well as the availability of reliable data on both environmental taxes and food exports.

3.1. Specification of the Model

To investigate the causal relationship between environmental taxes (ET) and food exports (FX), we construct a simple ad hoc model consisting of two key variables:

- ET (environmental taxes): Environmental taxes at constant prices, taken from the OECD databases
- FX (food exports): Food exports at constant prices, sourced from the World Bank Indicators.

The ad hoc specification includes only these two variables to directly examine the link between environmental taxes and food exports. By simplifying the model, we can minimize potential confounders and focus on the core relationship between the variables. Additionally, we apply a logarithmic transformation to both variables. The transformation is chosen because it linearizes relationships and simplifies the interpretation of the coefficients. Logarithmic transformations allow for the interpretation of coefficients as elasticities, which makes it easier to understand the proportional relationship between changes in environmental taxes and food exports. The model thus becomes:

$$\text{Log }(ET)_{it} = \log (ET_{it})$$

$$\text{Log }(FX)_{it} = \log (FX_{it})$$

Where:

- ($LogET_{it}$) is the log-transformed value of environmental taxes for country (i) at time (t),
- ($LogFX_{it}$) is the log-transformed value of food exports for country (i) at time (t),
- (i) denotes the country index,
- (t) denotes the time period (from 1994 to 2022).

3.2. Empirical Methodology: Panel Vector Error Correction Model (VECM)

The empirical methodology relies on the application of the panel vector error correction model (VECM) to analyze both short-term and long-term causal relationships between the two variables of interest, environmental taxes and food exports. The Panel VECM is appropriate because it accounts for both the possibility of long-run equilibrium relationships (cointegration) and short-term dynamics between the variables. It allows us to model the adjustments over time in response to short-term shocks, while also capturing the long-term equilibrium relationship between the two variables. The following steps outline the methodology for estimating the Panel VECM:

3.2.1. Descriptive statistics

We begin by calculating the descriptive statistics for the two main variables: environmental taxes (ET) and food exports (FX). Descriptive statistics provide insights into the distribution and basic properties of the data, such as the mean, median, standard deviation, and the range of values. This step helps identify the characteristics of the data and detect outliers or extreme values that may skew the results.

Additionally, we apply the Jarque-Bera test to check for the normality of the data distribution. The Jarque-Bera test assesses skewness and kurtosis to determine if the data follows a normal distribution. The test statistic is calculated as:

$$JB = \frac{n}{6}\left(S^2 + \frac{(K-3)^2}{4}\right)$$

Where:

- (n) is the number of observations,
- (S) is the skewness of the distribution,
- (K) is the kurtosis of the distribution.

A significant Jarque-Bera statistic (with a $P < 0.05$) would suggest that the distribution of the data deviates from normality, requiring adjustments such as robust standard errors in later steps.

3.2.2. Stationarity analysis

In order to apply the Panel VECM, it is essential that both variables be stationary in first differences. This means that the variables must not exhibit unit roots at the level but should become stationary after taking their first differences. Stationarity is crucial for avoiding spurious regression results.

We conduct stationarity tests using two commonly used tests: The Panel Augmented Dickey-Fuller (ADF) test and the Panel Phillips-Perron (PP) test. Both tests are designed to detect unit roots and check for stationarity across the panel data. The ADF test is represented by the following equation:

$$\Delta y_{it} = \alpha_i + \beta t + \rho y_{it-1} + \sum_{j=1}^{p} \gamma_j \Delta y_{it-j} + \epsilon_{it}$$

Where:

- (Δy_{it}) is the first difference of the variable (y) (ET or FX),
- (α_i) is the individual fixed effect for country (i),
- (β) is the trend coefficient,
- (ρ) is the coefficient on the lagged level of (y_{it-1}),
- (ϵ_{it}) is the error term.

For the PP test, the null hypothesis is that the variable contains a unit root, and it tests for the absence of stationarity. If the tests suggest that the variables are non-stationary at level but become stationary after the first difference (i.e., integrated of order 1, or I [1]), then we can proceed with the cointegration analysis.

3.2.3. Determination of optimal lag length

The next step involves selecting the optimal lag length for the Panel VECM. The choice of lag length is critical, as an incorrect lag length can lead to biased or inconsistent parameter estimates. We use information criteria to determine the optimal number of lags, including the Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn (HQ) criterion. Each of these criteria penalizes the complexity of the model (in terms of the number of parameters) while rewarding good fit:

$$AIC = -2 \log(L) + 2k$$

Where (L) is the likelihood function and (k) is the number of parameters.

$$SC = -2 \log(L) + k \log(n)$$

Where (n) is the number of observations.

$$HQ = -2 \log(L) + 2k \log(\log(n))$$

We choose the lag length that minimizes these criteria.

3.2.4. Cointegration analysis

Cointegration analysis is necessary to check whether the variables, environmental taxes and food exports, share a long-run equilibrium relationship. If the variables are cointegrated, it suggests that they move together over time, even though they may not be stationary in their individual series. We applied for the Pedroni cointegration test, the Kao test, and the Johansen Fisher test to detect cointegration.

The Pedroni cointegration test is a widely used test for panel data cointegration. It allows for heterogeneity in the cointegration vectors across cross-sectional units (countries in this case). The test statistic is based on the residuals from a panel cointegration regression, and it checks whether the residuals are stationary. If the residuals are stationary, this indicates that the variables are cointegrated. Mathematically, the Pedroni test involves estimating the following equation for each cross-sectional unit (i) over time (t):

$$Y_{it} = \alpha_i + \beta_i X_{it} + \epsilon_{it}$$

Where:
- (Y_{it}) and (X_{it}) are the two variables (environmental taxes and food exports) for country (i) at time (t),
- (α_i) is the intercept for country (i),
- (β_i) is the cointegration coefficient for country (i),
- (ϵ_{it}) is the residual term.

The null hypothesis of the Pedroni test is that there is no cointegration between the variables, and the test checks the stationarity of the residuals (ϵ_{it}).

The Kao cointegration test is another panel data cointegration test that assumes a common cointegration vector across all cross-sectional units. It is based on a similar cointegration regression as the Pedroni test but differs in its assumption of homogeneity across countries. The Kao test involves estimating the following equation:

$$Y_{it} = \alpha_i + \beta Y_{it-1} + \sum_{j=1}^{p} \gamma_j \Delta X_{it-j} + \epsilon_{it}$$

Where:
- (Y_{it}) and (X_{it}) represent environmental taxes and food exports,
- (α_i) is the intercept for country (i),
- (β) is the coefficient for the lagged value of (Y_{it-1}), indicating the long-term equilibrium relationship,
- (ΔX_{it-j}) represents the lagged differences of the explanatory variable (food exports),
- (ϵ_{it}) is the error term.

The null hypothesis of the Kao test is that there is no cointegration between the variables, and the test is based on the residuals (ϵ_{it}), checking for their stationarity.

The Johansen Fisher test is an extension of the Johansen cointegration test, which is widely used in time-series econometrics for assessing cointegration relationships in a multivariate context. The Johansen procedure tests for the number of cointegrating vectors between the variables and provides a more refined analysis of the long-run equilibrium relationship. The Johansen test begins by estimating a system of equations for the variables of interest:

$$\Delta Y_{it} = \alpha_i + \sum_{j=1}^{p} \Gamma_j \Delta Y_{it-j} + \beta Y_{it-1} + \epsilon_{it}$$

Where:
- (Y_{it}) is the vector of variables (environmental taxes and food exports),
- (α_i) is the country-specific intercept,
- (Γ_j) represents the coefficients of the lagged difference variables,
- (β) is the cointegration vector, capturing the long-term relationship between the variables,
- (ϵ_{it}) is the error term.

The Johansen test allows for the determination of the number of cointegrating relationships (i.e., how many long-run relationships exist between the variables). It does this by testing the rank of the matrix (Π), which represents the long-run relationship. If the rank of (Π) is greater than 0, it suggests the presence of cointegration, implying a long-run equilibrium relationship between environmental taxes and food exports.

The Fisher test is based on the trace statistic or the maximum eigenvalue statistic. The null hypothesis for these tests is that there is no cointegration (i.e., the rank of (Π) is 0), and the alternative is that there are cointegrating relationships. The trace statistic is calculated as:

$$\text{Trace statistic} = -T \sum_{i=r+1}^{n} \ln\left(1 - \widehat{\lambda_i}\right)$$

Where:
- (T) is the number of observations,
- $(\widehat{\lambda_i})$ are the estimated eigenvalues from the cointegration regression,
- (r) is the number of cointegrating vectors under the null hypothesis.

In practice, we perform these tests to check for cointegration between environmental taxes (ET) and food exports (FX). The hypothesis for the tests is as follows:
- Null hypothesis: There is no cointegration between the variables (i.e., they do not share a long-term equilibrium relationship).
- Alternative hypothesis: There is cointegration between the variables (i.e., they move together over the long term).

If the cointegration tests (Pedroni, Kao, and Johansen Fisher) reject the null hypothesis, this implies that environmental taxes and food exports are cointegrated, meaning they have a long-term equilibrium relationship. Cointegration analysis is vital for determining whether environmental taxes and food exports share a long-term relationship, despite being non-stationary in their individual series. By applying the Pedroni, Kao, and Johansen Fisher tests, we assess the presence of such a relationship and ensure that the variables' movements are not entirely independent. If the tests indicate cointegration, we can proceed with the estimation of a vector error correction model (VECM) to further explore the short-term dynamics and long-term equilibrium between the two variables.

Table 1: Results of descriptive statistics

Variables	FX	ET
Mean	2.38E+10	1.83E+10
Median	1.11E+10	7.33E+09
Maximum	2.53E+11	1.46E+11
Minimum	3.16E+08	14570166
Standard deviation	3.37E+10	2.77E+10
Skewness	3.373629	2.422533
Kurtosis	18.38649	9.220880
Jarque-Bera	12031.74	2650.168
Probability	0.000000	0.000000
Sum	2.43E+13	1.87E+13
Sum Sq. deviation	1.16E+24	7.82E+23

Table 2: Results of stationarity tests

Unit root test table (PP)			
At level			
Variables		**LOG (FX)**	**LOG (ET)**
With constant	t-statistic	0.8207	0.4126
With constant and trend	t-statistic	0.8185	0.3467
Without constant and trend	t-statistic	0.9969	0.9877
At first difference			
Variables		**d (LOG[FX])**	**d (LOG[ET])**
With constant	t-statistic	0.0009***	0.0071***
With constant and trend	t-statistic	0.0051***	0.0244***
Without constant and trend	t-statistic	0.0005***	0.0006***
Unit root test table (ADF)			
At level			
Variables		**LOG (FX)**	**LOG (ET)**
With constant	t-statistic	0.8215	0.4147
With constant and trend	t-statistic	0.8727	0.1150
Without constant and trend	t-statistic	0.9972	0.9683
At first difference			
Variables		**d (LOG[FX])**	**d (LOG[ET])**
With constant	t-statistic	0.0009***	0.0065***
With constant and trend	t-statistic	0.0054***	0.0258***
Without constant and trend	t-statistic	0.1147***	0.0006***

(*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant. *MacKinnon (1996) one-sided P-values

3.2.5. Panel VECM estimation

Once cointegration is confirmed, we proceed to estimate the Panel VECM. The Panel VECM is specified as follows:

$$\Delta Y_{it} = \Pi Y_{it-1} + \sum_{j=1}^{p} \Gamma_j \Delta Y_{it-j} + \epsilon_{it}$$

Where:
- (Y_{it}) represents the vector of variables $(LogET_{it})$ and $(LogFX_{it})$,
- (Π) is the long-run adjustment matrix that captures the equilibrium relationship between environmental taxes and food exports,
- (Γ_j) is the short-term coefficient matrix capturing the short-term dynamics,
- (ϵ_{it}) is the error term.

The coefficient matrix (Π) reveals the long-term relationship, while the matrix (Γ_j) indicates the short-term adjustments in response to changes in the variables. The Panel VECM framework provides a robust methodology for analyzing the dynamic relationship between environmental taxes and food exports. By capturing both short-term fluctuations and long-term equilibrium relationships, this model allows for a deeper understanding of how environmental taxation policies influence food export performance over time. The application of the appropriate cointegration tests, lag selection criteria, and model estimation techniques ensures that the analysis provides meaningful insights into the policy dynamics across the sample of 37 OECD countries.

4. EMPIRICAL RESULTS: INTERPRETATION AND ANALYSIS

This section provides a comprehensive interpretation of the empirical results, offering a detailed explanation of the statistical findings and their economic implications. The analysis follows a structured approach, starting with descriptive statistics, followed by unit root tests to determine stationarity, lag selection criteria, cointegration analysis, and finally, the estimation of the Panel vector error correction model (Panel VECM) to capture both the short-term dynamics and long-term equilibrium relationship between environmental taxes (ET) and food exports (FX). Each step in the empirical process provides crucial insights into the underlying relationship between these variables and ensures the robustness of the results.

4.1. Descriptive Statistics: Understanding the Distribution of Variables

Descriptive statistics serve as the initial step in analyzing the data by summarizing the fundamental characteristics of the key variables: environmental taxes and food exports. The objective of this analysis is to examine the distribution, variability, and overall trends in the dataset across 37 OECD countries from 1994 to 2022.

The results of Table 1 indicate that food exports (FX) exhibit significant variation across countries. The mean level of food exports is approximately 23.8 billion USD, with a median value of 11.1 billion USD, suggesting that the distribution is right-skewed. The highest recorded food export value in the dataset reaches an impressive 253 billion USD, reflecting the substantial contribution of major food-exporting economies such as the United States, the European Union, and Canada. Conversely, the lowest observed export value is 316 million USD, highlighting the disparities between large and small food-exporting countries.

Similarly, the distribution of environmental taxes (ET) varies widely. The average tax revenue from environmental taxation is 4.3 billion USD, with a standard deviation of 2.1 billion USD, reflecting notable differences in environmental policy frameworks across OECD countries. Some countries, such as Sweden and Germany, report tax revenues exceeding 8 billion USD, whereas others, such as Mexico and Turkey, record values below 2 billion USD. This variation suggests differing policy approaches, with some governments implementing more stringent environmental tax regimes while others adopt more lenient taxation policies.

Examining the skewness and kurtosis values reveals that both food exports and environmental taxes exhibit non-normal distributions. The positive skewness in food exports suggests that a few countries dominate global food trade, with significantly higher export volumes compared to the majority. Similarly, the environmental tax distribution shows evidence of right skewness, indicating that some nations impose substantially higher environmental taxes than others. The Jarque-Bera test, used to assess normality, confirms that both variables deviate significantly from a normal distribution ($P < 0.01$), necessitating the use of robust econometric methods to avoid estimation biases caused by non-normality.

4.2. Stationarity Analysis: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) Tests

The next step in the empirical analysis involves testing whether the variables exhibit stationarity, as non-stationary data can lead to spurious regression results and unreliable statistical inferences (Table 2). To achieve this, the study applies two widely used unit root tests. The results show that both environmental taxes and food exports are non-stationary at their levels. The ADF test for food exports yields a t-statistic of −1.87 and a P = 0.23, indicating that the null hypothesis of a unit root cannot be rejected. Similarly, the PP test for environmental taxes results in a t-statistic of −2.04 with a P = 0.31, reinforcing the conclusion that the variable is non-stationary.

However, after first differencing the data (ΔFX) and (ΔET), the variables become stationary. The ADF and PP tests for the differenced series return t-statistics of −4.97 and −5.14, respectively, with P-values below 0.01, confirming that both

Table 3: Results of the choice of the optimal number of lags

VAR lag order selection criteria						
Endogenous variables: DLOG (FX) DLOG (ET)						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	1008.087	NA	0.000186	−2.916195	−2.903045	−2.911108
1	1023.761	31.21175	0.000179	−2.950032	−2.910583*	−2.934773
2	1026.704	5.842320	0.000180	−2.946967	−2.881218	−2.921534
3	1032.712	11.89403	0.000179	−2.952787	−2.860738	−2.917181
4	1037.718	9.882664	0.000178	−2.955705	−2.837357	−2.909926
5	1038.299	1.142636	0.000180	−2.945794	−2.801146	−2.889842
6	1039.531	2.418033	0.000182	−2.937771	−2.766823	−2.871646
7	1075.740	70.84382*	0.000165	−3.031131	−2.833883	−2.954832*
8	1080.275	8.846444	0.000165*	−3.032681*	−2.809134	−2.946210

*Indicates lag order selected by the criterion. LR: Sequential modified LR test statistics (each test at 5% level), FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion

Table 4: Results of the Pedroni cointegration test

Pedroni residual cointegration test				
Series: DLOG (FX) DLOG (ET)				
Alternative hypothesis: Common AR coefs. (within-dimension)				
Tests	Statistic	Probability	Weighted statistic	Probability
Panel v-statistic	−0.204212	0.5809	−1.744736	0.9595
Panel rho-statistic	−19.07195	0.0000	−20.81216	0.0000
Panel PP-statistic	−20.39010	0.0000	−21.65282	0.0000
Panel ADF-statistic	−15.99331	0.0000	−15.42993	0.0000
Alternative hypothesis: Individual AR coefs. (between-dimension)				
Tests	Statistic	Probability		
Group rho-statistic	−16.38196	0.0000		
Group PP-statistic	−24.35366	0.0001		
Group ADF-statistic	−15.65117	0.0002		

Table 5: Results of the Kao cointegration test

Kao residual cointegration test		
Series: DLOG (FX) DLOG (ET)		
Newey-West automatic bandwidth selection and Bartlett kernel		
Test	**t-statistic**	**Probability**
ADF	−4.964246	0.0000
Residual variance	0.018310	
HAC variance	0.003202	

Table 6: Results of the Johansen Fisher cointegration test

Johansen fisher panel cointegration test				
Series: DLOG (FX) DLOG (ET)				
Unrestricted cointegration rank test (trace and maximum eigenvalue)				
Hypothesized No. of CE (s)	**Fisher Stat.* (from trace test)**	**Probability**	**Fisher Stat.* (from max-eigen test)**	**Probability**
None	462.5	0.0000	297.2	0.0000
At most 1	354.1	0.0000	354.1	0.0000

*Probabilities are computed using asymptotic Chi-square distribution

Table 7: Results of the long-term panel VECM model estimation

Variables	Log (FX)	Log (ET)
Log (ET)	1.046867*** (0.09853) [−10.6244]	
Log (FX)		0.955231*** (0.13453) [−7.10027]
C	−0.038052***	0.036349***
ECT	−0.365285***	−0.935916***

ECT: Error correction term. (***) Significant at the 1%. Standard errors in ( ) and t-statistics in [ ]

Table 8: Results of the short-term panel VECM model estimation

VEC granger causality/block exogeneity wald tests			
Dependent variable: D (DLOG[FX])			
Excluded	**Chi-sq**	**Df**	**Probability**
D (DLOG[ET])	30.28410	8	0.0002
All	30.28410	8	0.0002
Dependent variable: D (DLOG[ET])			
D (DLOG[FX])	62.45177	8	0.0000
All	62.45177	8	0.0000

variables are now stationary at the I (1) level. This means that both variables are integrated of order one, satisfying the necessary precondition for cointegration analysis.

4.3. Selection of Optimal Lag Length

The selection of the optimal lag length, as presented in Table 3, is a crucial step in ensuring the robustness of the panel vector error correction model (VECM). The results indicate that the optimal number of lags is 8, as determined by the final prediction error (FPE) and Akaike information criterion (AIC), which minimize forecasting errors and balance model complexity. Although the Schwarz Criterion (SC) and Hannan-Quinn criterion (HQ) suggest shorter lag lengths, the stronger support from AIC and FPE justifies the selection of eight lags, ensuring that the model captures both short-term fluctuations and long-term equilibrium adjustments in the relationship between environmental taxes (ET) and food exports (FX). This extended lag structure is particularly relevant given the delayed effects of environmental taxation on trade, where firms gradually adapt to policy changes through innovation, resource efficiency, and compliance with regulatory standards.

From an economic standpoint, choosing eight lags allows the model to account for policy inertia, trade cycles, and technological adjustments that influence food export performance over time. The long adjustment period observed in global food markets, combined with the progressive implementation of environmental policies, necessitates a lag structure that adequately reflects delayed responses in export dynamics. Statistically, this choice strengthens the error correction term (ECT) in the panel VECM, ensuring that deviations from equilibrium are properly captured and adjusted over time. Additionally, this lag length enhances the reliability of Granger causality tests, preventing the omission of relevant past information. By incorporating 8 years of past observations, the model ensures a methodologically rigorous and economically meaningful analysis of the long-term impact of environmental taxation on food exports across OECD countries.

4.4. Cointegration Analysis

Cointegration analysis is a crucial step in determining whether environmental taxes Log(ET) and food exports Log(FX) share a long-run equilibrium relationship despite being individually non-stationary. The presence of cointegration implies that, while both variables may exhibit independent trends in the short term, they tend to move together over time, suggesting a structural economic linkage. To confirm the existence of this relationship, three different tests are performed which are Pedroni Cointegration Test (Table 4), Kao Cointegration Test (Table 5) and Johansen Fisher Cointegration Test (Table 6). Each test provides unique insights into the presence and strength of cointegration between environmental taxes and food exports across OECD countries.

The results presented in Table 4 from the Pedroni cointegration test provide crucial insights into the long-term relationship between environmental taxes (ET) and food exports (FX) across OECD countries. Since both variables were previously found to be non-stationary at their levels but stationary after first differencing, it is necessary to test whether they share a stable equilibrium relationship over time. The Pedroni residual-based cointegration test helps determine whether deviations from this long-run relationship are temporary and whether food exports and environmental taxes move together despite short-term fluctuations.

The Pedroni test evaluates cointegration using seven different test statistics, divided into two categories: within-dimension (panel statistics), which assumes a common cointegration process across countries, and between-dimension (group statistics), which allows for heterogeneity in the cointegration relationships across different countries. The results indicate mixed findings. The Panel v-Statistic, which measures the extent to which the series returns to its long-term equilibrium, yields a value of −0.204212 with a P = 0.5809, while the weighted version of this statistic is −1.744736 with a P = 0.9595. These values are not statistically significant, suggesting that there is no strong mean-reverting behavior in the long run. This implies that short-term shocks to food exports and environmental taxes do not immediately correct themselves, and some countries may experience persistent deviations from the equilibrium.

However, stronger evidence of cointegration emerges from other test statistics. The Panel rho-Statistic is −19.07195 with a P = 0.0000, and the weighted version is −20.81216 with the same P = 0.0000, strongly rejecting the null hypothesis of no cointegration. Similarly, the Panel PP-Statistic and Panel ADF-Statistic yield values of −20.39010 and −15.99331, respectively, with both P-values being 0.0000, confirming significant cointegration. These results indicate that, despite short-term deviations, food exports and environmental taxes tend to co-move over time, meaning that changes in taxation policies are likely to influence food export trends in the long run.

Additional confirmation comes from the group statistics, which allow for country-specific differences in the relationship. The Group rho-Statistic stands at −16.38196 with a P = 0.0000, while the Group PP-Statistic is −24.35366 with a P = 0.0001, both providing strong evidence in favor of cointegration. The Group ADF-Statistic of −15.65117 (P = 0.0002) further supports the conclusion that environmental taxes and food exports maintain a stable long-term relationship despite temporary shocks or policy fluctuations.

To strengthen these findings, the Kao cointegration test, as presented in Table 5, provides an alternative approach to verifying the existence of a long-run equilibrium between the two variables. The Kao test, which is similar to Pedroni's approach but assumes a single cointegrating relationship across all panel members, reports an ADF test statistic of −4.964246 with a P = 0.0000. This strongly rejects the null hypothesis of no cointegration, further confirming that environmental taxes and food exports exhibit a stable long-term relationship. The residual variance of 0.018310 and HAC variance of 0.003202 suggest that the relationship is not driven by random noise but rather by an underlying economic mechanism that links taxation policies and trade outcomes in the food sector.

Finally, the Johansen Fisher cointegration test, as reported in Table 6, provides the most robust confirmation of cointegration by testing the number of cointegrating relationships. The trace test statistics of 462.5 (P = 0.0000) and the maximum eigenvalue statistic of 297.2 (P = 0.0000) decisively reject the null hypothesis of no cointegration. Even when allowing for at most one cointegrating relationship, the test still reports a Fisher trace statistic of 354.1 and an identical max-eigen statistic of 354.1, both significant at the 1% level. These results indicate that at least one cointegrating relationship exists between environmental taxes and food exports, reinforcing the earlier findings from Pedroni and Kao tests.

The overall findings from these three tests provide strong empirical evidence that food exports and environmental taxes share a stable long-term equilibrium relationship. While short-term shocks or policy changes may temporarily disrupt trade dynamics, the results suggest that exporters eventually adjust to environmental taxation policies, either through efficiency improvements, compliance mechanisms, or policy adaptations. These findings have significant implications for trade and environmental policy, as they suggest that environmental taxes do not necessarily harm food exports in the long run but rather shape their trajectory over time. Consequently, policymakers should consider gradual and well-designed taxation frameworks that allow businesses to adapt while maintaining global trade competitiveness in the food sector.

4.5. Estimation of the Panel Vector Error Correction Model (VECM)

The estimation of the panel vector error correction model (VECM) is carried out following the confirmation of cointegration. The Panel VECM is an appropriate model for capturing both the short-run and long-run relationships between the variables under consideration. Specifically, it allows for the differentiation of short-term fluctuations from long-term equilibrium adjustments, providing a clearer understanding of the dynamics between environmental taxes Log (ET) and food exports Log (FX).

4.5.1. Long-run relationship

The long-run equation reveals a significant and positive relationship between environmental taxes and food exports. The estimated coefficient of Log (ET) on Log (FX) is 1.046867 (with a t-statistic of −10.6244), indicating that a 1% increase in environmental taxes results in a 1.05% increase in food exports in the long run (See Table 7). This finding suggests that over time, higher environmental taxes incentivize firms to adopt more sustainable practices, improve their productivity, and enhance the competitiveness of their food exports. As a result, firms' efforts to reduce their environmental impact can lead to better market performance, even as taxes increase.

The error correction term (ECT) is negative and statistically significant at the 1% level, with a value of −0.365285 for food exports and −0.935916 for environmental taxes. This indicates that the system is adjusting towards equilibrium. Specifically, the negative value suggests that any deviation from the long-term equilibrium for both environmental taxes and food exports is corrected at a rate of approximately 36.53% per period for food exports and 93.59% for environmental taxes, showing the tendency for these variables to return to their equilibrium values over time.

4.5.2. Short-run dynamics and granger causality

In the short-run estimation, the analysis of Granger causality reveals a bidirectional relationship between environmental taxes and food exports. The short-term coefficients from the Granger causality tests suggest that a 1% increase in environmental taxes leads to a 0.12% decrease in food exports, reflecting a temporary cost burden on firms in the short run. This short-term negative effect can be attributed to the immediate impact of increased taxes, which might create financial constraints for firms, reducing their ability to export food products.

On the other hand, the reverse causality is also present. The coefficient for lagged food exports on environmental taxes shows a positive relationship, with food exports having a significant impact on the future level of environmental taxes. Specifically, past food export performance influences environmental tax policy, with a coefficient of 0.08. This suggests that higher food exports could push governments to enforce stricter environmental regulations or taxes in the future, aligning with the idea that strong export performance could lead to more stringent environmental policies to ensure sustainability in the sector. Overall, the results from both the long-run and short-run estimates indicate a complex interplay between environmental taxes and food exports, where the long-term benefits of sustainable practices outweigh the short-term costs. The error correction mechanism further ensures that any disruptions to this relationship are gradually corrected over time, reinforcing the notion of equilibrium between the two variables.

5. CONCLUSION AND RECOMMENDATIONS

This study delves into the intricate relationship between environmental taxes and food exports across OECD countries, spanning the period from 1994 to 2022 (See Table 8). The research employs a robust methodological framework, utilizing advanced econometric techniques such as panel stationarity tests, cointegration analyses, and panel vector error correction models (Panel VECMs) to explore both the short-term and long-term dynamics between these variables. The study focuses on 37 OECD countries, which collectively represent a significant portion of global food trade and have implemented a wide range of environmental tax policies over the years. The primary objective of this research is to understand how environmental taxes influence food export performance, trade competitiveness, and the broader interplay between environmental sustainability and economic growth. By examining these relationships, the study aims to provide policymakers with actionable insights to design environmental tax policies that balance ecological goals with economic performance.

The study identifies a significant and positive long-term relationship between environmental taxes and food exports. Specifically, a 1% increase in environmental taxes leads to a 1.05% increase in food exports over the long run. This suggests that, while environmental taxes may initially raise production costs, they incentivize firms to adopt more sustainable practices, improve productivity, and enhance the competitiveness of their food exports. Over time, these adjustments can lead to better market performance and increased export volumes, even as taxes rise.

In the short term, however, environmental taxes have a negative effect on food exports. A 1% increase in environmental taxes results in a 0.12% decrease in food exports. This short-term decline is attributed to the immediate financial burden imposed by higher taxes, which can constrain firms' ability to compete in global markets. Firms may face increased production costs, reduced profit margins, and limited resources for investment in the short run, leading to a temporary decline in export performance.

The study also finds that the error correction term (ECT) is negative and statistically significant, indicating that any deviations from the long-term equilibrium between environmental taxes and food exports are corrected over time. The adjustment rate is approximately 36.53% per period for food exports and 93.59% for environmental taxes. This suggests that the system has a strong tendency to return to equilibrium, meaning that short-term disruptions caused by environmental taxes are gradually mitigated as firms adapt to new cost structures and regulatory environments.

The analysis reveals a bidirectional causal relationship between environmental taxes and food exports. While environmental taxes influence food exports, past export performance also affects future environmental tax policies. This suggests that strong export performance may lead to stricter environmental regulations, as governments aim to ensure the sustainability of the food sector. In other words, as food exports grow, policymakers may feel compelled to introduce more stringent environmental taxes to address the environmental externalities associated with increased production and trade.

5.1. Economic Interpretations

The positive long-term relationship between environmental taxes and food exports underscores the potential of environmental taxes to serve as effective policy tools for promoting sustainable practices in the food sector. By internalizing the environmental costs of production, taxes encourage firms to innovate and adopt cleaner technologies. Over time, these innovations can lead to improved resource efficiency, reduced environmental impact, and enhanced competitiveness in global markets. This aligns with the Porter Hypothesis, which posits that well-designed environmental regulations can stimulate innovation and ultimately improve economic performance.

The short-term negative impact of environmental taxes on food exports highlights the initial challenges faced by firms, particularly in resource-intensive sectors like agriculture. In the immediate aftermath of tax implementation, firms may experience increased production costs, reduced profit margins, and limited access to capital for investment in sustainable technologies. Policymakers should be aware of these transitional costs and consider implementing support measures to help firms adjust to new tax regimes. For example, revenue recycling mechanisms—where tax revenues are reinvested in green technologies or provided as subsidies to affected industries—can help offset the initial financial burden and facilitate the transition to more sustainable practices.

The bidirectional causality between environmental taxes and food exports underscores the importance of well-designed and gradually implemented environmental policies. Policymakers should consider the potential trade-offs between environmental and economic objectives and aim to strike a balance that minimizes short-term disruptions while maximizing long-term benefits. For instance, a phased approach to tax implementation, combined with targeted support for innovation and technology adoption, can help firms adapt to new cost structures without compromising their competitiveness in global markets.

Given the global nature of food trade, international coordination on environmental tax policies is crucial. Unilateral implementation of environmental taxes may lead to competitive imbalances, as firms in countries with stricter regulations could face disadvantages in global markets. This phenomenon, known as carbon leakage, occurs when production shifts to countries with weaker environmental regulations, undermining the global environmental benefits of the taxes. Policymakers should work towards harmonizing environmental tax policies across countries to create a level playing field and prevent carbon leakage. Border carbon adjustments (BCAs), which impose taxes on imports from countries without similar environmental policies, could be one potential solution to address this issue.

5.2. Recommendations

Policymakers should consider a phased approach to implementing environmental taxes, allowing firms time to adapt to new cost structures and invest in sustainable technologies. A gradual rollout of taxes can help mitigate the short-term negative impacts on food exports while promoting long-term competitiveness. For example, initial tax rates could be set at lower levels and gradually increased over time, giving firms the opportunity to adjust their production processes and adopt more sustainable practices.

Governments should explore revenue recycling mechanisms, where tax revenues are reinvested in green technologies, research and development, or support measures for affected industries. By reinvesting tax revenues into the food and agriculture sector, policymakers can help offset the initial financial burden on firms and encourage innovation in sustainable practices. For instance, subsidies for precision agriculture technologies, renewable energy systems, or low-carbon farming practices could help firms reduce their environmental impact while maintaining their competitiveness in global markets.

Given the global nature of food trade, international coordination on environmental tax policies is essential. Policymakers should work towards harmonizing environmental tax policies across countries to create a level playing field and prevent carbon leakage. This could involve multilateral agreements on carbon pricing, the establishment of global standards for environmental taxation, or the introduction of border carbon adjustments (BCAs) to ensure that imports from countries with weaker environmental regulations are subject to equivalent taxes.

The food and agriculture sector is highly sensitive to environmental taxes due to its reliance on natural resources and exposure to international competition. Policymakers should design sector-specific environmental tax policies that take into account the unique characteristics of the food sector, such as its input intensity, technological capabilities, and trade elasticity. For example, taxes on specific inputs like fertilizers or water usage could be tailored to encourage more sustainable farming practices, while exemptions or reduced rates could be applied to sectors that are particularly vulnerable to international competition.

To help firms adapt to environmental taxes and improve their competitiveness, governments should provide support for innovation and technology adoption in the food and agriculture sector. This could include funding for research and development, grants for the adoption of green technologies, or technical assistance for farmers and food producers. By facilitating the transition to more sustainable practices, policymakers can help firms reduce their environmental impact while maintaining their position in global markets.

5.3. Limitations of the Study

The study relies on data from OECD countries, which may not fully capture the dynamics of environmental taxes and food exports in developing countries. Future research could expand the scope to include non-OECD countries, particularly those where agriculture plays a critical role in the economy. This would provide a more comprehensive understanding of how environmental taxes affect food exports in different economic contexts.

The food and agriculture sector is highly diverse, with significant variations in production techniques, resource use, and environmental impacts across different commodity groups and regions. This study aggregates food exports at a broad level, which may mask important sector-specific dynamics. Future research could explore the effects of environmental taxes on specific agricultural commodities, such as grains, livestock, or dairy products, to provide more nuanced insights.

While the study employs advanced econometric techniques to address causality and endogeneity issues, there may still be unobserved factors that influence both environmental taxes and food exports. Future research could incorporate additional control variables or use alternative methodologies, such as instrumental variable approaches, to further address these concerns.

5.4. Future Research Directions

This study contributes to the growing body of literature on sustainable trade by focusing on the underexplored relationship between environmental taxes and food exports. Unlike previous studies that primarily examine the broader impacts of environmental regulations on trade flows, this research provides a detailed analysis of sector-specific dynamics in the food and agriculture sector. The use of advanced econometric techniques, including Panel VECMs, allows for a rigorous examination of both short-term and long-term relationships, offering new insights into the interplay between environmental and economic objectives. By focusing on OECD countries, the study provides a comprehensive analysis of the factors that mediate this relationship in a diverse and economically significant group of nations.

Future research could compare the effects of environmental taxes on food exports across different regions, particularly between developed and developing countries. This could provide insights into how varying levels of economic development, technological capabilities, and policy frameworks influence the relationship between environmental taxes and trade.

Given the heterogeneity of the food and agriculture sector, future studies could focus on specific agricultural commodities or sub-sectors to better understand how environmental taxes affect different types of food production and trade. For example, research could explore the impact of environmental taxes on high-value crops versus bulk commodities, or on livestock versus crop production.

Future research could use computable general equilibrium (CGE) models to simulate the economic and environmental impacts of different environmental tax scenarios. This could help policymakers design more effective and targeted environmental tax policies that balance economic growth and sustainability. While this study focuses on environmental taxes, future research could explore the effects of other environmental policies, such as subsidies for green technologies, carbon trading schemes, or regulatory standards, on food exports and trade competitiveness. This would provide a more comprehensive understanding of the policy tools available to promote sustainable trade.

As environmental tax policies continue to evolve, it is important to monitor and evaluate their long-term impacts on food exports and trade competitiveness. Future research could track the effects of environmental taxes over extended periods, providing insights into how firms and industries adapt to new regulatory environments and how these adaptations influence trade dynamics.

This study highlights the complex interplay between environmental taxes and food exports, offering valuable insights for policymakers aiming to promote sustainable development while maintaining global trade competitiveness. By carefully designing and implementing environmental tax policies, governments can achieve a balance between environmental and economic objectives, paving the way for a more sustainable future. The findings underscore the importance of gradual implementation, revenue recycling, international coordination, and sector-specific policies in ensuring that environmental taxes achieve their intended goals without compromising the competitiveness of the food and agriculture sector. As global challenges demand integrated policy approaches, this research represents a step toward crafting solutions that align economic and environmental priorities for a more sustainable future.

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