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Essays on sustainability: the impact on firms' performance and innovation

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Abstract

Eco-innovation is crucial for companies to balance environmental compliance with profitability. It involves implementing more efficient resource use and reducing harmful environmental effects. However, eco-innovation requires significant resources and corporate commitment. This thesis examines how sustainability affects firms' performance and how some firms' structures influence this relationship. Three articles are included: one studies the moderating role of the supply chain network in the relationship between corporate environmental and financial performance; the second studies how board gender diversity impacts eco-innovation through a moderated mediation model introducing the CSR committee as a mediator and board-independent members as a moderator; and the third studies the link between eco-innovation and productivity in reducing GHG emissions.

Keywords: sustainability, eco-innovation, corporate financial performance, corporate environmental performance, supply chain, CSR committee, productivity

Contents

Chapter 1

Introduction

The world is facing significant environmental challenges, including climate change, resource scarcity, and increasing pollution levels. The economic consequens of these issues cannot be ignored, leading to a growing demand for environmentally sustainable and economically viable solutions. The environmental impact of economic activities has gained increasing attention from various stakeholders, making it crucial for companies to adopt environmentally conscious practices to gain long-term competitive advantages and market legitimacy. Companies now face the challenge of balancing environmental compliance with profitability and cash flow (Berry & Rondinelli, 1998). Sustainability refers to the ability of an economy to maintain its productive capacity over time without degrading the natural resources on which it depends (Kuhlman & Farrington, 2010). It involves considering the long-term impact of economic activities on the environment and balancing economic, social, and environmental outcomes. In this sense, Eco-Innovation (EI) has become essential in response to this challenge. The term was first introduced in the works Fussler and James (1996) and James (1997). The authors showed the emergence of a specific type of innovation that provides added value to customers and companies while reducing the environmental impact. Over the years, the concept has evolved and now encompasses a wide range of activities and technologies connected to economic and ecology (Chen et al., 2006; Schiederig et al., 2012).

However, defining eco-innovation boundaries is challenging due to its extensive range of activities and subjects. Different authors have proposed different frameworks to evaluate eco-innovation performance indicators (EIPI), with some focusing on reducing environmental risk and pollution and others emphasising the increased value for customers and companies (Arundel & Kemp, 2009; Garcìa-Granero et al., 2018). Despite the differing definitions, they all focus mainly on more efficient use of resources and reducing harmful environmental effects (Hojnik & Ruzzier, 2016). Implementation requires significant resources and strong corporate commitment (Bansal et al., 2014). Efficiency and innovation rely on different approaches. Efficiency is based on incremental improvements, while innovation is based on radical change and experimentation that is more connected to higher risk (Porter, 1980; Sarkees & Hulland, 2009). Companies that pursue both simultaneously may face difficulties, and overemphasising efficiency or innovation can have negative consequences. For this reason, organisations that engage in a high degree of innovation and efficiency can have a sustainable competitive advantage by using resources from one strategy to implement the other (Gibson & Birkinshaw, 2004; Gupta et al., 2006). Some companies directly delegate environmental issues to a subcommittee created to make social and environmental recommendations while protecting stakeholders' interests and managing related risks (Orazalin, 2020; Peters & Romi, 2014). This Doctoral dissertation which consists of three self-contained research papers, enters this discussion and aims to investigate the role of different aspects of sustainability by studying its effect on the supply chain, corporate governance and productivity.

The first study explores the moderating role of supply chain network positioning in the relationship between corporate environmental performance (CEP) and corporate financial performance (CFP) in the automotive sector. The trend of globalisation has led to a dispersed global supply chain (González et al., 2008), making management more complex (Hashemi et al., 2015). The automotive industry is facing increasing pressure to implement sustainable processes and products (Katiyar et al., 2018). This increases the number of actors involved and places the burden of success on managing supply chain relationships (Alinaghian et al., 2020). Financial resources are critical for implementing sustainable strategies within firms and supply chains. The relationship between corporate financial performance and environmental practices has been found to be positive and partially bidirectional (Endrikat et al., 2014), with green supply chain management being a significant driver (Miroshnychenko et al., 2017). However, few studies have incorporated social network analysis to investigate the automotive industry's relationship between corporate environmental practices and corporate financial performance in the global supply chain. Using a sample of companies constituting the global automotive supply chain from 17 countries and their ESG (Environmental, Social and Governance) scores as CEP indicators. The study found a negative relationship between CEP and CFP. Still, the network structure, captured through different measures, positively moderates this relationship. Four network measures (i.e., Influence, Accessibility, Flow Control and Interconnectedness) were used to estimate the different effects of the network topology on CFP. Only second-tier Influence has a negative moderating role. Instead, Accessibility, Flow Control and Interconnectedness exhibit a positive moderating role. The findings suggest that implementing environmental strategies may have a negative impact on financial performance in the short term. However, this can be mitigated by designing the supply chain properly. The study found that close connections with other firms increase control and expose other firms to incentive and penalty mechanisms, improving environmental and financial performance and reducing the negative impact on financial performance.

The second study examines the impact of board characteristics and corporate governance mechanisms on EI. A sample of 527 listed companies from the Standards and Poor (S&P) 1500 index from 2010 to 2018 were used to examine how board gender diversity (BGD) affects EI, applying a moderated mediation model with the CSR committee (CSRCom) as a mediator and the percentage of board independent directors as moderators (BoardInd). The characteristics of a board of directors significantly impact strategic decisions. Diversity, in terms of age, experiences, education, ethnicity, and gender, enhances overall performance and helps companies better tackle multi-dimensional and complex issues through increased knowledge and skill set (Tingbani et al., 2020). Among the diverse aspects, board gender diversity (BGD) has been found to enhance ethical conduct and increase social responsiveness towards multiple stakeholders (Nuber & Velte, 2021). Additionally, according to various studies, BGD positively impacts EI (Hussain et al., 2018;

Lu & Herremans, 2019). To increase efficiency and institutionalise their efforts, some companies delegate environmental issues to a specific committee known as a CSR committee. Board independence, another characteristic of the board of directors, has also been found to affect CSR-related issues positively and consequently EI (Endrikat et al., 2021). Independent directors act as additional protection for stakeholders' interests against opportunistic behaviour by other directors (Dalton et al., 1998). Although different studies have been conducted on the topic, few studies have focused on the interrelationships between BGD, EI and the CSR committee. The paper suggests that the board of directors delegates the CSR committee to act on their behalf in implementing EI, implying that the impact of BGD on EI is indirect and mediated through the CSR committee. To date, no study has explicitly analysed the possible mediating effect of the CSR committee. The study shows that BGD indirectly affects EI through the CSR committee, with the indirect effect decreasing as board BoardInd increases. The component and index approaches of the mediated-moderated model confirmed the results. Testing for possible tokenistic phenomena, two female directors on the board were found to be significant for one-year lagged variables but not for the non-lagged model. Independent and internal directors, regardless of gender, are interested in implementing EI because it reduces external dependencies while increasing market legitimacy, making opportunistic behaviour among the board unlikely. Intergroup conflicts among board members due to male biases towards female directors may explain the negative interaction that leads to slowing the implementation of EI. Still, when at least two female directors are present, their influence on decision-making is substantial and not tokenistic.

The third article investigates the role of EI and productivity in reducing Greenhouse gas (GHG) emissions. Using a panel dataset of 438 carbon-intensive companies from 2015 to 2019, this study represents the first attempt to disentangle the role of productivity and EI on GHG emissions, including the interaction between them. The study first measures production efficiency using DEA analysis and its increase using the Malmquist index(MI). Then it estimates the relationship between EI, productivity and their interaction using linear regression analysis with the OLS estimator. The interest in GHG emissions and their impact on climate change has grown among various stakeholder groups. GHG emissions cannot be ignored due to their economic consequences on climate change (Stern, 2006). Companies are expected to disclose information on their carbon management, which affects economic activities and investors' decisions (Ben-Amar et al., 2017). To address the issue of climate change, many resources are being directed towards promoting technology transfer and innovation to reduce the environmental impact of economic activities (Ferreira et al., 2020). Efficient use of resources is critical in reducing environmental impact, particularly in the case of GHG emissions (Picazo-Tadeo et al., 2014). Production efficiency is crucial in allowing firms to reduce the input needed to produce the same quantity of output. However, increasing efficiency and innovation require different approaches, which are difficult to pursue simultaneously. The former approach focuses on improvements and refinements, while the latter requires radical changes and experimentation (Sarkees & Hulland, 2009). The first stage of the study found that production efficiency was similar and productivity increased for all sectors except the Industrial sector. Technical efficiency increased while technological change only increased for two sectors and decreased for two others. The second stage found that production efficiency was negatively correlated with GHG emissions, and EI was positively correlated. The interaction between the two variables was negatively correlated with carbon emissions. The negative impact of EI is due to the cumulative, path-dependent nature of innovation in the sector analyzed, leading to some sectors choosing to increase production efficiency instead of using or developing new, cost-ineffective technologies (Grubb et al., 2021). This is also confirmed by the fact that carbon-intensive sectors use more energy, and the most efficient way to reduce emissions is through energy efficiency (Picazo-Tadeo et al., 2014).

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Chapter 2

The moderating role of the supply chain structure in the relationship between corporate financial practices and corporate environmental practices in the automotive industry

2.1 Introduction

The study aims to investigate the relationship between Corporate Environmental Performance (CEP) and Corporate Financial Performance (CFP) in the global automotive sector, focusing on the supply chain position and its potential moderating impact on this connection. The primary objective is to explore how a company's supply chain position may influence the association between CEP and CFP. The research utilises social network analysis techniques to investigate how the supply chain position affects the link between CEP and CFP in the automotive sector. By scrutinising the structure and connections within the global automotive supply chain, the study assesses how a company's supply chain position shapes its environmental and financial performance with its interconnections and interdependencies among companies. Particularly, this relationship is investigated by expressing CEP as a function of CFP. Through this analysis, the study contributes to the existing body of knowledge on environmental and financial performance, specifically focusing on the automotive sector and the effect of supply chain positioning.

Many businesses are taking proactive steps towards sustainability in response to growing concerns about the environmental impact of companies' production cycles. This involves developing and implementing new management procedures that incorporate sustainable practices into their industrial processes and institutionalising them as part of their overall business culture (de Oliveira et al., 2018). The automotive sector, which is one of the most influential industries worldwide (Mayyas et al., 2012), is at the forefront of this trend.

The automotive sector is one of the most analysed in supply chain literature (de Oliveira et al., 2018) because of its trajectory in the production process. Zhu et al. (2007b) found a lag in implementing environmental practices between it and other industries. However, current studies have pointed out that the situation is the opposite (Damert & Baumgartner, 2018). Historically, the automotive industry has been characterised by fluctuations in customer demands and tough competition, which has recently experienced growing political pressure to implement sustainable processes and products (Katiyar et al., 2018). Moreover, some decades ago, concurrently with a generalised trend towards globalisation, a large part of manufacturing components were decentralised or outsourced (González et al., 2008), resulting in a supply chain globally dispersed. With the lengthening of the supply chain, managing the entire process has become more complex than before (Hashemi et al., 2015).

Nevertheless, stakeholder pressure has led the sector to focus on integrating environmental thinking into supply-chain management (Srivastava, 2007; Yu et al., 2014). Incorporating sustainability into supply chains requires firms to manage materials, information and capital flow optimally while cooperating with other companies considering all three dimensions (economic, environmental, and social) of sustainable development (Seuring & Müller, 2008). However, supply networks develop without the control of a single entity, resulting in complex adaptive systems (Choi et al., 2001) with unique and complicated

connectivity patterns (i.e. network structure) (Y. Kim et al., 2011). Therefore, the number of actors involved in these operations increases along with the complexity and places the burden of success on managing supply chain relationships (Alinaghian et al., 2020).
In addition to these issues, financial resources became fundamental to implementing sustainable strategies inside the firms and along the supply chain (Waddock & Graves, 1997). Although the debate around the effects of CFP on corporate environmental performance CEP is still open, recent studies have demonstrated that the relationship between them is positive and partially bidirectional (Endrikat et al., 2014) and green supply chain management is one of the significant drivers (Miroshnychenko et al., 2017).
Supply chain structural properties and interconnectedness influence embedded firms' financial and environmental performance (Alinaghian et al., 2020). Since supply chains can be seen as a network of relationships –i.e. companies that interact to carry on their economic activity–social network analysis techniques have already found application in the supply chain literature (Bellamy & Basole, 2013). Two are the main research streams for analysing supply chains using social network analysis (Alinaghian et al., 2020). The first branch has been identifying and investigating various network properties, such as centrality and density, that influence supply chain members' sustainability and environmental performance (Saunders et al., 2019; Tate et al., 2013). The second branch focuses on connectivity patterns in the management and governance of multi-tier sustainable supply chains (Sauer & Seuring, 2018; Tachizawa & Wong, 2014).
Although one of the most analysed sectors, few studies incorporate social network analysis in the automotive industry. None of them examined the relationship between CEP and CFP using social network measures considering the global supply chain. Recent studies that have employed social network analysis have focused only on administrative environmental innovations (Bellamy et al., 2020). The only research that has investigated the financial performance and firms' position has examined only a global subsector of the global automotive industry while not considering environmental performance (Seiler et al., 2020).
Therefore, this paper represents the first study examining how the supply chain position

influences the relationship between CEP and CFP in the global automotive sector. More precisely, given the importance of the supply chain structure on different firm performances simultaneously, this study further hypothesises that it moderates the relationship between CEP and CFP.

The results on a unique sample of 4320 unique companies from 17 different geographical areas operating in 135 sectors and a supply network with 15451 links among firms show that CFP negatively impacts CEP. However, other network measures moderate this relationship and strengthen the positive and negative effects. This study contributes to the literature in several ways. First, it provides a theoretical contribution to the CEP and CFP literature and sustainable supply chain management. Previous studies on sustainable supply chains have not analysed the moderating effects of network variables between CEP and CFP (de Oliveira et al., 2018). Therefore, this study provides a better understanding of this relationship. Second, some managerial implications could be drawn from these results. This research suggests that firms closely connected with other firms increase control over other companies. This increases the force of implementing incentive and penalty mechanisms, improving operational and financial risk-sharing and better monitoring of resources and information, improving CEP and reducing the negative impact on CFP.

The paper is structured as follows. Section 2 provided the theoretical background about environmental performance, social network structure, and their interactions. In Section 3, we develop our research hypotheses. Section 4 describes our data, measures and the methods used in the analyses. Section 5 describes our main results and adds some robustness checks, and we discuss our findings and their implication. Section 6 concludes with a discussion of limitations and future research directions.

2.2 Theoretical background

2.2.1 Green supply chain management (GSCM) in corporate environmental performance (CEP)

The recent increasing concern for environmental issues has received increasing attention from managers and scholars that have proposed a holistic approach that include these concerns in supply chain management. This approach is called green supply chain management (GSCM). Over the years, the literature has provided different definitions of GSCM. Still, the first and most used of them is by Srivastava (2007), which describes GSCM as "Integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as the end-of-life management of the product after its useful life". Therefore, GSCM can be described as the management of all the activities related to the minimisation of the environmental impact of all the process that contributes to its final products (da Rocha & Sattler, 2009) to increase business performance and competitiveness through greater efficiency and ultimately increase value for stakeholders (Woo et al., 2016). To achieve these goals, a company needs to manage at least these seven activities: green purchasing and procurement, green design, green manufacturing, green logistics, waste management, green operation, and end-of-life management (Badi & Murtagh, 2019). Given the centrality of environmental, economic and operational performances, a recurrent topic in GSCM literature is its impact on them.

Specifically, GSCM can be considered an output of CEP. Defining CEP is a complex task, and the lack of a unanimous definition confirms it despite its importance in several research streams (Ilinitch et al., 1998; Poser et al., 2012). Trumpp et al. (2015) in their review, have found 16 articles explicitly defining CEP, but five of them have used the definition provided by the ISO standard 14031, while the remaining have proposed their own. However, each description has common traits to derive CEP essential constituents. It can be described as the outcomes of management activities that focus on the natural environment and these activities themselves (Trumpp et al., 2015). Following this definition, GSCM represents a specific output of CEP that focuses more on the environmental management of the supply chain.

2.2.2 The relationship between CEP and CFP

The debate on the relationship between CEP and CFP is far from its conclusion, as no univocal results have been pointed out. Traditionally old economic literature (Friedman, 1970) proposed a negative relationship between CEP and CFP, but the recent literature has inverted this relationship (Endrikat et al., 2014; Miroshnychenko et al., 2017). There are several mechanisms through which CFP affects CEP. An increase in CFP can increase available (slack) resources that allow companies to invest in environmental activities (Waddock & Graves, 1997). Implementing environmental strategies does not always result in an immediate payoff because they need time and resources to be implemented (Bansal, 2005). Therefore, having a slack of financial resources allows firms to manage better external pressures and direct more resources to improve CEP (Kock et al., 2012). However, it is not always true that an increase in CFP increases organisational slack (Endrikat et al., 2014). Nevertheless, in the corresponding literature, CFP is considered a precursor of slack resources (Seifert et al., 2004).

Moreover, a firm's operation usually depends on acquiring valuable resources controlled by its stakeholders. Thus, improving CEP can allow firms to access resources owned by environmentally concerned stakeholders, gaining a potential competitive advantage over other competitors (Buysse & Verbeke, 2003). For these reasons, proactive management of environmental strategies may constitute a source of competitive advantage enabling firms to achieve superior CFP (Hart & Dowell, 2011; Surroca et al., 2010). However, as CEP increases, its related costs increase as well. Firms to further improve CEP needs additional resources such as infrastructure and facilities and part of employees or new professional figures directly committed to its improvement (Duanmu et al., 2018; Zhang et al., 2020).

Given the previous arguments, the relationship between CEP and CFP is not univocal but is rather reciprocally casual, forming a virtuous circle (Hart & Ahuja, 1996). Although it is impossible to identify where this process begins, financially successful firms may have the financial resources necessary to implement environmental strategies to increase CEP, which in turn increases CFP generating new resources to continue the cycle (Hart & Ahuja, 1996; Makni et al., 2009; Surroca et al., 2010).

Focusing on supply chain performance inside CEP, GSCM has the potential to develop new business models increasing the firm's competitiveness (Sarkis, 2003). Using different activities such as written policies, collaborative research and development and purchasing policies, firms can create a stronger environmental relationship with their customers and suppliers, increasing the mutual benefit (Dangelico & Pontrandolfo, 2015; Golicic & Smith, 2013). The impact of GSCM is particularly true for manufacturing firms, with recent studies suggesting that the market values adopting GSCM strategies (Bose & Pal, 2012; Testa & Iraldo, 2010). Inside both GSCM and CEP literature, the automotive sector is one of the most analysed (Bhatia & Gangwani, 2021; de Oliveira et al., 2018; Miroshnychenko et al., 2017).

2.2.3 Automotive sector and CEP

The automotive industry has received much attention in the sustainability debate because of its impact on the environment (Zhu et al., 2007a). Its products affect the environment when manufactured and during their life cycles due to their resource-burning functioning (Koplin et al., 2007; Thun & Müller, 2010). Therefore, the entire sector has experienced increased external pressure from different stakeholders. Normative, imitative and regulative pressures (Scott et al., 1995) have urged the implementation of environmentally concerned strategies.

Remarkably, the most critical stakeholder in adopting sustainable systems are customers (Held et al., 2018). They are demanding more ecologically sustainable products from car manufacturers and are willing to remunerate those who comply with their requests by paying an extra (Hetterich et al., 2012). In a B2B setting, these customer pressures

emerge in supply chains as firms press their suppliers to comply with sustainable requirements (González et al., 2008). However, due to its global scale, the automotive sector is characterised by significant barriers and complexity, hindering its environmental management (Thun & Müller, 2010).
These challenges arise from suppliers' limited resources and capabilities that hamper an effective response to pressures and a lack of eco-oriented partnership, sometimes associated with a lack of environmental commitment that leads to poor cross-functional integration (Lee & Klassen, 2008; Oh & Rhee, 2010; Thun & Müller, 2010). Despite these difficulties, each actor in the automotive sector has implemented sustainable strategies representing additional pressures on other competitors (Szász et al., 2021).
Companies cannot lag behind their competitors in implementing sustainable strategies in a competitive environment such as the automotive industry, especially with the over-mentioned customer pressure that rewards those who firstly comply (Huang et al., 2012; Walker et al., 2008). Ultimately, this trend has forced automotive companies to focus on increasing their CEP through GSCM strategies to maintain their competitive advantage. In the literature, the effect of GSCM initiatives on the automotive industry performance has always been debated, and most studies have shown a positive relationship with CFP (Szász et al., 2021). However, few studies have used social network analyses to investigate this relationship. Bellamy et al. (2020) using a Belief–Action–Outcome framework to examine the moderator role of the focal firm's structural position in administrative environmental innovations has shown that it is positively correlated with environmental disclosure. Seiler et al. (2020) investigated how the network position of the German automotive plastics processing industry in an extended supply chain network impacts their financial performance, discovering that profitability is related to connectedness among firms and market share.

2.3 Hypotheses development

The structural properties of the supply chain network and how firms are embedded highly influence GSCM and CEP ultimately (Alinaghian et al., 2020). Given the link between CFP and CEP exposed in the previous section and the importance of the supply chain structure in implementing environmental practices, it is reasonable to hypothesise that the latter also influences CFP. In this sense, network structure moderates the relationship between CFP and CEP by affecting the efficiency of the second, which in turn impact the first, creating the virtuous cycle described previously.

The study proposes that the supply chain network moderates the relationship between CFP and CEP by mainly three mechanisms: (i) facilitating the acquisition of resources and information timely, (ii) leveraging network learning of best practices reducing financial and environmental practices costs, (iii) increasing monitoring over the implementation of correct strategies increasing the punishing mechanisms in case of non-compliance. The following sections discuss each of these mechanisms.

2.3.1 Supply network flow accessibility

The speed by which firms access information and resources from their supply chain is defined by the distance between them and other firms in the network (Freeman, 1978). Therefore, the shortest the number of edges (the geodesic distance) connecting a firm i to all other firms j, the more exposed a firm is to different sources of information and resources than firms with higher distances. As the geodesic distance between focal firms and other firms in the supply network is reduced, they have access to other companies dealing with fewer intermediaries, obtaining less distorted information (Schilling & Phelps, 2007), and having adequate access to distant information and resources that otherwise would be difficult to get (Fleming et al., 2007).

On the contrary, suppliers relegated to peripherical roles are usually more passive in adopting sustainable initiatives due to the difficulty of focal firms to impose them stemming from the distance (Gong et al., 2018). To solve this situation, focal firms tend to bypass first-tier suppliers and directly connect with lower-tier suppliers (Alexander, 2020), investing in their capability development and monitoring programs (Mejìas et al., 2019). Therefore, since firms with a low geodesic distance are exposed to more stimuli and can easily access information and resources, we can reasonably expect that their CEP can positively benefit from their central position in the supply chain. Accordingly, it is hypothesised that:

H1: *A high flow accessibility of a firm positively moderates the relationship between CEP and CFP*

2.3.2 Supply network interconnectedness

The importance of the interconnectedness of supply chain members has been highlighted in recent literature. As members of a supply chain become more interconnected, more information, knowledge, resources and trust flow inside the network, becoming denser (Fleming et al., 2007). The economic interest and shared objectives in dense networks could be more easily transmitted to every entity thanks to increased visibility, reducing the cost of opportunism and passive behaviours (Phelps, 2010). Due to the high interdependencies, dense networks' normative pressure and distributed power demand that firms be accountable for other firms' actions (Chen, 2018). This creates a community logic that facilitates collaboration between firms reducing costs, increasing the information flow and fostering embedded suppliers toward sustainable practices and increasing the information flow (Chan et al., 2016; Nath et al., 2021).

Additionally, denser networks increase learning opportunities since all members are more frequently exposed to multiple information that reaches them from multiple paths (Villena et al., 2011). Hence, it becomes easier to cooperate with other firms to implement sustainable practices. Once identified, each strength and weakness exchange resources and develop capabilities to achieve specific goals (Herczeg et al., 2018; Villena & Gioia, 2020). Therefore, the interconnectedness among firms positively impacts all performance by increasing efficiency and action accountability, affecting CEP. This leads to hypothesise that:

H2: *A high interconnectedness of a firm positively moderates the relationship between CEP and CFP*

2.3.3 Supply network influence

In a network, having a high number of connections increases the bargaining power and strengthens the negotiating power with partners (N. Lin, 2017). In enforcing sustainable practices, a firm's Influence on others is directly linked to the number of connections (Tachizawa & Wong, 2014). These firms use their power and authority to establish direct contact with a high number of first-tier and lower-tier companies in response to stakeholders' pressure, influencing their suppliers to adopt their vision of sustainable practices by implementing monitoring and governance mechanisms (Kauppi & Hannibal, 2017; Sauer & Seuring, 2019). Multiple stimuli and initiatives are proposed to suppliers to encourage or force them to achieve sustainability and not be related to a marginal role in the supply chain (MacCarthy & Jayarathne, 2012; Villena & Gioia, 2018).
Also, central companies are more under public scrutiny, so they could receive more pressure to become more sustainable. Focal firms are more effective when sustainable targets are supported with a compliance-based approach that does not require increased cooperation with suppliers, reducing the compliance-information asymmetry (Lim & Phillips, 2008; Tachizawa & Wong, 2015; Touboulic et al., 2014).
According to Alinaghian et al. (2020), focal companies have a stronger influence due to their dimensions, allowing them more connections. Nevertheless, second-tier suppliers are essential since they act as a bridge that connects these bigger firms to many other smaller ones. Extant studies have shown that bridge firms support the spread of sustainable practices to peripheral firms or sub-network (Saunders et al., 2019) by transferring knowledge and innovation while adopting sustainable initiatives themselves (Nair et al.,

2016; Villena & Gioia, 2018).

Therefore, the more influential a firm is, the more power it has over its suppliers to enforce governance and monitoring practices that increases financial and environmental performance. It is thus possible to hypothesise that:

H3: *A high degree of Influence of a firm positively impacts the relationship between CEP and CFP*

2.3.4 Supply network flow control

Firms occupying a linking position between network partners that otherwise would be disconnected can control information and resource flow within the supply network (Y. Kim et al., 2011). Companies with high control over information and resources can potentially affect other firms' daily operations and performance by interfering with normal product flows (Kleindorfer & Saad, 2005) and creating operational hiccups (Hendricks & Singhal, 2003). Moreover, these firms can affect interactions among others mediating many pathways. In sustainable supply chains, they are usually first-tier suppliers or third-party firms such as NGOs, trade associations or auditors. Such companies have high control over information and resources since they are delegated on behalf of focal firms to assist lower-tier suppliers in developing sustainable initiatives and monitor their performance (Baum et al., 2010; Tachizawa & Wong, 2014).

The delegation of authority by focal companies occurs when the perceived risk of experiencing lower-tier passivity in sustainability implementation is low (Gong et al., 2018). If the perceived risk is high, focal firms connect directly to lower-tier bypassing middle-tier firms as already written (Alexander, 2020). The role of these bridging firms increases when the suppliers they bridge have denser networks (Baum et al., 2010). Still, at the same time, if power asymmetries increase towards these lower-tiers suppliers, they may be unable to commit to the role of sustainable practices' enforcers (Wilhelm et al., 2016). Therefore, firms with a high flow control receive resources from other firms to enforce sustainable actions and spread and monitor them to lower-tier suppliers. Accordingly, it is hypothesised that

H4: *A high flow control of a firm positively moderates the relationship between CEP and CFP*

2.4 Methodology

2.4.1 Data

The dataset used to develop our empirical analysis was created through different stages, combining data from two databases: the Eikon Refinitiv ESG Research Data (formerly known as ASSET4) of Thomson Reuters and the Bloomberg database. Firstly, we derived from the Bloomberg database a list of 95 companies classified as Automobile Manufacturers accordingly to the Global Industry Classification Standard (GICS). We use dyadic customer and supplier data from Bloomberg's Supply Chain Relationships (SPLC) database to define the starting company (Focal Company) links to the Second-tier firms. Then we repeat the process using the latter companies to determine the Third tier. The method used to determine the supply network is similar to the one used by Bellamy et al. (2020). The score indicator of each company's ESG (Environmental, Social and Governance) was used to quantify CEP performance. This database was chosen because of its extensive use in the literature and by practitioners since it provides data about sustainability and financial performance (Nirino et al., 2021). The supply network data from Bloomberg were merged with the ESG and financial data from Thomson Reuters to obtain a comprehensive dataset. The final sample consisted of 4320 unique companies from 17 different geographical areas operating in 135 sectors for 2016-2019. Moreover, using the SPLC database to derive supply network relationships, 15451 links among firms were identified. The reference period chosen for our analysis was 2019 to avoid the effects of the Covid pandemic on the financial and non-financial markets.

To summarise, our study is the initial and primary attempt to utilise a comprehensive dataset that combines ESG and financial data from Thomson Reuters with supply network information from Bloomberg to assess the relationship between CEP, CFP, and the supply chain network structure.

2.4.2 Variables

Dependent variable

The objective variable of the study is the CEP, measured using the Environmental Pillar of the Thomson Reuters Refinitiv ESG score as a proxy. Two reasons support the choice. First, Refinitiv is one of the most popular databases that measure ESG performance, and it has been used extensively in the literature (Aslam et al., 2021; Chouaibi et al., 2021; Gangi et al., 2020). Second, ESG data are formulated sector-wise. Therefore, they are comparable in relative terms and, for construction, are not sensitive to outliers. The overall score of each company's Environmental Pillar was used because it includes different aspects of environmental practices. It is not only limited to the use of the resources but also has managerial criteria, such as certifications and policies, and policy about GSCM that gives a more comprehensive view of CEP.

Independent variable

ROA (return on asset) was selected to evaluate CFP. This measure is one of the most widely used in the literature (Earnhart, 2018) and especially in association with ESG data (Lahouel et al., 2020; Nirino et al., 2021). It is defined as the ratio between net income and total assets.

Moderators: network measures

In Section 3, four supply chain features were hypothesised to moderate the relationship between CFP and CEP. One effective moderation analysis approach is the interaction effect method. It is particularly viable when the focus is on a specific relationship and when dealing with continuous moderator variables, such as in the case of this study (Memon et al., 2019). To model a moderator, researchers can create an interaction term by multiplying the moderator and predictor variables in a regression, and the significance of the interaction effect can reveal the presence of a moderating effect (Hayes, 2018).

Since supply chains can be seen as a network of relationships – i.e., companies that interact to execute their economic activity – social network analysis is used to analyse the interconnectedness of firms. Social network analysis is used to analyse the inter-connectedness of social entities (Granovetter, 1973) such as people (Kumar et al., 2010) and organisations (Mizruchi, 1996). Since supply chains are a group of companies that interact, this technique has already found application in the supply chain literature (Bellamy & Basole, 2013). It is used to understand different phenomena that range from the network structure (Y. Kim et al., 2011) and its evolution (Choi et al., 2001) to how connectedness impacts innovation (Bellamy et al., 2014) and how knowledge transfer improves performance (Nair et al., 2016).

For this study, four measures were implied using the notion of centrality to capture the supply network's structural properties. Then different interaction terms were created by multiplying the dependent variable with each network measure. The mathematical description of each measure is provided in the Appendix.

Closeness Centrality is used to evaluate the degree of exposure of a firm to different sources of information and resources coming from all the other firms in the network. This refers to the number of steps required for a piece of information or resource to reach a particular company. As the number of steps increases, there is an increased risk of information becoming corrupt or distorted, as well as other resources. We label this aspect supply chain flow accessibility (hereafter referred to as *"Accessibility"*).

Supply network interconnectedness (hereafter referred to as *"Interconnectedness"*) is measured by *"Bonacich Power Centrality"* (Bonacich, 1987). It expresses how a node is central based on its connections' number of connections, particularly the centrality measure increases as a company is connected with well-connected nodes.

The degree of centrality refers to the extent to which the firm influences other firms on their operations or decisions as it has more direct contact with others (Y. Kim et al., 2011). For this reason, this study captures the supply network influence (hereafter referred to as *"Influence"*) that a company has on the different tiers (focal companies, second tier and third tier) using the *Degree of Centrality.*

Betweenness Centrality allows assessing the gatekeeping/bridge role in controlling the supply network flow (hereafter referred to as *"Flow Control"*). When a firm takes on a gatekeeping role, it receives more resources and information. This figure plays a crucial role in effectively spreading information to the rest of the network.

The network values are calculated using a network representing the average disposition of the firms in the dataset for the period studied.

Control variables

The models include several control variables chosen following previous studies. The first control variable is the Size (*Size*), widely used in literature. It is expected that larger companies will have higher ESG practices on average. Size is calculated as the natural logarithm of total employees (Becker-Blease et al., 2010). Further, to control the influence of firms' financial risk of CEP, we include the leverage ratio (*leverage*), defined as the ratio between the total debt and equity of the firm (Surroca et al., 2010). To comply with the requirements of the different stakeholders about sustainability, companies with high financial leverage are forced to implement some ESG practices, such as green innovation (Gupta & Newberry, 1997). Firms' geographical regions of origin and operating sectors were included as controls to capture differences in performance due to these factors. The 17 geographical areas represent commercial regions (i.e., Nord-Est Europe, China, Oceania, etc.). The 135 sectors are derived from the GICS sectoral level at the sector level.

Econometric model

Using the dataset specifically created to test our hypotheses, we analyse the influence of CFP and network positioning on the CEP using a multivariate linear regression model with the following specification:

$$
\begin{aligned}
CEP_i = {} & \beta_0 + \beta_1 ROA_i + \beta_2 Accessibility_{i(t-3,t)} + \beta_3 ROA_i * Accessibility_{i(t-3,t)} + \\
& + \beta_4 Interconnectedness_{i(t-3,t)} + \beta_5 ROA_i * Interconnectedness_{i(t-3)} + \\
& + \beta_6 InfluenceFocalCompany_{i(t-3,t)} + \beta_7 InfluenceSecondTier_{i(t-3,t)} + \\
& + \beta_8 InfluenceThirdTier_{i(t-3,t)} + \beta_9 ROA_i * InfluenceFocalCompany_{i(t-3,t)} + \\
& + \beta_{10} ROA_i * InfluenceSecondTier_{i(t-3,t)} + \beta_{11} ROA_i * InfluenceThirdTier_{i(t-3,t)} + \\
& + \beta_{12} FlowControl_{i(t-3,t)} + \beta_{13} ROA_i * FlowControl_{i(t-3,t)} + \\
& + \beta_{14} Size_i + \beta_{14} Leverage_i + \beta_{16} CONTROLS_i + \varepsilon_{it}
\end{aligned}
\tag{2.1}
$$

Where i is the index for the firm, t represents the year of the observation, namely 2019; $(t-3, t)$ is the period over which we calculate average network measures, namely from 2016 to 2019; CEP is a measure of corporate environmental performance, ROA is the return on assets, Accessibility is the value of Betweenness Centrality, Interconnectedness is the value of Bonacich power, Influence Focal Company is the number of connections with focal companies measured using Degree of Centrality, Influence Second Tier is the number of connections with second tier companies measured using Degree of Centrality, Influence Third Tier is the number of connection with third tier companies measured using Degree of Centrality, Flow Control is the value of Closeness Centrality, Size is the natural logarithm of total employees, leverage is the ratio between the total debt and total equity, $CONTROLS$ is a vector of the sector, and geographical area dummies and ε_{it} is an i.i.d. error term. Note that the model includes interaction effects for ROA and, respectively: Influence Focal Company, Influence Second Tier, Influence Third Tier, Accessibility, Flow Control and Interconnectedness.

The ordinary least squares (OLS) estimator has been used to estimate the model parameters.

Network measures can be rendered unreliable due to the ever-changing nature of links between companies, leading to a failure to reflect the actual state of the supply chain accurately. A more effective approach is integrating average measures that exclude temporary partnerships from the evaluation process, resulting in a more precise representation of the network's original structure. This data aggregation methodology allows the study to explore the correlation between CEP and CFP while considering the network structure's impact. Adopting this approach makes the network configuration stable, eliminating potential disruptions caused by changes in firms' connections.

Furthermore, despite previous literature suggesting that implementing CEP requires time, this is not true for all environmental practices. The variable used as a proxy for CEP contains different environmental practices with various implementation times. Therefore, due to this reason and in line with recent researchers (Nirino et al., 2021; Seiler et al., 2020), this study utilises the non-lagged version of the independent variable in the base model. To guarantee the results' accuracy and investigate delayed effects, we examine the lagged form of the independent variable as a robustness check.

2.5 Results

2.5.1 Analysis

Table 2.1 reports the means and standard deviations of the variables used in the regression models, the correlation matrix and their significance level. No collinearity issues seem to arise from the correlations. The correlation between *"Interconnectedness"* and *"Influence second tier"* presents the highest value of 0.78, which in any case, it is below a critical threshold to induce bias in the results of the full model. It is worth noting that multicollinearity does not have any impact on the significance test of the interaction effect (Echambadi & Hess, 2007) and does not affect "the estimation accuracy, hypothesis tests, or standard errors" in the majority of cases (Hayes, 2018, p.312).

Table 2.2 reports the results of the different models on the relationship between CEP and CFP with the four supply network structure variables as moderators. The baseline

	MEAN	SD	1	2	3	4	5	6	7	8	9	10
1. CEP	30.82	30.82	1.00									
2. ROA	4.04	6.94	0.43***	1.00								
3. ACCESSIBILITY	0.20	0.03	0.45***	0.24***	1.00							
4. INTERCONNECTEDNESS	0.29	0.95	0.22***	0.03***	0.39***	1.00						
5. INFLUENCE FOCAL COMPANY	0.77	2.98	0.12***	0.07***	0.41***	0.26***	1.00					
6. INFLUENCE SECOND TIER	2.28	8.90	0.26***	0.04***	0.41***	0.78***	0.26***	1.00				
7. INFLUENCE THIRD TIER	3.07	5.43	0.28***	0.15***	0.37***	0.21***	0.26***	0.38***	1.00			
8. FLOW CONTROL	7182.91	29058.3	0.27***	0.08***	0.38***	0.39***	0.26***	0.38***	0.61***	1.00		
9. SIZE	5.91	4.28	0.24***	0.08***	0.07***	0.06***	0.04***	0.07***	0.00***	0.01***	1.00	
10. LEVERAGE	72.89	1702.96	0.02***	−0.01***	0.00	0.00	0.00	0.00	−0.00	0.00	−0.00	1.00

Table 2.1: Pearson correlation coefficients of all the variables in the model. The first two columns report some descriptive statistics of the variables.

Hp tested:	Baseline Model (1)	(2) H1	Interactions models (3) H2	(4) H3	(5) H4	Full Model (6)
ROA	0.194**	0.154*	0.014	-0.104	−2.663***	−2.456***
	(0.071)	(0.076)	(0.097)	(0.111)	(0.499)	(0.645)
Accessibility	71.624***	93.942***				38.910*
	(16.259)	(16.784)				(18.245)
Accessibility * ROA		12.042***				11.443***
		(2.080)				(3.030)
Interconnectedness	−0.458		1.681**			−3.820**
	(0.642)		(0.546)			(1.184)
Interconnectedness* ROA			0.224**			0.742***
			(0.082)			(0.218)
Influence Focal Company	0.005			0.123		0.128
	(0.142)			(0.169)		(0.203)
Influence Second Tier	0.244***			0.221***		0.510***
	(0.057)			(0.047)		(0.099)
Influence Third Tier	0.499***			0.438***		0.357**
	(0.094)			(0.101)		(0.126)
Influence Focal Company* ROA				−0.006		−0.024
				(0.019)		(0.020)
Influence Second Tier * ROA				0.012*		−0.062***
				(0.006)		(0.018)
Influence Third Tier* ROA				0.046***		0.008
				(0.012)		(0.016)
Flow Control	0.000*				0.000***	0.000
	(0.000)				(0.000)	(0.000)
Flow Control * ROA					0.000*	0.000
					(0.000)	(0.000)
Size	1.134***	1.205***	1.327***	1.200***	1.158***	1.158***
	(0.280)	(0.287)	(0.291)	(0.281)	(0.286)	(0.279)
Leverage	0.000	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Sector	YES	YES	YES	YES	YES	YES
Z_{Sector}	0.000	0.000	0.000	0.000	0.000	0.000
Region	YES	YES	YES	YES	YES	YES
Z_{Region}	0.000	0.000	0.000	0.000	0.000	0.000
(Intercept)	18.967**	51.522***	41.820***	35.418***	31.542***	26.100***
	(6.018)	(4.038)	(4.668)	(4.972)	(5.856)	(6.331)
R^2	0.807	0.798	0.791	0.806	0.796	0.811
Adj. R^2	0.791	0.782	0.774	0.789	0.779	0.794

Table 2.2: Regression models. Dependent variable: Corporate environmental performances (CEP). OLS estimations. Z_{Region} and Z_{Sector} are the results of the Wald test for region and sector dummies.

model (Column 1) includes all the network measures and the control variables. Models (2), (3), (4) and (5) analyse each network measure, respectively, Accessibility, Interconnectedness, the Influence of tiers and Flow Control together with their interaction term with ROA. Finally, the full model (Column 6) includes all the variables of interest and their interactions with ROA.

This result can be rationalised as follow. Model (1) only analyses the network variables' first-order effects on CEP. We found that CFP is positively and statistically significant ($\beta = 0.194, p < 0.01$) related to CEP, in line with the literature (Earnhart, 2018). According to models (2) and (3), there is a positive correlation between CEP and CFP, but only the former is statistically significant. However, models (4) and (5) indicate a negative correlation, with the first model not being statistically significant. Nonetheless, in the full model (6), we found a negative and significant relationship between CEP and CFP ($\beta = -2.456, p < 0.001$). Moreover, the same model confirms the significance of network structure in enhancing CEP. All the network variables except for the Influence Focal Company and Flow Control are positively associated with CEP, confirming the recent literature (Alinaghian et al., 2020).

Accessibility, which represents the easiness of reaching and being reached by information and resources, in model (2) and the full model (6) is positively and highly significant (in the model (6): $\beta = 11.443, p < 0.001$), supporting H1. Interconnectedness is positive and significant both in the partial model (3) and in the full model (6) ($\beta = 0.742, p < 0.001$), supporting *H2*.

In model (4), Focal Company Influence negatively impacts the relationship between CEP and CFP, while Second and Third Tier Influences strengthen it. The former and the latter results are confirmed in the complete model (6), while the other changes its sign. These results are not significant except for the second Tier ($\beta = -0.062, p < 0.001$), showing pieces of evidence against *H1*, although not robust. In model (5) and the full model (6), Flow Control, representing firms that occupy a linking position in the network, positively moderates the relationship between CEP and CFP. Although these results are coherent with *H4*, both are not significant.

Regarding control variables, Size has a positive and significant impact on CEP in all the models (in model (6): $\beta = 1.158, p < 0.001$), as expected. In contrast, although estimated coefficients for leverage are positive, they are not significant, as expressed in previous studies (Nirino et al., 2021; Surroca et al., 2010). Wald's tests in each model reject the null hypothesis that regional and sectoral dummies are jointly equal to zero. To summarise, the results in Table 2 show some strong evidence in support of *H1* and *H2* while not supporting *H3* and *H4*. However, in the case of *H3*, not all the Influence measures negatively moderate the relationship, but the statistical significance of the results is low. This also occurs for the evidence against *H4*.

2.5.2 Robustness Analysis

As highlighted previously, implementing CEP across the supply chain redirects resources that do not always result in an immediate payoff (Bansal, 2005), negatively impacting CFP. Some lags in the effects can be thus assumed. Therefore, Table 2.3 shows the results for the previous complete model (6), but leverage, Size and ROA variables lagged to one year. Compared to the results with the non-lagged model, the negative and significant relationship between CEP and CFP ($\beta{-2.823}, p < 0.001$) is confirmed. Regarding the network measures, the Second Tier and Third Tier Influence remain positive and significant (βInfluence Second Tier $= 0.515, p < 0.001$; βInfluence Third Tier $= 0.697, p < 0.001$) while Interconnectedness and Accessibility have the same sign as the non-lagged model but are no longer significant. The interactions between ROA and the different network measures are aligned with previous results.

2.6 Discussion

The results of this paper foster the debate in the literature about CEP and CFP performance relationship (Earnhart, 2018; Endrikat et al., 2014). Although the literature suggests that CFP is positively related to CEP, all the previous studies have stated that this relationship may change depending on different elements. The dimension of CEP (process-based versus outcome-based) and CFP (market-based versus accounting-based), portfolio and nonportfolio studies and various methodological applications have an impact

	Model (1)
ROA	-2.823***
	(0.693)
Influence Focal Company	0.139
	(0.256)
Influence Second Tier	0.515***
	(0.145)
Influence Third Tier	0.697***
	(0.186)
Accessibility	33.912
	(18.563)
Flow Control	-0.000
	(0.000)
Interconnectedness	-2.688
	(1.506)
Influence Focal Company * ROA	-0.001
	(0.028)
Influence Second Tier * ROA	-0.054*
	(0.024)
Influence Third Tier * ROA	-0.002
	(0.022)
Accessibility X* ROA	13.583***
	(3.321)
Flow Control * ROA	0.000
	(0.000)
Interconnectedness * ROA	0.497*
	(0.253)
Size	1.191***
	(0.294)
Leverage	0.068**
	(0.025)
Sector	YES
Z_{Sector}	0.000
Region	YES
Z_{Region}	0.000
(Intercept)	26.403***
	(6.532)
R^2	0.820
Adj. R^2	0.804

Table 2.3: Regression models with 1-year lagged independent variables. Dependent variable: Corporate environmental performances (CEP). OLS estimations. Z_{Region} and Z_{Sector} are the results of the Wald test for region and sector dummies.

on determining the final relationship (Earnhart, 2018; Endrikat et al., 2014).

In the automotive literature, recent studies do not find a positive relationship (Azevedo et al., 2012) or mixed results at best (W. L. Lin et al., 2020; Zhu et al., 2007a).

Nevertheless, numerous other researchers have established a positive relationship (W.-L. Lin et al., 2019; Zhu & Sarkis, 2004). To reconcile these results, a possible solution could be to investigate whether and through which mechanisms the firm's position in the value chain network plays a role. In other words, the models used in the literature must be extended with specific measures of social network analysis positioning of firms. However, studies that apply social network analysis in the automotive industry are limited and have not yet analysed this specific issue of the relationship between CFP and CEP. From this perspective, these results represent a first attempt to untangle this relationship using the global automotive supply chain.

Although the relationship between CEP and CFP is negative in the non-lagged and lagged full model, the overall effect of network measures turns this relation positive. However, not all network measures have the same effect. Moreover, they differ among the different tiers in the supply chain.

Figures 2.1, 2.2 and 2.3 represent the marginal effects that the three statistically sig-

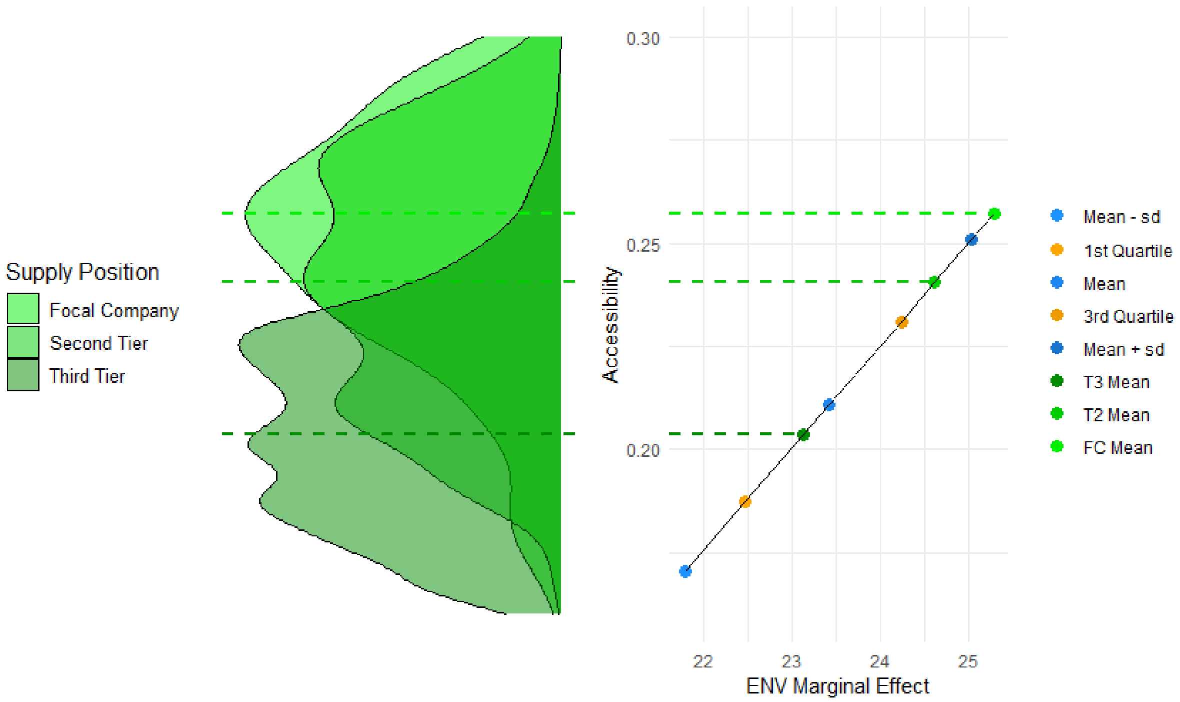

Figure 2.1: Distribution of Accessibility by supply position. (a) Data distribution of Accessibility, divided by supply chain tier groups (Focal Company, Second Tier and Third Tier). (b) Marginal effect on CEP of different values of Accessibility calculated at each other variables' means.

nificant measures have on CEP calculated in the model (6). Panels (a) represent the data distribution of each network measure (Accessibility, Interconnectedness, and Influ-

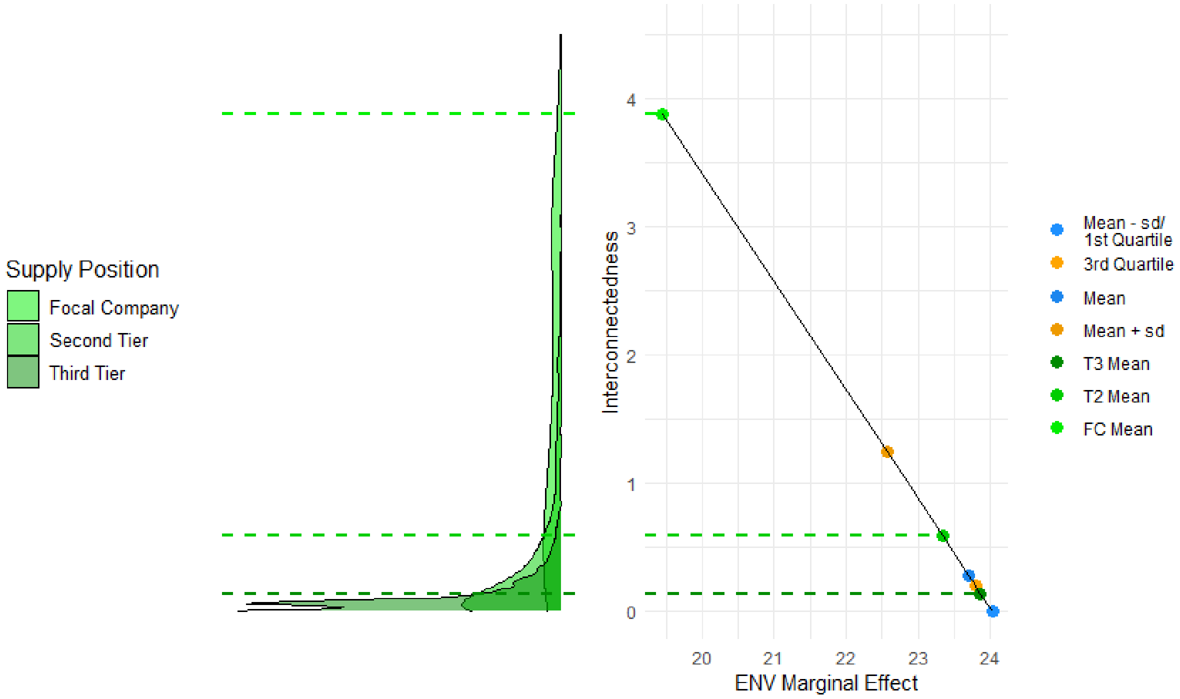

Figure 2.2: Distribution of Interconnectedness by supply position. (a) Data distribution of Interconnectedness, divided by supply chain tier groups (Focal Company, Second Tier and Third Tier). (b) Marginal effect on CEP of different values of Interconnectedness calculated at each other variables' means.

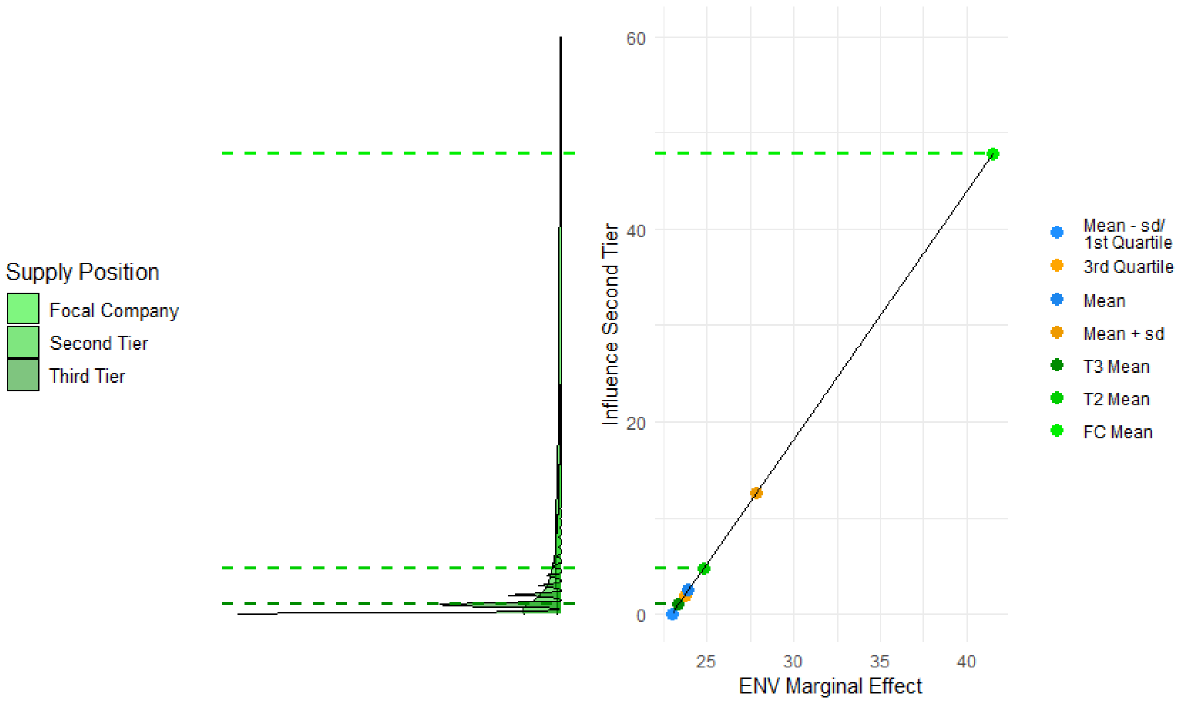

Figure 2.3: Distribution of Influence Second Tier by supply position. (a) Data distribution of Influence Second Tier, divided by supply chain tier groups (Focal Company, Second Tier and Third Tier). (b) Marginal effect on CEP of different values of Influence Second Tier calculated at each other variables' means.

ence Second Tier) divided by supply chain tier groups (Focal Company, Second Tier and Third Tier). Panels (b) represent the marginal effect on CEP of different values of selected network measures calculated at each other variables' means. The highlighted points in the line represent the mean of that network variable divided by supply chain positions, the mean of the total sample, values for mean + sd and mean – sd for the complete sample and first and third quantile values of the complete sample. The dashed lines represent the mean value of that network variable by supply chain positions.

Compared to the usual interaction graph, these figures help understand better how the network measures impact differently depending on the position in the supply chain. As said in the presentation of the network variables, they are highly influenced by the position of a firm inside the network. Therefore, since the network was created using a top-down approach from 95 companies classified as Automobile Manufacturers to the GICS classification, we have three distinct tiers representing different steps of the supply chain process with different numbers of companies. Therefore, instead of only showing the measures means and values for mean + sd and mean – sd of the complete sample, it is interesting to investigate how they vary from tier to tier to grasp differences in the supply chain structure.

As shown in Figure 2.1a, Accessibility is distributed similarly to a normal distribution among supplier tiers, with the mean of the groups being higher for companies in higher supply positions. Figure 1b shows that Accessibility has positive marginal effects on CEP, that increase as the measure increases, with Focal companies having the highest values. Figure 2.2a and 2.3a show Interconnectedness and Influence Second Tier distributions. Their distribution is skewed to the left side of the graph, resembling a gamma distribution. In both figures, mean values for the Second and Third tiers are similar, while Focal companies have noticeably higher mean values. These differences in mean values have a different impact on CFP since the slope of the measure is negative for the Interconnectedness and positive for the Influence Second Tier. Therefore, the final effect of the measure for the Second and Third tiers is similar (in Interconnectedness, values vary from approximately 23 to 24, and for Influence Second Tier values vary around 25). At the same time, for Focal Companies, the range is considerably higher (less than 20 for the first measure and over 40 for the second). To summarise, the Influence of Second

Tier and Accessibility positively affect CEP, while Interconnectedness has the opposite effect. Particularly, focal companies have above-average values that strengthen network measures' positive and negative effects on CEP.

According to this study, greater Influence positively moderates the relationship between CEP and CFP, thereby increasing CEP. Firms with a high degree of centrality (e.g. Influence) usually have more influence in forcing their connections' adoption of sustainable initiatives, using their power to enforce their vision of sustainability and its practical application (Sauer & Seuring, 2019; Vurro et al., 2009). Nevertheless, studies have also shown that firms with a high degree of centrality need an increased resource allocation to develop sustainable goals that lead to less efficiency (Y. H. Kim & Davis, 2016). Implementing CEP across the supply chain redirects resources that do not always result in an immediate payoff (Bansal, 2005), along with management issues that reduce efficiency. This is particularly true for firms that have high connections with second-tier companies. These firms are responsible for assisting lower-tier suppliers with the final implementation of sustainable initiatives on behalf of the focal firm (Tuni et al., 2020).

The results show that focal companies in the automotive industry tend to connect more with second-tier suppliers than others. This is confirmed by Figure 2.3, which suggests that a higher level of second-tier influence compensates for the negative impact on CFP from investing in CEP. This confirms the focal companies' effectiveness in monitoring and forcing lower-tier suppliers to implement CEP. As the connections with focal and second-tier companies increase over the sample average, the higher the decrease in financial performance.

A central position provides easier Accessibility to resources and information in the supply chain, which positively moderates the relationship between CEP and CFP. Firms tend to receive more information through different actors in the supply chain if they occupy a high closeness centrality (Meehan & Bryde, 2015), and this increases the incentives to adopt sustainable practices because they are exposed to focal companies' influence and penalty mechanisms in case of not compliance (Villena & Gioia, 2018). This exposition of other firms' compliance pressure and their direct control also positively impacts the efficiency of resource allocation. As depicted in Figure 2.1, focal companies and second-tier suppliers exhibit greater Accessibility than the average sample. This higher Accessibility, when combined with CFP, leads to an increased CEP. This result highlights that the supply chain is quite tight for the first two tiers, suggesting a reinforcement effect on the focal companies' influence and penalty mechanisms that increase their and second-tier suppliers' CEP.

Although there is no significant evidence of the effect of Flow Control, some conclusions can be drawn. By combining it with second-tier link results, we can confirm the delegated role of second-tier suppliers in implementing and monitoring sustainable actions at lower-tier levels. As a result of their bridging role, they positively influence the relationship between CEP and CFP. Bridge actors are well-positioned to diffuse sustainability targets to lower levels or inaccessible clusters contributing to the execution of these initiatives (Saunders et al., 2019), increasing the efficient allocation of resources.

Finally, our results reveal that Interconnectedness negatively moderates the relationship between CEP and CFP. Interconnectedness increases as a firm is connected to well-connected firms. Its negative moderation role has different explanations. One possible explanation is that within the network, the well-connected firms are represented by Focal Companies, which hold considerable significance in the supply chain. These firms typically aim to implement their own CEP throughout the supply chain. As a result, high Interconnectedness means that a company is mainly connected to these firms, limiting its influence over their sustainability practices and vision enforcement. Figure 2.2 confirms this, showing that Focal Companies have lower CEP levels than other supplier tiers. For the second group, a potential explanation for these results could be that highly connected nodes have a lower ability to monitor supplier CEP leading to inefficiency in resource allocation.

2.7 Conclusions

This study explores the moderating role of network measures in the relationship between CEP and CFP in the automotive sector. The findings may contribute to the academic debate about the network's role in implementing CEP strategies across the supply chain giving insights into network structure learning in the automotive sector.

This study shows a negative relationship between CEP and CFP and then highlights the importance of some network structures in moderating this relationship. Notably, only Interconnectedness negatively moderates the CEP – CFP relationship, while all other performances have a positive effect. However, Flow Control results are insignificant, making it difficult to conclude this measure.

Our findings have implications for managers in the automotive industry that are willing to increase their environmental performances. In this sector, the results show that investing in CEP may have some drawbacks to CFP. Implementing environmental strategies require investments in assets that sometimes take time to pay off, leading to poor financial performance in the short run. However, correctly designing the supply chain could mitigate this negative effect. From our study, being closely connected with other firms increases focal firms' control over other companies. This exposed other firms to their incentive and penalty mechanisms, improving operational and financial risk-sharing and better monitoring of resources and information, improving CEP and reducing the negative impact on CFP. Therefore, managers designing their supply chain should increase their direct connection with second-tier suppliers and work closely with them to develop shared projects, reducing connected financial risks.

The main limitations of this study provide ground for further investigation. First, the study used a comprehensive set of listed and non-listed belonging to different sectors and geographical areas. Therefore, although the study is a valuable indication of how CEP affects the global automotive industry, differences among industries and geographical regions may influence the studied phenomena. Future studies may focus on examining single parts of the global value chain to grasp specific sub-chain dynamics that may lead to identifying valuable practices or features to enhance CFP in the automotive sector.

Second, environmental performances are calculated using the Environmental Pillar of the ESG score provided by Asset4, aggregating quantitative and dummy variables that capture some specific practices but not their intensity. Moreover, it includes a broad spectrum of procedures that may lead to losing specificity and identifying essential practices. Thus, future studies have two different directions to undertake. They may use other data to evaluate aggregate CEP and examine whether there are differences in the results. They may also rearrange already used datasets to investigate if some practices significantly impact the overall CEP.

Third, this study did not consider the strength of links between firms. Having stronger links with some specific company or companies might directly affect CEP or could moderate the relationship between CEP and CFP with a different intensity.

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Chapter 3

Board gender diversity, Eco-Innovation and CSR committee: a moderated mediation model

3.1 Introduction

The present paper posits that the board of directors usually delegate the responsibility of implementing Environmental Innovation (EI) to the CSR committee, suggesting that the impact of Board Gender Diversity (BGD) on EI is not direct but rather indirect through the mediation of the CSR committee. The study also includes a moderation effect between independent board members and BGD in creating the CSR committee, hypothesising that the former moderates the creation of the CSR committee resulting in a first-stage moderated mediation model. In other words, this paper hypothesises that the indirect effect of BGD on EI through the CSR committee is a linear function of the board independent member.

Economic activities' environmental impact has received increasing attention from different stakeholders leading to be essential for companies being environmentally concerned to create competitive advantages in the long run and have market legitimacy. Complying with environmental issues while balancing them with cash flow and profitability is the challenge that firms are now facing (Berry & Rondinelli, 1998). In this scenario, environmental innovation has become vital to coping with these issues. EI is developing or modifying product design to use minimum resources, reducing negative environmental impacts (Kemp & Arundel, 1998). Minimising waste and reducing waste (by-products and energy) positively affect the environment and directly impact firms' profitability, increasing efficiency and market legitimacy. However, it requires significant resources and strong corporate commitment to be implemented (Bansal et al., 2014).

The board of directors' characteristics greatly influence strategic decisions. Diversity is among the most critical enhancers of overall performance regardless of the dimension expressed (age, experiences, education, ethnicity and gender). It improves companies' ability to handle multi-dimensional and complex issues by increasing knowledge and skill set (Tingbani et al., 2020). Among the various aspect of diversity, board gender diversity has been demonstrated to enforce ethical conduct and higher social responsiveness by engaging and responding to the needs of multiple stakeholders (Nuber & Velte, 2021). Moreover, BGD has been shown to affect EI positively in more than one study (Hussain et al., 2018; Lu & Herremans, 2019).

However, some companies delegate environmental issues to a specific committee to increase efficiency and institutionalise their efforts. These committees are usually defined as CSR committees. They are subcommittees of board directors that assist board members in their CSR-related functions by making social and environmental recommendations (Orazalin, 2020). Their primary function is to protect stakeholders' interests in implementing corporate actions regarding sustainability while monitoring and managing the attached risks (Peters & Romi, 2014). The role of this committee has been vastly investigated in the literature (Velte & Stawinoga, 2020), confirming its positive role in implementing EI (Nadeem et al., 2020). Moreover, some studies have highlighted its moderating role in various CSR-related issues (I. Garcìa-Sánchez et al., 2019; Martìnez-Ferrero et al., 2020).

Another board characteristic that has been found to affect CSR-related issues positively, and thus EI, is board independence (BoardInd) (Endrikat et al., 2021). Independent directors act as additional protection for stakeholders' interests from the opportunistic behaviour of other directors (Dalton et al., 1998). CSR strategies need time to be translated into firm values (Eccles et al., 2014) and need a long-term orientation (Carroll & Shabana, 2010), and external directors are more inclined to invest in them due to their role and long-term vision(De Villiers et al., 2011).

Although several research has been conducted on this topic (Konadu et al., 2022; Nadeem et al., 2020), only a few research focus on untangling the nature of interrelationships between BGD, EI and the CSR committee.

The present paper argues that the board of directors delegates the CSR committee to act on their behalf when implementing EI, suggesting that BGD affects EI not directly but indirectly through the mediation of the CSR committee. To date, no study explicitly analyses the possible mediation effect of the CSR committee. The work of Issa and Bensalem (2022) represents the first step to address this topic, but it uses CSR strategies as a moderator instead of the CSR committee. A recent literature review (Velte & Stawinoga, 2020) has suggested that this committee has an active role in implementing CSR strategies when present, channelling CSR strategies. Therefore, its inclusion as a moderator allows us to study the causes of implementing CSR strategies that lead to EI, making this study the first to analyse this relationship.

Moreover, a recent study of Endrikat et al. (2021) has shown that BGD, BordInd, and the CSR committee are partially interrelated and jointly influence CSR. The study includes the interaction between BordInd and BGD in creating the CSR committee, hypothesising that the former moderates the creation of the CSR committee. The resulting model is a first-stage moderated mediation model (Edwards & Lambert, 2007) in which the moderation affects only the indirect effect. Compared to others, this study applies intergroup conflicts (Böhm et al., 2020) to explain the moderation effects. Although part of the same group, the board's directors could perceive themselves as part of different subgroups, creating tensions that could degenerate into conflicts and discrimination. Independent and internal directors may perceive themselves as two distinct groups and the same with male directors and female directors. These tensions could lead to the non-implementation of some strategies, including creating a CSR committee. The literature on women's representation on the board of directors suggests that these conflicts could lead to tokenistic behaviour (Kanter, 2008). In analysing the role of female directors is thus essential to understand the effectiveness of their participation in decision-making. For this reason, this study also considers this phenomenon by analysing the critical mass (Dahlerup, 1988) to have more robust results in assessing BGD. Finally, in determining the degree of EI, other studies rely mainly on the EI index of Thomson Reuters Eikon ESG databases (Issa & Bensalem, 2022; Konadu et al., 2022; Nadeem et al., 2020). In contrast, a new indicator based on the work of Garcìa-Granero et al. (2018) was explicitly created for this study, which analyses three dimensions of EI: product innovation, process innovation and organisational innovation.

The first-stage moderated mediation model results on a sample of 527 companies from the Standards and Poor (S&P) 1500 index from 2010 to 2018 show that BGD on EI through the CSR committee decreases as BordInd increases. This study contributes to the literature in several ways. First, it provides a theoretical contribution to the BGD and EI literature. Previous studies have only assumed a direct relationship between BGD and EI (Konadu et al., 2022; Nadeem et al., 2020) and, to date, only one study (Issa & Bensalem, 2022) has suggested an indirect effect. However, none of them has included the moderating role of the CSR committee despite the literature suggesting its intervening role. Therefore, this work provides a better understanding of this relationship while confirming the presence of an indirect effect.

Second, in addition to being the first paper that uses the CSR committee as a mediator, it also includes independent board members as a moderator leading to a more comprehensive model. Compared to other studies, to define the presence of a moderated mediation model and increase the results' robustness, this study follows the recommendations of Yzerbyt et al. (2018) that suggest applying two approaches: the component and the index approach. The findings reveal a negative moderation effect between female and independent directors in creating the CSR committee, although the total moderated effect on EI is positive. The intergroup conflict theory (Böhm et al., 2020) suggests that some divergences about the attribution of merit of the implementation of EI may arise due to different social groups (male and female directors) on the board that want to be recognised as advocating them. Nevertheless, creating a CSR committee is not hindered because the costs of implementation failures are not sustainable for all the groups, slowing down the decision-making process. Although not all the results on tokenistic behaviour were significant, they show that the presence of two female directors on the board has been effective in creating the CSR committee for the one-year lagged model.

Moreover, some managerial implications could be drawn from these groups' dynamics. Female representation has been confirmed to affect EI through the implementation of the CSR committee positively. To increase their decision-making efficiency, managers need to reduce intergroup conflicts in the imputation of EI to reduce decision stalls and increase firms' competitivity. This can be achieved by increasing the exposure of individuals with group-specific biases to that group (Pettigrew & Tropp, 2006). However, due to the low number of female directors, a considerable effort must be made on the antecedent of appointing directors on board (Guldiken et al., 2019).

The paper is organised as follows. Section 2 presents a literature review of the study's topic. Section 3 provides a theoretical background and relevant research hypotheses. Section 4 outlines the methodology and the data used, while Section 5 presents the results and additional analysis. The results are discussed in Section 6, and the conclusions with suggestions for future research are in Section 7.

3.2 Literature review

3.2.1 Eco-Innovation

In literature, different terms of innovation have been developed linked to reducing the negative impact on the environment of economic activities. The most used are: "green", "eco", "environmental", and "sustainable". The latter term was the first coined to describe and incorporate economic, ecological and social aspects in the innovation process (Brundtland, 1987). After that, the term "environmental" was prevalently used until nowadays, when the terminologies "green" and "eco" have substituted it. Compared to the original formulation, these definitions of innovation focus more on the economic and ecological aspects (Schiederig et al., 2012).

Although this first distinction is still not simple to derive a unique meaning of eco-innovation, different authors define it differently depending on the nuances included. For example, Kemp and Pearson (2007, p.7), EI is "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives". In contrast, Oltra and Saint Jean (2009, p.1) defined it as "innovations that consist of new or modified processes, practices, systems and products which benefit the environment and so contribute to environmental sustainability". Other scholars include in the definition of eco-innovation new processes, products, equipment, services, techniques and management systems which provide customers and business value but also reduce environmental impact (Bartolomeo et al., 2003; Fussler & James, 1996; Kemp & Arundel, 1998).

The discussion on what can be considered eco-innovation is not limited to scholars. Different world organisations have provided their definition. The EIO (2012, p.8) has defined it as the "introduction of any new or significantly improved product, process, organizational change or marketing solution that reduces the use of natural resources and decreases the release of harmful substances across the whole life-cycle." Instead, the EU (2013, p.4) has considered "eco-innovation projects will therefore aim to produce quality products with less environmental impact, whilst innovation can also include moving towards more environmental-friendly production processes and services. Ultimately, they will contribute towards reducing greenhouse gases or the more efficient use of various resources". Considering all the different nuances of the definitions, two main aspects are constantly present in each description: more efficient use of resources and reducing harmful effects on the environment (Hojnik & Ruzzier, 2016).

3.2.2 Board gender diversity

According to the upper echelon theory (Hambrick & Mason, 1984), executive managers' experiences, values, and personalities play a fundamental role in developing an organisation's strategy. Their characteristics can partially predict organisations' strategic choices and performance levels since they are used to facing and interpreting strategic decisions (Hambrick, 2007). Therefore, homogenous groups may harm innovation because of their problem-solving and decision-making approaches. More heterogeneous groups have less pressure to conform, which leads to a broader range of perspectives in analysing the issues at stake, producing unique information sets for better decision-making (Miller & del Carmen Triana, 2009; Milliken & Martins, 1996).

In this perspective, a higher female representation increases the diversity inside the board. This diversity is achieved by females' different individual traits and backgrounds. Social barriers fostered by social biases usually prevent female representation on board (Knippen et al., 2019), which requires female directors' higher educational level and a background in community, academic services and non-business roles to be overcome (Dalton & Dalton, 2010; Hillman et al., 2002). Moreover, prior studies have demonstrated that female representation on board is associated with higher financial performance and market valuation (Adams & Ferreira, 2009; Erhardt et al., 2003), innovation in products and services (Torchia et al., 2011), and better CSR performance (Nadeem et al., 2017).

Females, on average, possess different traits from males that increase the board's resource capability in terms of values and problem-solving approaches according to resource dependency theory (Robinson and Dechant, 1997). They are more sympathetic, interpersonally sensitive, and more concerned about others' welfare (Eagly et al., 2003), and these characteristics are empirically supported to be present not only in general but also in corporate executives (Bord & O'Connor, 1997; Konrad et al., 2008).

However, board gender diversity could also harm firm performance. Different opinions and solutions to problems arising from different backgrounds and values can lead to conflict and delay decision-making, reducing board effectiveness (Lau & Murnighan, 1998). Female directors are more risk-averse than males, leading to fewer risky operations and reducing the firm performance (Jianakoplos & Bernasek, 1998). Moreover, intergroup biases can marginalise them from being part of board committees reducing the available resources to solve problems and increasing firm costs (Knippen et al., 2019).

3.2.3 CSR committees

CSR committees are specific corporate committees composed of elected board members who make social and environmental recommendations and assist the board of directors in their CSR-related function (Dixon-Fowler et al., 2017). Their primary function is to protect stakeholders 'interests in implementing corporate actions regarding sustainability while monitoring and managing the attached risks (Peters & Romi, 2014). The presence of this specific commission increases the board's capabilities to develop and implement social and environmental programs and its involvement in sustainable development while improving the disclosure of these activities (Cucari et al., 2018).

A recent literature review (Velte & Stawinoga, 2020) has confirmed a positive relationship between CSR committees and CSR performances, supporting some indications about the not symbolic role of these committees that instead have a substantial effect on CSR performance. However, industry and country-specific effects could lead to inclusive results. Although positive results were found in cross-country (Baraibar-Diez & D Odriozola, 2019) and single-country designs (Burke et al., 2019), some researchers stated the not influence of CSR committees on CSR performance (Lin et al., 2015) and environmental performance (Konadu, 2017) in some specific contexts.

3.3 Theoretical background and hypotheses

3.3.1 Board gender diversity and eco-innovation

The individual characteristics of board members represent one of the three categories identified as concurrent factors for implementing green innovation besides contextual factors and firm-level characteristics (He & Jiang, 2019). The previous section shows that diversity plays a fundamental role in implementing innovation. Notably, studies have shown that demographic heterogeneity is more effective in the case of advancing environmental innovations policy (Glass et al., 2016). In literature, the possible link between BGD and eco-innovation is usually expressed using mainly three theories: upper echelon theory, gender socialisation theory and resource dependence theory (He & Jiang, 2019; Konadu et al., 2022; Nadeem et al., 2020).

Combing these theories, it is possible to derive that board gender diversity affects eco-innovation for multiple reasons. On average, females possess different traits from males, increasing the variety of problem-solving approaches and including diverse perspectives in interpreting situations inside the board (Hillman et al., 2000; Robinson & Dechant, 1997). Moreover, female directors are usually more concerned with environmental issues and attach higher relevance to the consequences of violating them (Harris & Jenkins, 2006; Jaffee & Hyde, 2000). Therefore, an increase in female presence on the board of directors would increase the interest of a company in environmental and social issues. This is confirmed by recent studies that have suggested that women on boards support strategies that minimise the environmental risk and increase environmental disclosure (Ben-Amar & McIlkenny, 2015; Frias-Aceituno et al., 2013).

Internal factors are one of the drivers of eco-innovation. Among them, the environmental concerns of management, environmental leadership, environmental capabilities and environmental culture represent essential components (Bossle et al., 2016). Top executives' ecological concerns play a determinant role in implementing an eco-innovation strategy (Chang, 2011; Eiadat et al., 2008), which other elements should support to have a positive impact on companies' performance (Chen et al., 2012; Tseng et al., 2013).

Therefore, since female directors are more interested in environmental issues and support corporate actions in this field, it is possible to assume that they will direct resources towards products, production processes, or services that positively impact the environment, increasing eco-innovation. Accordingly, it can be hypothesised that:

H1: Firms with a high degree of board gender diversity have a higher level of eco-innovation

Two recent studies that have demonstrated a positive relationship between board gender diversity and eco-innovation (He & Jiang, 2019; Nadeem et al., 2020) confirmed this hypothesis. Nevertheless, little evidence supports it due to the lack of studies explicitly disentangling this relation.

3.3.2 The mediating role of CSR committee and the mediator role of independent board member

Board gender diversity is not the only element that impacts eco-innovation. CSR committees can be considered structures that increase management and coordination capabilities in developing eco-innovation. As previously exposed, these committees are not symbolic institutions but substantially affect firm performance (Velte & Stawinoga, 2020). Moreover, different studies have shown a positive relationship between their existence and the quality of environmental reports (Helfaya & Moussa, 2017), the compliance with the Global Reporting Initiative standards (Fuente et al., 2017), and the more efficient development of CSR programs (Cucari et al., 2018). However, can the existence of a CSR committee influence a firm's eco-innovation?

The role of CSR committees has been extensively explored in the literature, showing consistent evidence supporting its positive relationship with different variables. Studies explicitly addressing the link between board gender diversity and eco-innovation have included it as a controlling variable (He & Jiang, 2019; Nadeem et al., 2020), showing a positive effect. Moreover, the reduction of greenhouse gases is an output of eco-innovation (Garcìa-Granero et al., 2018) and different research investigating the reduction of greenhouse gas emissions and board gender diversity (Konadu, 2017; Konadu et al., 2022) have confirmed its positive effect as a control variable. Despite all the previous results showing a positive impact, only limited studies have included it as a moderator, and even fewer analyse it as a mediator (Velte & Stawinoga, 2020). Therefore, considering the demonstrated effectiveness of the CSR committee and its fundamental and positive role in implementing different environmental activities, this study argues that its presence mediates the relationship between board gender diversity and eco-innovation. It is possible to hypothesise that:

H2: The presence of a CSR committee in a firm mediates the relationship between board gender diversity and eco-innovation.

In support of this thesis, a recent study demonstrated that the CSR committee mediates the relationship between board gender diversity and the affiliation with the UN Global Compact (Martìnez-Ferrero et al., 2020). The UN Global Compact comprises ten principles, and principle nine explicitly states: "encourage the development and diffusion of environmentally friendly technologies" (Compact, n.d.). Furthermore, another study has shown a positive mediating role of CSR strategies between BGD and EI (Issa & Bensalem, 2022). As previously said, CSR strategies are delegated to the CSR committee when implemented, suggesting that it can channel this effect.

A recent study supports this idea of the moderating role of the CSR committee and introduces another essential element in describing the phenomenon. Endrikat et al. (2021) in their meta-analytical investigation has confirmed the mediating role of the CSR committee between some board characteristics and CSR performance. These features were board size, board independence and female board representation. Besides the confirmation of the validity of our hypothesis, another conclusion is worth to be mentioned. All the features are partially interrelated and jointly influence CSR performance (Jain & Jamali, 2016).

In the literature, the presence of independent members has been linked with an increase in the possibility of creating a CSR committee to protect stakeholder interests and address CSR strategy (Elmaghrabi, 2021; I. Garcìa-Sánchez et al., 2019). Moreover, they have also been shown to affect eco-innovation positively (I.-M. Garcìa-Sánchez et al., 2021; Nadeem et al., 2020). This confirms that their exclusion from the model will lead to a lower understanding of the phenomenon. Specifically, their interaction with internal directors is not straightforward. According to the stakeholder agency, independent directors are vital in addressing stakeholders' interests and concerns (I. Garcìa-Sánchez et al., 2019; Hill & Jones, 1992). Moreover, their presence is associated with better monitoring of decisions (Fama & Jensen, 1983; Liao et al., 2015), CSR controversies (Johnson & Greening, 1999) and reduction of management opportunism (Fama & Jensen, 1983;

Post et al., 2011). Their prestige is strongly linked to business results and the company's social image, incentivising them to push the board to adopt long-term strategies that consider stakeholders' interests despite managers' aversion (I.-M. Garcìa-Sánchez et al., 2019; Naciti, 2019). In the environmental field, this long-term horizon is translated into more engagement in investments and a higher tendency toward reporting (Liao et al., 2015). Therefore, the intergroup conflict theory (Böhm et al., 2020) suggests that internal and external (independent) managers may perceive themselves as belonging to different groups, engaging in intergroup discrimination and conflict. Moreover, dividing into groups may also involve gender (male and female directors), extending discrimination and conflict. Therefore, creating a CSR committee represents a situation of conflict in which independent board managers and board gender diversity interact with each other. Accordingly, it is possible to hypothesise that:

H3: The presence of independent directors moderates the relationship between board gender diversity and the creation of a CSR committee

The three hypotheses are interdependent in reinforcing the model's robustness. Although the third hypothesis advances the literature, the previous two are propaedeutic for developing the final moderated mediated model.

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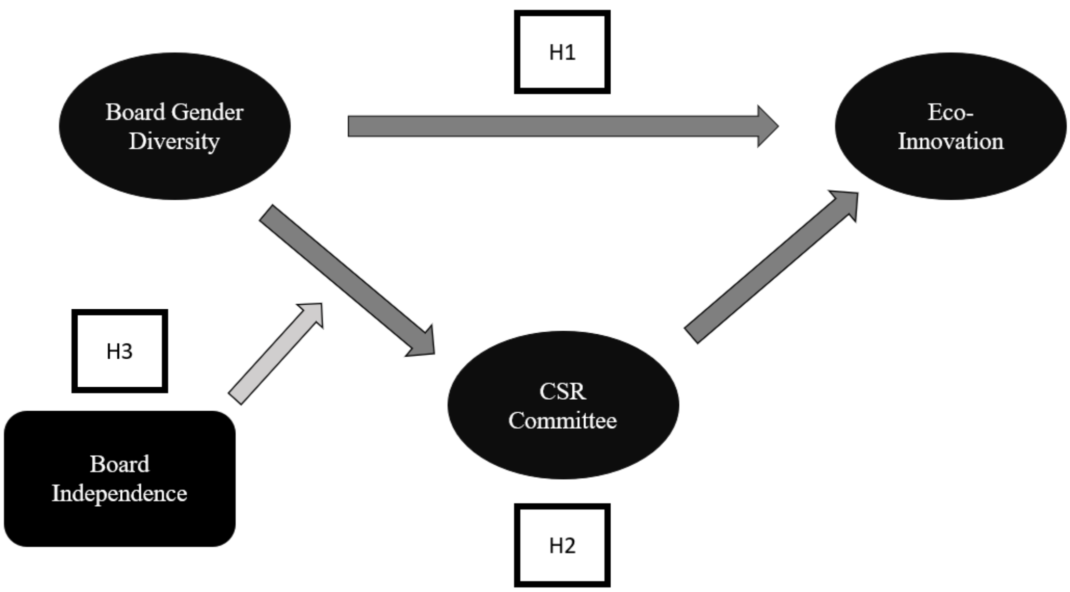


3.4 Method

3.4.1 Sample

Data were collected from Thomson Reuters Eikon ESG databases to test the study hypotheses. Following recent studies on these topics (Konadu et al., 2022; Nadeem et al., 2020), we selected a sample of listed companies from the Standards and Poor (S&P) 1500 index from 2002 to 2018. Then, we excluded all the companies that had missing data for gender diversity for a minimum of eight years, leaving a sample of 527 companies. After this, we decided to consider only data from 2010 to 2018. The reasons why we chose this period are several. First, Eikon provides data from 2002, but there isn't much information on the following years. Moreover, some big companies in the sample went public later than the starting date, providing a lack of data. Second, in 2007-2008, the global financial crisis reduced companies' performance worldwide and took several years to recover. Starting from 2010 allows mitigating the influence of that crisis, reducing the risk of having misleading data. Some studies analyse ESG performance before and after those dates (Konadu et al., 2022). In contrast, others introduce a dummy variable to account for its effect (I.-M. Garcìa-Sánchez et al., 2021), but we prefer not to include that period. Finally, we obtain an unbalanced panel dataset with 527 companies with 4743 observations.

3.4.2 Model and econometric methodology

The existence of direct and indirect relations between the variables is tested following the recommendations of Yzerbyt et al. (2018). In defining the presence of a mediation model, he suggested applying two different approaches: the component and the index approach. The component approach confirms mediation if the two components of the indirect effects (ab) are *both* significant in steps 2 and 3 of the Baron and Kenny (1986) three-Step procedure. However, as hypothesised in **H3**, board independence moderates the relationship between the independent variable (Board gender diversity) and the potential mediator (CSR committee), resulting in a first-stage moderation model (Edwards

& Lambert, 2007). Therefore, the three models are as follows:

$$\begin{aligned}\text{Prob(CSRCom)}_{it} = {} & \beta_{a1}\text{BGD}_{it} + \beta_{a2}\text{BoardInd}_{it} + \beta_{a3}\text{BGD}_{it} * \text{BoardInd}_{it} + \beta_{a4}\text{Growth}_{it} \\ & + \beta_{a5}\text{Slack}_{it} + \beta_{a6}\text{ROA}_{it} + \beta_{a7}\text{BoardSize}_{it} + \beta_{a8}\text{Duality}_{it} \\ & + \beta_{a9}\text{Fsize}_{it} + \beta_{a10}\text{CGCom}_{it} + \beta_{a11}\text{Exec}_{it} + \eta_i + \mu_{it}\end{aligned} \tag{3.1}$$

$$\begin{aligned}\text{Prob(EcoInno)}_{it} = {} & \beta_{b1}\text{CSRCom}_{it} + \beta_{b2}\text{Growth}_{it} + \beta_{b3}\text{Slack}_{it} + \beta_{b4}\text{ROA}_{it} \\ & + \beta_{b5}\text{BoardSize}_{it} + \beta_{b6}\text{Duality}_{it} + \beta_{b7}\text{Fsize}_{it} + \beta_{b8}\text{CGCom}_{it} \\ & + \beta_{b9}\text{Exec}_{it} + \eta_i + \mu_{it}\end{aligned} \tag{3.2}$$

$$\begin{aligned}\text{Prob(EcoInno)}_{it} = {} & \beta_{c1}\text{BGD}_{it} + \beta_{c2}\text{CSRCom}_{it} + \beta_{c3}\text{Growth}_{it} + \beta_{c4}\text{Slack}_{it} \\ & + \beta_{c5}\text{ROA}_{it} + \beta_{c6}\text{BoardSize}_{it} + \beta_{c7}\text{Duality}_{it} + \beta_{c8}\text{Fsize}_{it} \\ & + \beta_{c9}\text{CGCom}_{it} + \beta_{c10}\text{Exec}_{it} + \eta_i + \mu_{it}\end{aligned} \tag{3.3}$$

The first model applied a panel data logistic regression since the dependent variable (CSR committee, the moderator) is a dummy variable. The following two used a panel data ordinal logistic regression because the study dependent variable (Eco-Innovation) is ordinal. In addition, while it has been suggested that implementing CEP requires time, this may not be the case for all environmental practices. The variable used as a proxy for CEP encompasses various environmental practices, each with its own implementation timeline. Therefore, this study uses the non-lagged version of the independent variable in the base model to ensure accurate results, in line with recent researchers (Konadu et al., 2022; Nadeem et al., 2020). However, to thoroughly analyse potential delayed effects, we also examine the lagged form of the independent variable as a robustness check.

Hayes (2015) in his study shows that when a moderator is included in mediation models, the indirect effect of the dependent variable on the independent variable is a linear function of the moderator. In the case of the first stage moderation model, the indirect effect is equal to:

$$\omega = \beta_{a1}\beta_{b1} + \beta_{a3}\beta_{b1}\text{BoardInd} \tag{3.4}$$

The weight for BoardInd, $\beta_{a3}\beta_{b1}$, is called the index of moderated mediation (IMM) (Hayes, 2015). Reframing, the component approach confirms moderated mediation if the components of IMM are *both* significant in steps 2 and 3. The index approach uses different statistical methods to test whether the indirect effect (IMM) differs significantly from zero rather than its components individually. The tests usually used in literature are percentile bootstrap, bias-corrected bootstrap, accelerated bias-corrected bootstrap, and Monte Carlo (MC) simulations (Hayes & Scharkow, 2013; MacKinnon et al., 2007; Preacher & Selig, 2012). This research used the latter method because the abovementioned study of Yzerbyt et al. (2018) has shown that MC is the best method for both type 1 error and power in moderated mediation models. Specifically, the MC method applied is the one proposed by Selig and Preacher (2008).

3.4.3 Variables

Dependent variable

Prior studies on environmental innovation/eco-innovation used ESG data from Eikon and ASSET4 as proxy (I.-M. Garcìa-Sánchez et al., 2021; Konadu et al., 2022; Nadeem et al., 2020). Arena et al. (2018) argued that Asset4 data provides objective, auditable, and systematic information about ESG performance. The use of data differs from study to study. It ranges from the comprehensive use of the innovation score (Konadu et al., 2022) to the use of some indicator inside it (I.-M. Garcìa-Sánchez et al., 2021) or the creation of a composite measure of different information (Arena et al., 2018; Nadeem et al., 2020). This study follows the latter approach.

Using as reference the study of Garcìa-Granero et al. (2018) that identifies 30 key EIPIs (Environmental Innovation Performance indicator), we have derived from the information provided by the Eikon database 12 KEIPIs. These KEIPIs were identified by comparing the rationale behind the ones identified in the previous studies with the ESG data of Eikon. The final set represents three dimensions of EI: product innovation, process innovation and organisational innovation (Marcon et al., 2017; Rodriguez & Wiengarten, 2017). Each KEIPI identified from the Eikon database is reported in the appendix.

The first dimension is composed of 4 indicators, the second dimension of 5 and the latter of 3. Each KEIPI has been assigned a value of 1 if the firm has disclosed information about implementing that specific KEIPI and 0 otherwise. As done in previous studies (Cheng et al., 2014; Nadeem et al., 2020), equal weight was given to each performance metric. Therefore, the variable eco-innovation is a compound categorical indicator that ranges from 0 to 12. Higher values of this measure show that a firm has implemented different types of eco-innovation, while lower values show an implementation lack.

Independent variable

Following previous studies (He & Jiang, 2019; Konadu et al., 2022; Nadeem et al., 2020), this study has used the percentage of female directors on board as a proxy for board gender diversity.

Mediator and Moderator variables

The mediator variable (CSRCom) was coded as a dummy variable with only two values (0 and 1) to identify the existence of this committee. The moderator variable (BoardInd) is expressed as a percentage of the board's independent directors. As stated in the methodology subsection, the effect of these two variables on the independent variable is a linear function, namely the IMM.

Control variables

The controls included in the study are mainly of three categories: financial, organisational and female executive effectiveness. The first group of variables include growth, slack and ROA. The former is the ratio of the current year's net sales to the previous one. Slack represents the available resources to invest in environmental performances (Berrone et al., 2013; Welsh, 1981) measured as the current asset divided by the current liabilities. Calculated as net income over total assets and widely used in literature about environmental performances (Earnhart, 2018; Endrikat et al., 2014), ROA measures the profitability of firm assets.

The second group of variables includes board size, CEO – chairman duality, firm size, and corporate governance committee. Previous studies have found that these organisational variables may impact eco-innovation, so they have been included in the study. The board size is the total number of directors. CEO duality is a binary variable that takes a value of 1 if the CEO is also the chairman of the board and 0 otherwise. Firm size is calculated as the natural logarithm of the total number of employees. The corporate governance committee is a binary variable that takes a value of 1 if it is present and 0 otherwise.

Following previous studies (Guldiken et al., 2019; He & Jiang, 2019), to control the effectiveness of female executive directors on the board of directors (the third group), Exec represents the total number of female executive directors expressed in percentage.

3.5 Analysis

	Frequency	
CSRCom	54.63%	
Duality	69.39%	
CGCom	98.02%	
	Mean	Std. dev.
BGD(%)	18.39	9.91
BoardInd(%)	82.16	10.30
Growth	6.52	24.8
Slack	1.17	0.65
ROA	0.07	0.05
BoardSize	10.40	2.08
Fsize	9.56	1.55
Exec	14.36	12.65

Table 3.1: Descriptive statistics

Table 3.1 summarises the descriptive statistics, the mean and standard deviation for all model variables. Among them, the average diversity on the board is 18.39%, while the board's average independent directors are 82.16%. Although a high disproportion between the two variables, the CSR committee is present in slightly more than half of the sampled companies (54.64%).

Table 3.2 shows the correlation among variables with their confidence interval.

Table 3.3 shows the results obtained from the three steps procedure, confirming the existence of a moderated mediation effect according to the component approach. The moderation term is significant and negative ($a_3 = \beta_{a3}$BGD *BoardInd $= -0.002, p-value < 0.01$) and the mediated variable, CSRCom, has a significant positive effect ($b = \beta_{b1}$CSRCom $= 1.893, p-value < 0.001$). The indirect effect is equal to the linear function 0.47325 - 0.003786*BordInd, with intercept $a_1b = \beta_{a1}\beta_{b1} = 0.47325$ and slope (IMM) $a_3b = \beta_{a3}\beta_{b1} = -0.003786$. The IMM graphically depicted in Figure 3.1a shows that the indirect effect of BGD on EcoInno through the CSRcom seems to decrease as BordInd increases. The index approach confirms this result and rejects the indirect effect's null effect. A 95% MC confidence interval for the IMM is provided in Figure 3.1b. The previous conclusion is confirmed since the interval is -0.007656 to -0.00002264 and does not include zero with both the lower and negative bound negative. Concerning control variables, Fsize is positive and significant in all three steps confirming previous literature (Liao et al., 2015), and Slack is negative and significant only in steps 2 and 3, partially contradicting the literature. Two board-related control variables, BoardSize and Duality, are significant in step 1, but the former is positive while the latter is negative. The first result confirms previous studies that found that as the number of directors approximates 15, the ethical commitment of a company increases (Frias-Aceituno et al., 2014; I.-M. Garcìa-Sánchez et al., 2015). Notably, the role of CEO duality in constituting a CSR committee is not deeply analysed in the literature and, to the best of this study's knowledge, the only studies that include this variable found a positive relationship that is in contrast with this result (I. Garcìa-Sánchez et al., 2019).

	EcoInno	BGD	BoardInd	CSRCom	Growth	Slack	ROA	BoardSize	Duality	Fsize	CGCom	Exec
EcoInno	1.000											
BGD	0.2904***	1.000										
BoardInd	0.2346***	0.2243***	1.000									
CSRCom	0.6198***	0.2605***	0.2039***	1.000								
Growth	−0.0850***	−0.0888***	−0.0403***	−0.0926***	1.0000							
Slack	−0.1510***	−0.1199***	−0.0710***	−0.1684***	0.0279	1.0000						
ROA	0.0710***	0.0303*	-0.0150	-0.0102	0.0839***	0.0703***	1.0000					
BoardSize	0.3449***	0.2016***	0.1483***	0.3420***	−0.0772***	−0.1620***	−0.0515***	1.0000				
Duality	0.0958***	0.0053	0.0265	0.0464***	-0.0074	0.0151	0.0401***	0.1104***	1.0000			
Fsize	0.4322***	0.2402***	0.1043***	0.3280***	−0.0875***	−0.1579***	0.1540***	0.4030***	0.1378***	1.0000		
CGCom	0.0647***	0.0136	0.1600***	0.0697***	0.0109	−0.0393***	-0.0030	0.0017	0.0112	0.0010	1.0000	
Exec	0.1221***	0.3280***	0.1187***	0.1291***	−0.0434***	−0.1044***	0.0169	0.1360***	-0.0215	0.1208***	0.0012	1.0000

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Table 3.2: Correlation table

	Step 1	Step 2	Step 3
BGD	0.250**		0.050***
	(0.084)		(0.005)
BoardInd	0.103***		
	(0.023)		
BGD * BoardInd	−0.002**		
	(0.001)		
CSRCom		1.893***	1.893***
		(0.138)	(0.137)
Growth	−0.004	−0.000	0.000
	(0.003)	(0.001)	(0.001)
Slack	−0.211	−0.286*	−0.222*
	(0.271)	(0.112)	0.112
ROA	0.617	−0.593	−0.816
	(2.232)	(0.980)	(0.981)
BoardSize	0.134*	0.039	0.029
	(0.066)	(0.028)	(0.028)
Duality	−0.888**	−0.040	0.021
	(0.310)	(0.126)	0.126
Fsize	1.593***	1.121***	1.048***
	(0.206)	(0.098)	(0.098)
CGCom	3.124*	0.381	0.574
	(1.124)	(0.455)	(0.457)
Exec	0.011	0.011*	0.001
	(0.010)	(0.004)	(0.004)
Rho	0.922		
Log Likelihood	−1116.405	−6815.661	−6767.796
Wald χ^2	139.93	386.31	475.36

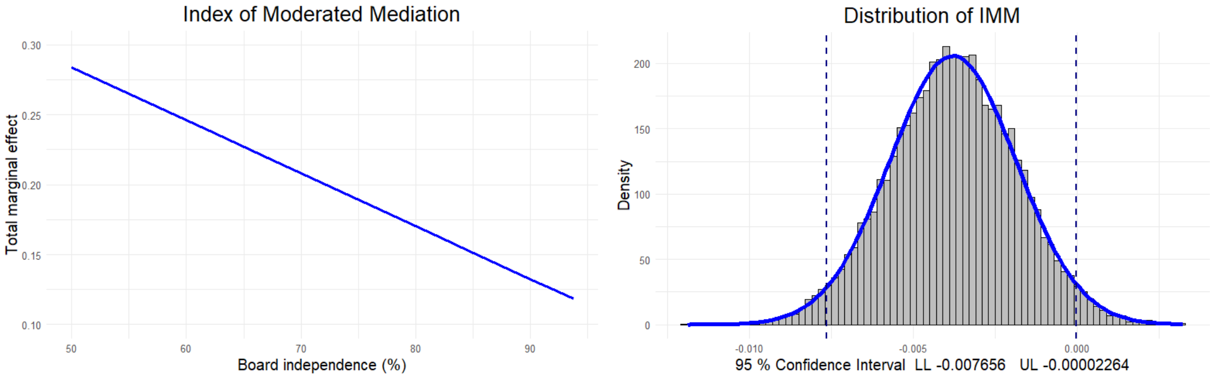
$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 3.3: Three steps procedures to test mediation

3.5.1 Additional analysis

Other analyses have been conducted to ensure the robustness of the previous results. Specifically, a one-year lagged value analysis and a deep analysis of the effectiveness of female directors are employed.

Environmental strategies, such as EI, needed technical requirements to be implemented, not always resulting in an immediate payoff (Bansal, 2005; Bansal et al., 2014). Therefore, board members may have decided before the actual implementation, resulting in an increase in EI in the following year that is not caused by decisions taken that year. Analyses described in Section 4.1 are recalculated, substituting independent, modera-



(a) IMM graphical representation

(b) 95% MC confidence interval

Figure 3.1: Plots of the IMM graphical representation and a 95% MC confidence interval on the distribution of IMM obtained by models in Table 3.3.

tor, mediator and control variables with one-year lagged values to test this hypothesis. Table 3.4 shows the results obtained, and accordingly to the previous result, a moderated mediation effect is confirmed. The component approach confirms the negative and significant moderation effect among BGD and BoardInd ($a_3 = \beta_{a3}$BGD *BoardInd $= -0.004, p - value < 0.001$) and the positive and significant effect of the mediated variable ($b = \beta_{b1}$CSRCom $= 1.622, p - value < 0.001$). Notably, the results are significant at a higher confidence level, and the effects are slightly less negative. In this case, the indirect effect is equal to the linear function 0.634202 - 0.006488*BordInd, with intercept $a_1 b = \beta_{a1}\beta_{b1} = 0.634202$ and slope (IMM) $a_3 b = \beta_{a3}\beta_{b1} = -0.006488$. The IMM graphically depicted in Figure 3.2a shows that the indirect effect of BGD on EcoInno through the CSRcom seems to decrease as BordInd increases. The index approach confirms this result and rejects the indirect effect's null effect. A 95% MC confidence interval for the IMM with the lagged variables is provided in Figure 3.2b. The interval is - 0.01002 to - 0.003196 and does not include zero with both the lower and negative bound negative, reconfirming the moderated mediation. Concerning control variables, Fsize is confirmed to be positive and significant in all models and Slack, although with an opposite sign.

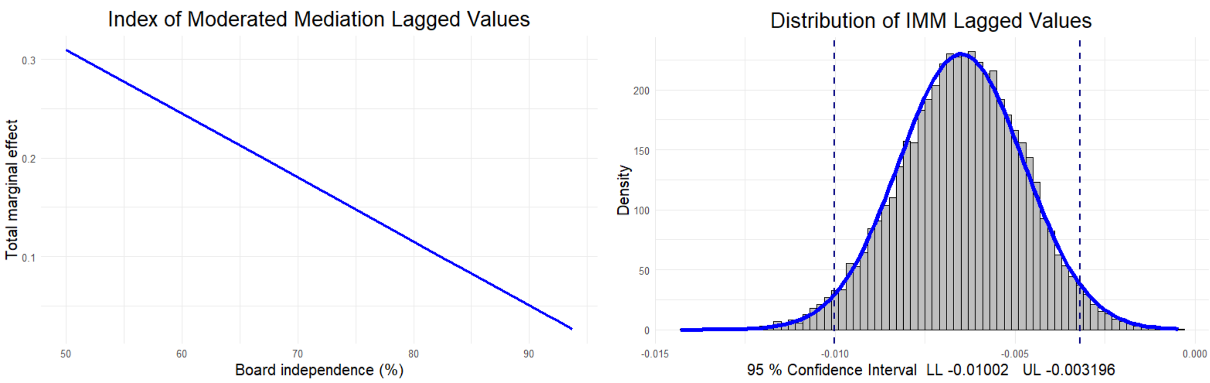
Although, in each of the previous models, BGD was found to be significant, there is no evidence about the effectiveness of the women on the board. Exec was found to be positive and significant in the latter lagged model, suggesting that female executives play an active role in implementing EI in a longer-oriented perspective. However, there is no information about non-executive female directors. It is worth investigating whether

	Step 1	Step 2	Step 3
BGD	0.391***		0.044***
	(0.087)		(0.005)
BoardInd	0.133***		
	(0.023)		
BGD * BoardInd	−0.004***		
	(0.001)		
CSRCom		1.650***	1.622***
		(0.136)	(0.136)
Growth	−0.000	−0.000	0.000
	(0.003)	(0.001)	(0.001)
Slack	−0.375	−0.306**	−0.262*
	(0.264)	(0.111)	0.112
ROA	0.956	−0.264	−0.533
	(2.251)	(0.999)	(1.000)
BoardSize	0.214**	0.017	0.008
	(0.066)	(0.028)	(0.028)
Duality	−0.686*	0.017	0.069
	(0.303)	(0.128)	0.128
Fsize	1.553***	1.195***	1.128***
	(0.198)	(0.098)	(0.098)
CGCom	2.745*	0.729	0.809*
	(1.120)	(0.430)	(0.429)
Exec	0.008	0.016***	0.009*
	(0.010)	(0.004)	(0.004)
Rho	0.917		
Log Likelihood	−1094.335	−6726.113	−6693.976
Waldχ^2	159.06	377.14	437.26

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 3.4: Three steps procedures to test mediation with one-year lagged variables

female directors actively implement EI to disclose some tokenistic behaviour. This phenomenon, called tokenism, was first studied by Kanter (2008) in her seminal work and then refined by Dahlerup (1988) into the critical mass theory. It has recently evolved into the critical actor's theory of Childs and Krook (2009). Stakeholders and regulatory bodies put external pressures on the institutional legitimacy of gender homogeneous board (Perrault, 2015), decrying and compelling firms to add at least one female on the board (Konrad et al., 2008; Perrault, 2015). Further, studies have shown that benefits from a gender-diverse board are achieved when the number of women exceeds one, reaching its peak at three female directors with diminishing returns over that number (Torchia et al.,



(a) IMM graphical representation (b) 95% MC confidence interval

Figure 3.2: Plots of the IMM graphical representation and a 95% MC confidence interval on the distribution of IMM obtained by models in Table 3.4

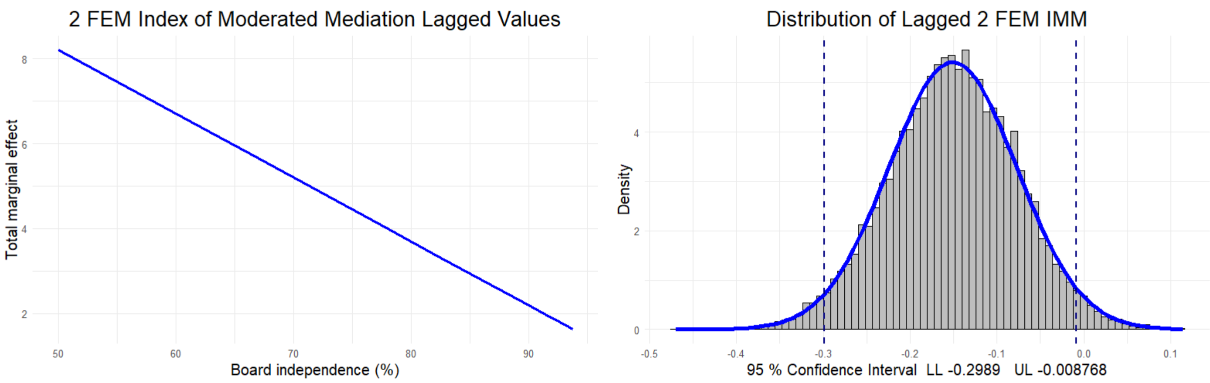
2011). However, after the first female director, the likelihood of appointing another one drops significantly (Farrell & Hersch, 2005) due to internal dynamics related to strategic leaders (Konrad et al., 2008). Therefore, an ordinal variable substituting BGD is created to grasp these differences: FEM. It has four levels representing no female directors on the board, at least one, at least two and at least three.

Table 3.5 summarises the models from equation 3.1,3.2 and 3.3 with non-lagged and one-year lagged variables. The component approach does not suggest a moderated mediation in the models with non-lagged variables since none of the moderation effects among FEM variables and BoardInd is significant. On the contrary, the moderation between 2 FEM and BoardInd is negative and significant ($a_3 = \beta_{a3}$2 FEM *BoardInd $= -0.095, p - value < 0.05$) and CSRCom is positive and significant ($b = \beta_{b1}$CSRCom $= 1.587, p - value < 0.001$) in the one-year lagged models. Therefore, the index approach analyses on the null effect of IMM were done only on 2 FEM of the one-year lagged model. IMM displayed in Figure 3.3a is equal to the linear function 15.75256 - 0.150765*BordInd, with intercept $a_1 b = \beta_{a1}\beta_{b1} = 15.75256$ and slope (IMM) $a_3 b = \beta_{a3}\beta_{b1} = -0.150765$. Figure 3.3b shows the 95% MC confidence interval of the variable, excluding the null effect as the interval is -0.2989 to - 0.008768. This result suggests that a moderated mediation is present only when the number of female directors is two, confirming previous studies on tokenism and critical mass. The number of two female directors seems to be the threshold of the effectiveness of women's presence on the board of directors. Moreover, it confirmed Exec's positive and significant effect in the one-year lagged model.

	Non Lagged Models			Lagged Models		
	Step 1	**Step 2**	**Step 3**	**Step 1**	**Step 2**	**Step 3**
FEM						
1 FEM	0.445		0.888***	2.623		0.939***
	(3.005)		(0.174)	(3.277)		(0.168)
2 FEM	5.573		1.701***	9.926**		1.568***
	(3.21)		(0.192)	(3.556)		(0.190)
3 FEM	0.324		1.966***	3.179		1.823***
	(3.578)		(0.212)	(3.872)		(0.213)
BoardInd	0.065			0.105		
	(0.036)			(0.038)		
FEM * BoardInd						
1 FEM * BoardInd	0.009			−0.018		
	(0.037)			(0.039)		
2 FEM * BoardInd	−0.043			−0.095*		
	(0.039)			(0.042)		
3 FEM * BoardInd	0.014			−0.021		
	(0.043)			(0.045)		
CSR		1.893***	1.847***		1.650***	1.587***
		(0.136)	(0.138)		(0.136)	(0.137)
Growth	−0.003	−0.000	0.000	−0.002	−0.000	0.000
	(0.003)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)
Slack	−0.182	−0.286*	−0.232*	−0.236	−0.306**	−0.259*
	(0.283)	(0.112)	(0.112)	(0.288)	(0.111)	(0.112)
ROA	0.924	−0.593	−0.722	0.640	−0.264	−0.430
	(2.261)	(0.980)	(0.985)	(2.305)	(0.999)	(1.002)
BoardSize	0.070	0.039	−0.047	0.160*	0.017	−0.062*
	(0.069)	(0.028)	(0.030)	(0.073)	(0.028)	(0.030)
Duality	−0.895**	−0.040	0.068	−0.960**	0.017	0.098
	(0.318)	(0.128)	(0.126)	(0.326)	0.128	(0.128)
Fsize	1.609***	1.121***	1.036***	1.803***	1.195***	1.105***
	(0.198)	(0.098)	(0.098)	(0.222)	(0.098)	(0.098)
CGCom	3.286**	0.381	0.510	1.931*	0.729	0.746
	(1.127)	(0.430)	(0.455)	(0.911)	(0.429)	(0.430)
Exec	0.007	0.011*	0.003	0.003	0.016***	0.010*
	(0.010)	(0.004)	(0.004)	(0.011)	(0.004)	(0.004)
Rho	0.927			0.929		
Log Likelihood (-)	1106.18	6815.66	6758.89	1079.24	6726.11	6683.96
Waldχ^2	144.22	386.31	488.30	168.51	377.14	452.80

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 3.5: Two three steps procedure models, on the left with non-lagged variables and on the right with one-year lagged variables, with number of female directors (FEM) instead of BGD



(a) IMM graphical representation (b) 95% MC confidence interval

Figure 3.3: Plots of the IMM graphical representation and a 95% MC confidence interval on the distribution of IMM of 2 FEM obtained by models in 3.5.

3.6 Discussion

The results obtained in the previous section give several insights into interpreting the mechanisms through which different board characteristics influence EI. First, results demonstrate that BGD affects EI by creating a CSR committee confirming **H2**. Therefore, although the direct effect is lower than the indirect effects, **H1** is also confirmed. It is interesting to notice that **H3** is confirmed, but the moderating effect of independent directors is negative. So, although overall positive, how is it possible that the moderation effect of female and independent directors is negative despite several studies demonstrating that both positively affect CSR-related issues and the creation of a CSR committee? The results show that to increase the probability of creating the CSR committee, a company needs to reduce either female directors or independent members and increase the number of others. The two groups' similar roles inside organisations can explain this substitution effect. However, relying solely on this effect does not provide a comprehensive solution. Both groups seek to influence EI strategies by implementing a CSR committee, and therefore, they should collaborate rather than compete. This collaboration is also supported by the fact that they share similar functions and hold the power to influence a company's strategy. It is perplexing to consider that these similar functions may have a negative impact on the creation of a CSR committee when group interests appear to be aligned. This study suggests that the reason for the negative moderation effect between BGD and BoardInd is to be found in group conflict.

The managers' vision and concern are fundamental in implementing and adopting environmental strategies (Paraschiv et al., 2012; Qi et al., 2010). The board of directors has primarily two essential functions: monitoring and resource provision (Hillman & Dalziel, 2003). They act as a monitoring system that ensures managers' decisions are aligned with the interest of shareholders. Nevertheless, different natures and conflicting interests exist inside the board, creating different subgroups. The self-categorization theory (Turner et al., 1987) states that individuals identify themselves as member of certain groups based on the different levels of categorical abstraction (relative accessibility), the ease in distinguishing within social categories (comparative fit) and the expectations about in-group and out-group behaviours (normative fit). According to the agency theory (Eisenhardt, 1989), the directors' nature drives them to take opportunistic decisions. Independent directors are appointed to the board to assure shareholders that decisions are made for their interests, avoiding these opportunistic behaviours of other directors. In this sense, environmental strategies represent a potential opportunity for the arising of agency problems. They stem from the fact that EI is characterised by a higher degree of complexity and novelty than other innovations (Horbach, 2008), requiring high investment in human and technical capabilities (Bansal et al., 2014) that can drain resources from other remunerative projects. Therefore, an internal conflict between internal and independent directors may arise, with female managers being part of the former. In this scenario, the first group decides not to create a CSR committee that implements EI strategies because they consider other projects more remunerative.

However, this hypothesis is not supported by empirical results. Suppose all previous studies have shown a direct positive correlation between board gender diversity, EI and the creation of CSR committees (Endrikat et al., 2021). Why would the former hinder investments in that direction? Different studies have demonstrated that investing in corporate environmental performances, such as EI, positively impacts financial performances (Dixon-Fowler et al., 2013) and are a basis for some competitive strategies (Garcìa-Granero et al., 2018). Moreover, resource dependency theory (Hillman et al., 2009) suggests that the totality of board members is interested in implementing them to minimise external dependencies. Therefore, how is it possible to explain the negative moderation effect?

The negative moderation effect is due to intergroup conflict in the merit attribution of creating the CSR committee. Its implementation required allocating resources from both groups, which want to maximise their in-group values (Karp et al., 1993). The attribution of merit of creating a CSR committee is considered valuable because, as said, it increases market legitimacy and creates competitive advantages through the implementation of EI, which in turn generates higher business performance. Social identity theory (Tajfel & Turner, 2004) suggests that prejudice and discrimination occur naturally when individuals create groups, influencing intergroup allocations and maximising the in-group members' absolute gain at the cost of out-group members. However, intergroup discrimination is not costless for discriminating individuals (Böhm et al., 2020). The costs connected to the missed implementation of a CSR committee and the subsequent advantages related to the implementation of EI may be considered too high for both groups. Therefore, the decision process is slowed but not hindered to avoid connected loss.

In our sample, on average, 82% of board directors are independent, while only 18% are females, showing that the categorisation of internal and independent directors may not completely grasp the phenomenon. Internal male directors may categorise themselves as a different group from female independent directors, although belonging to the same group. The previous conclusion on intergroup conflicts still holds in this scenario, but male directors' biases towards female directors may exacerbate these dynamics. As highlighted by Guldiken et al. (2019), directors are usually older males who see them as not belonging to their group compared to younger ones, increasing intra-group conflicts. This raises the question of the tokenism of women in the decision-making process. Because of group discrimination, two problems may arise (Larcker & Tayan, 2015). One is the marginalisation of female directors in making decisions, and the other is the presence of gatekeepers in appointing other women to the board. This study has tried to address this problem by analysing the role of female executives and the number of female directors. The former positively impacted EI, confirming the literature strand that suggests that females in apical positions are more environmentally concerned, although only in the lagged model. As said, this may be connected to their long-term vision. The more interesting result is that the analyses have confirmed that the moderated mediation model is still present when at least two women are on the board of directors. This suggests that the considerations done before using intragroup theory are consistent in that scenario. Female directors incur marginalisation in the decision-making that is overcome due to their critical mass (Dahlerup, 1988) and the cost connected to implementation failures, increasing their effectiveness in the process.

The total IMM effect confirms that the CSR committee mediates the effect of BGD on EI. CSR-related strategies, particularly EI, require a high commitment from board members and specific managerial and organisational capabilities. Therefore, boards delegate specific committees with specialised knowledge to take these complex decisions, channelling the impacts of board characteristics and increasing efficiency (Dalton et al., 1998). Moreover, creating a CSR committee increases the legitimacy of CSR orientation of corporate activities to external stakeholders (Dyllick & Muff, 2016).

Moreover, the firm's size seems essential in implementing EI, which is aligned with previous research (Liao et al., 2015). Although negative, financial resources seem not to have significant effects, excluding Slack. This result was found in other studies (He & Jiang, 2019; Konadu et al., 2022).

3.7 Conclusion and implications

This study examined how board gender diversity (BGD) affects environmental innovations (EI), measured as an index composed of three dimensions: product, process and organisation. This study has applied a moderated mediation model with the CSR committee (CSRCom) as a mediator and the percentage of board independent directors as moderator (BoardInd). The results show a positive moderated mediation with the indirect effect of BGD on EcoInno through the CSRcom decreasing as BordInd increases. The component and index approaches on non-lagged and one-year lagged models confirm this. Moreover, it has been tested for possible tokenistic phenomena. The results for the non-lagged model were not significant, while the presence of two female directors on the board has found to be significant for one-year lagged variables. These results endorse different managerial theories while putting some doubts on the agency theory interpretation. Both independent and internal directors, regardless of gender, are interested in implementing EI since they produce several strategies to gain market legitimacy and create competitive advantages to reduce external dependencies. Therefore, it is improbable that opportunistic behaviour in implementing EI may arise. Divergencies in the attribution of merit of CSR committee implementation due to different social groups on the board may explain the negative moderation effect. In our sample, approximately three-quarters of board members are independent (82.16%), and only 18 % are females, creating intergroup conflicts among them. The results of intergroup conflict may be exacerbated by male directors' biases towards female directors. Biases toward female directors could marginalise them from taking effective decisions, reducing them to tokens. Despite this, both groups want to implement EI to minimise related failure costs, not hindering the process but only slowing it down. Although not all the results are significant, when at least two female directors are sitting on the board, their influence on decision-making is substantial and not tokenistic.

This study provides different theoretical, managerial and methodological implications. Theoretically, the study's results align with the upper-echelon theory confirming the critical role of board members' cognition, capability, and interaction in implementing strategies. The results also align with the resource dependency theory. On average, female directors have different individual traits and backgrounds than males, increasing the set of resources used to face and interpret strategic decisions. Interestingly, the results broadly support the theoretical framework that indirectly links the effect of BGD on EI (Issa & Bensalem, 2022). Compared to the previous research, this study introduces two new elements: the mediating role of the CSR committee and the moderating role of board independent members. Introducing these variables leads to a better understating the phenomenon, as the literature has suggested a joint effect of different board elements (Endrikat et al., 2021). A previous study has focused on the mediating role of

CSR strategies in the relationship between BGD and EI. However, the literature and this study confirm that these committees are not symbolic institutions but substantially affect firm performance, especially in implementing CSR-related strategies (Velte & Stawinoga, 2020). In this sense, CSR strategies are an output of the CSR committee. Therefore, not including it when present is equivalent to analysing the effect, not the causes.

Managerially, these results are significant because they provide insights into the implementation process of EI. They require specialised knowledge to implement timely decisions to grasp fleeting opportunities (Bansal et al., 2014). Delegating these processes to specific committees increases board efficiency and better decision-making (Dixon-Fowler et al., 2017), resulting in a positive impact of the CSR committee on the enforcement of EI. To improve firms' performances, managers should implement this committee while avoiding intergroup conflicts in the imputation of EI that could create decision stalls. Reducing time in decision-making is essential to react effectively to the occurrences of the market, especially when environmental issues are prominent. A solution would be reducing the negative outcomes interdependence and increasing positive outcomes through common incentives. This idea is shared by agency theory and realistic group conflict theory, showing that "doing things together" to achieve shared outcomes decreases group conflicts (Sherif, 1958). Another solution is to improve group communication and reduce biases towards specific groups, such as female directors. Intergroup contact theory suggests that increasing the exposure of individuals with group-specific biases to that group mitigates them and reduces conflict(Pettigrew & Tropp, 2006). However, due to the low number of female directors, a considerable effort must be made on the antecedent of the appointment of directors on board (Guldiken et al., 2019).

Methodologically, this paper does not limit assessing a mediation model's existence, only relying on the component approach. Applying the index approach in conjunction with the previous leads to more robust results and reduces the possibility of type 1 error. Further studies are invited to use both approaches to increase the validity of the results.

Despite these contributions and implications, this study has some limitations. First, data were selected from S&P 1500, an index including only US firms. This creates problems in the generalizability of the results because of country-level differences, particularly in investigating gender parity (Byron & Post, 2016). Future studies may use a dataset including firms from different countries to grasp differences. Second, EI has been calculated using a study-specific measure, as a widely accepted standard for calculation does not exist. Therefore, future studies may use a different index to calculate EI, untangling the relationship between the various dimensions of EI. Moreover, the measure comprises three dimensions (product, process and organisation), but only the general effect was used. Future research may analyse if differences in the dimensions exist. Third, other board characteristics, such as the age of board members, could also play a role in defying eco-innovation. Further research may include more of these characteristics to better understand the relationship between gender diversity and eco-innovation. Fourth, only the moderation effect between BGD and BoardInd has been analysed, but other characteristics of boards may jointly influence CSR outcome, as suggested by Velte and Stawinoga (2020). Further research may investigate the interaction of other elements in implementing CSR performances. Finally, the study confirms the effectiveness of the CSR committee in implementing EI. Investigating only the board of directors instead of the CSR committee is similar to looking at the finger, not the moon. Future research may focus on the CSR board member characteristics and dynamics instead of the board of directors to understand what elements foster EI and other CSR-related outputs.

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Chapter 4

Productivity of Eco-Innovation

4.1 Introduction

Prior research has explored the impact of eco-innovation (EI) on GHG emissions at the firm level (Puertas & Marti, 2021), but most studies on GHG emissions and efficiency have only focused on the country level and solely examined EI efficiency (Łącka & Brzezicki, 2022). However, direct analysis of the relationship between production efficiency and EI in reducing carbon emissions has been lacking. This study aims to be the first to explore the crucial role of productivity and EI in reducing GHG emissions, including their interaction.

The irreversible impact of greenhouse gas (GHG) emissions on climate has increased the interest of different stakeholder groups over the years. Its effect on climate change cannot be overlooked (Stern, 2006), especially for the economic consequences of this phenomenon. Therefore, companies are under constant pressure to disclose information about the management of their carbon impact, impacting economic activities and investors' decisions (Ben-Amar et al., 2017). Resource scarcity, desertification, pollution and other harmful effects of global warming affect all territories (Engelhardt et al., 2019; Watts et al., 2018). For this reason, many economic resources have been targeted at promoting technology transfer and innovation to respond to climate change (Ferreira et al., 2020). Experimentation and the spread of cleaner technologies have a prominent role in reducing the environmental impact of economic activities. Countries have also created international agreements to create synergy to address the problem of climate change (Hildén et al., 2017).

Innovations aiming to reduce the negative impact of economic activities are spreading across sectors, including economic, ecological and social aspects of innovation. These innovations are eco-innovations and focus mainly on the more efficient use of resources while reducing harmful environmental effects (Hojnik & Ruzzier, 2016).

The efficient use of resources is a fundamental factor in reducing environmental impact, particularly in the case of GHG emissions (Picazo-Tadeo et al., 2014). In this sense, production efficiency becomes essential because it allows firms to reduce the amount of input to produce the same quantity of output. However, increasing efficiency and being innovative rely on different approaches that are difficult to pursue simultaneously. The former approach is based on improvements and refinement, opposite to radical changes and experimentation necessary to innovate (Sarkees & Hulland, 2009). Previous studies have shown that not all the investments in R&D are helping to reduce GHG emissions, suggesting that possible implementation problems could occur.

The results from a panel dataset of 438 carbon-intensive companies from the Standards and Poor (S&P) 1500 index and the Eurostoxx 600 from 2015 to 2019 show that productivity negatively correlates with GHG emissions while EI is positively correlated. Moreover, the interaction term is negatively correlated with carbon emission.

This study contributes to the literature in several ways. First, it provides a theoretical contribution to assessing the role of EI and productivity in carbon-intensive sectors, representing the first attempt that analyses this relationship. Second, some managerial implications could be drawn: productivity strategies have a better payoff for GHG emission reduction than EI. However, strategies involving both strategies lead to superior outcomes than pursuing only one strategy.

The rest of the paper is structured as follows. Section 2 provides the theoretical background about EI, productivity and their interactions, developing some research hypotheses. Section 3 describes the data and methods applied. Section 4 reports the main results that are discussed in Section 5. Section 6 summarises the study's conclusions, contributions, and limitations.

4.2 Literature review

4.2.1 Eco-Innovation

Recently, a vast set of innovations aiming to reduce the negative impact of economic activities on the environment has risen. The literature has defined them using different terms. The most used are: "green", "eco", "environmental", and "sustainable". The latter term was the first coined to describe and incorporate the concept of economic, ecological and social aspects in the innovation process (Brundtland, 1987). The concept of eco-innovation appeared for the first time in the works of Fussler and James (1996b) and James (1997). The authors show the emergence of a specific type of innovation that provides added value to customers and companies while reducing the environmental impact. Over the years, the concept has evolved, focusing more on the economic and ecological parts (Schiederig et al., 2012) by including a wide range of activities and technologies (Chen et al., 2006). International organisations and governments have intensified their interest in this subject due to its positive impact not only limited to economic activities. They are creating new paradigms and frameworks to assess eco-innovation results and identify the key drivers to implement sustainable plans to reduce environmental impact, especially global warming (Arundel & Kemp, 2009; Garcìa-Granero et al., 2018). However, delineating the boundaries of EI is not straightforward.

It includes an extensive range of activities and subjects, making it difficult to define clearly some performance indicators. Moreover, identifying eco-innovation performance indicators (EIPI) changes whether it is calculated at a firm or national level. In the latter case, most instruments developed to quantify EI have used the work of Acs and Audretsch (1993) as reference. The authors identified four main categories to evaluate EI: input measures, intermediate output, direct output measures and indirect impact measures. At the firm-level analysis, there is not a single study used as a reference to develop a common framework since every author has proposed its own set of indicators. For example, Kemp and Pearson (2007, p.7) defines EI as "the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives". In contrast, other scholars emphasise the increased value for customers and companies of new processes, products, equipment, services, techniques and management systems that reduce environmental impact (Bartolomeo et al., 2003; Fussler & James, 1996a; Kemp & Arundel, 1998).

Although each definition emphasises one or more aspects to others, they all focus on mainly two aspects: more efficient use of resources and reducing harmful effects on the environment (Hojnik & Ruzzier, 2016).

Therefore, EI becomes an essential element for companies to proactively respond to their stakeholders on environmental issues, becoming a necessary resource for reducing toxic emissions such as GHG emissions (Carrión-Flores & Innes, 2010). Due to its irreversible impact on climate, studies addressing EI have used carbon emission reduction as an indicator to measure EI efficiency (Konadu et al., 2022; Nadeem et al., 2020). Therefore, this study hypothesises the following:

H1: Eco-innovation is negatively associated with greenhouse gas emissions.

4.2.2 Productivity

Productivity is a topic that has been extensively discussed in the economic literature since the seminal work of Solow (1956). It can be defined as the quantity of output derived from a given set of inputs and thus expressed as an output-input ratio. Although productivity is a relatively simple concept, its measurement is not so simple (Syverson, 2011). Quality and measurement issues arise when productivity measures are derived from actual production data.

First, the output measure represents an issue since many businesses produce more than one output. Thus, the question relies on whether to aggregate the output into one measure and how to do it. For this reason, revenues are usually used as a proxy for output. However, this measure is not subjected to limitations (Syverson, 2011). If revenue differences are not related to product quality but to market power, this measure could reflect more on firms' local market state than production efficiency.

Second, issues may arise from input selection. Labour is typically used as input for production, but its measurement is inconsistent in all studies. Some studies use the number of employees, employee hours, or quality-adjusted labour measures that could produce different results. Another widespread input is capital, measured as a firm's book value of its capital stock. This raises several questions on whether the measure is a good proxy for capital (Ackerberg et al., 2007). The last issues on input are related to intermediate goods and unmeasured input variations.

Despite the issues described, empirical studies have shown little sensitivity to measurement choice. Many of the results have shown measurement robustness regardless of the different specifications. Whichever productivity measure is used, high-productivity producers will be more productive than other firms (Van Biesebroeck, 2008).

The primary benefit of productivity is the reduction in the amount of input for a given amount of output. Therefore, a more productive company will use fewer resources for a given amount of output, reducing its environmental impact. In literature, GHG emissions are a proxy for the environmental effects of productivity (Łącka & Brzezicki, 2022) since different production inputs are carbon emission determinants, such as energy (Picazo-Tadeo et al., 2014). Thus, it is possible to hypothesise the following:

H2: Productivity is negatively related to GHG emissions.

4.2.3 Productivity and EI

The literature on productivity has identified innovation as one of the drivers to increase productivity (Syverson, 2011). In particular, the extensive literature on R&D and productivity started from the seminal work of Griliches (1998a, 1998b), which identified that link at the firm level. On the aggregate industrial level, this relationship has been confirmed by the study of Mansfield (1984).

Some studies have reported a bidirectional causality between R&D and productivity, showing causal effects and selection effects affecting the link between productivity and R&D (Aw Bee Yan, 2009; Doraszelski & Jaumandreu, 2009), making there difficult to separate correlation from causation. R&D expenditures do not represent all the observable components of firms' innovation, limiting the ability to comprehensively analyse the relationships between productivity and innovation. Nevertheless, it is a reliable measure to investigate a firm's innovation.

Innovation could be represented in terms of product, process, organisational and marketing innovation and not all these dimensions could be reported in the R&D expenditures, although they affect productivity differently(Marcon et al., 2017). Increasing product quality through any product innovation may not lead to an increase in output quantity per input used. Still, it can increase the final market price increasing the firm's revenue per unit input (Acemoglu & Linn, 2004). Studies have also shown that customisation of products could increase productivity, especially in IT-based products (Bartel et al., 2007). Moreover, reorganising inputs and particularly reallocating high-quality employees could increase productivity increase (Lentz & Mortensen, 2008). The variety of product expansion could also increase productivity, albeit the relationship seems to be bidirectional (Bernard et al., 2010). Increasing efficiency and being innovative rely on different approaches. The former is more based on incremental improvements and refinement, while the latter is based on radical change and experimentation that is more connected to higher risk (Sarkees & Hulland, 2009). Therefore, firms pursuing production efficiency and innovation simultaneously are likely to be stuck between the approaches (Porter, 1980). Nevertheless, relying on only one strategy is not the best option in the long term. Overemphasis on efficiency could lead to missing market opportunities and ignoring threats, stifling a firm's ability to adapt to market changes (Cyert, March, et al., 1963). On the contrary, overemphasising innovation could lead firms to take too many risks without extracting profits (Levinthal & March, 1993). For this reason, ambidextrous organisations - i.e., companies engage in a high degree of innovation and efficiency - could have a sustainable competitive advantage by performing both strategies since they are complementary, obtaining resources from one of the strategies to be implemented in the other (Gibson & Birkinshaw, 2004; Gupta et al., 2006).

Therefore, since GHG emissions are correlated and influenced by productivity and innovation, this study hypothesises that their interaction influences corporate emissions. Accordingly, the following hypothesis is formulated:

H3: The interaction between productivity and innovation is negatively related to GHG emissions.

4.3 Methodology

4.3.1 Data

The research used study-specific panel data from 2015 to 2019 from the Thomson Reuters Eikon ESG database. Following recent studies on EI and carbon emission (Konadu et al., 2022; Nadeem et al., 2020), this study created its dataset starting from the company listed in the Standards and Poor (S&P) 1500 index. To that list was added the Eurostoxx 600 index, obtaining a total of 2096 companies. Following the work of Konadu et al. (2022), only companies classified as carbon-intensive were selected. Carbon-intense companies are companies operating in the sector of industrials, materials, energy and utilities, according to GISC classification. To obtain the final dataset, we removed all companies that lacked values for the variable used as inputs and outputs in DEA analysis. This resulted in a sample size of 478 companies.

4.3.2 Stage 1: Productivity

DEA and MI

Different methods of measuring efficiency exist, starting from the original paper by Farrell (1957) on stochastic frontier analysis (SFA) and DEA. These two techniques are used to estimate the production and efficient frontier.

Particularly, DEA is a non-parametric model developed by Charnes et al. (1978), and it is the most used method in the literature to measure efficiency both for the country (Beltrán-Esteve & Picazo-Tadeo, 2017; Feng et al., 2017; Mavi & Mavi, 2021; Mavi et al., 2019) and the firm level analysis (Majumdar, 2017; Memon & Tahir, 2011). It has two significant advantages. First, it allows for defining the relationship between the inputs and outputs of the decision-making units (DMUs) without specifying their functional form. Second, it can provide insights into how inputs or outputs can be modified to improve the performances of the inefficient DMUs (He et al., 2016). The central assumption of the first formulation is that production generates constant returns to scale, and any change in the inputs produces a proportional change in the outputs.

However, the assumption of proportionality does not hold in all contexts. Banker et al. (1984) in a subsequent formulation introduced the possibility of variable returns to scale (BCC model), mitigating the last assumption. Both models can be either input- or output-oriented. The difference between the two approaches leads to different interpretations of the efficiency of decision-making units (DMUs). In the first case, the model aims to minimise the resources needed to obtain a given output, while the second is to maximise the output obtained from the available inputs. The efficiency levels are calculated by solving a linear programming problem and are bounded to vary from 0 to 1, with 1 being the maximum level.

Despite the popularity of the DEA technique among the scientific community, it does have some important limitations: the presence of outliers can distort the results; the exclusion of variables can lead to inefficiencies being identified; and as it is a non-parametric technique, it is not possible to formulate hypotheses to test to confirm its suitability. All this justifies the appropriateness of using DEA-Bootstrap, an extension of DEA that enables the researcher to improve the estimates' robustness by providing confidence intervals for the efficiency scores (Simar and Wilson, 1999). Although the DEA technique is widely used in the scientific community, it has a few limitations. Outliers can skew the results, excluding variables can lead to identifying inefficiencies, and being a non-parametric technique, it cannot test hypotheses to confirm suitability. Therefore, as suggested by (Simar & Wilson, 2000) this study uses DEA-Bootstrap to increase the results' robustness and avoid the influence of outliers. This study applied an input-oriented BCC model with 2000 bootstrap replications.

In addition, an intertemporal analysis of DMUs productivity was included to capture differences over the years and identify potential distortions (Puertas et al., 2020). This study used the MI index to evaluate the evolution of EI efficiency during the studied period. The MI was first developed by Caves et al. (1982) based on an intuition of Malmquist (1953), and then it was further elaborated by Färe et al. (1992) introducing DEA to measure it. MI represents productivity changes, which can be decomposed into two components to analyse the sources of these changes: technical efficiency change (EC) and technological progress (TC). This decomposition helps us understand the reasons underlying the increase or decrease in DMUs productivity. An overall increase in productivity (MI $>$ 1) might stem from an increase in TC and EC or only an increase in one of the two components. For this reason, a DMU could become more technologically advanced (TC $>$ 1) while also reducing its technical efficiency (EC $<$ 1). On the contrary, it might experience an increase in technical efficiency (EC $>$ 1) while lagging in technology (TC $<$ 1). Therefore, MI decomposition provides different insights into where the increase in efficiency stems from.

Input and Output

This study used a production function composed of three inputs and two outputs, following other research that applies DEA and MI to evaluate efficiency (Majumdar, 2017; Memon & Tahir, 2011). Inputs are the total number of employees, total assets and cost of revenues. Instead, outputs are net sales and net income. All the data is referred to as balance sheet data from the Thomson Reuters Eikon ESG database.

4.3.3 Stage 2: Determinants of GHG emissions, EI and productivity

The second stage of the study estimated the impact of productivity and eco-innovation on GHG emissions by relying on multivariate modelling techniques. Before describing any models, some specifications about the variables must be discussed. Data used in the study were used as provided by the Thomson Reuters Eikon ESG database without any further standardisation.

Dependent variable

Following recent studies on carbon emission (Konadu et al., 2022; Nadeem et al., 2020; Puertas & Marti, 2021), the Scope 1 data from the Thomson Reuters Eikon ESG database were used as a proxy for GHG emission. The Scope 1 emission represents all the direct emissions from sources owned or controlled by the company and is expressed in CO2 and CO2 equivalents emissions in tonnes.

Independent variables

Based on the research conducted by Puertas and Marti, 2021, the productivity proxy utilised in the study was derived from the bootstrap DEA analysis described in the previous section. The model employed could either be input or output oriented, with each approach yielding a different interpretation of DMU efficiency. The analysis, however, utilised the output-oriented approach, which aims to maximise output from the available inputs. Through linear programming, the model calculates the efficiency levels, ranging between 0 to 1, with 1 denoting the highest level achievable.

Moderating variable

As discussed previously, defining a unique measure of EI is not simple. Some previous research (Eiadat et al., 2008; Peng & Liu, 2016), have utilised surveyor questionnaire techniques to evaluate environmental innovation/eco-innovation. However, this approach may not be reliable or impartial, as participants' responses could be influenced by their perspectives and beliefs (Arena et al., 2018). Another indicator widely used in literature is the number of green patents. "Green patents" are considered a reliable indicator of environmental innovation (Berrone et al., 2013), as they provide a detailed description of the invention, which can be used to categorise patents by technological sector, type of use, area of origin, and technical characteristics. However, green patents can at least represent only two dimensions of EI (product innovation and process innovation), not considering organisational and managerial innovation (Marcon et al., 2017; Rodriguez & Wiengarten, 2017).

Most environmental and eco-innovation research has utilised ESG data from Eikon and ASSET4 as a proxy(Konadu et al., 2022; Nadeem et al., 2020). Eikon provides information on EI from all the dimensions and is especially used at the firm level due to its reliability and objectivity (Arena et al., 2018). The use of data varies from study to study, ranging from a comprehensive use of the innovation score (Konadu et al., 2022) to the use of specific indicators within it (Garcìa-Sánchez et al., 2021) or the creation of a composite measure using different information(Nadeem et al., 2020). However, this study prefers to define a unique indicator in two steps based on the review of Garcìa-Granero et al., 2018 and Refinitiv's ESG scores calculation methodology.

The first step identified from the cited study 30 key EIPIs (Environmental Innovation Performance Indicators) to evaluate EI. By comparing the rationale behind the previously identified KEIPIs with the ESG data of Eikon, 12 KEIPIs were identified. These EIPIs represent three dimensions of EI: product innovation, process innovation and organisational innovation (Marcon et al., 2017; Rodriguez & Wiengarten, 2017). The first dimension is composed of 4 indicators, the second dimension of 5 and the latter of 3. To ach KEIPIs has been assigned a value of 1 if the firm has disclosed information and 0 otherwise. As done in previous studies (Cheng et al., 2014; Nadeem et al., 2020), equal weight was given to each performance metric. The first EI indicator is a categorical variable that varies from 0 to 12.

The final EI score for each company is then defined in a second step that follows Refinitiv's ESG calculation methodology. It uses the percentile rank scoring methodology to calculate each category of the ESG score since it is based on rank and is relatively sensitive to outliers. Refinitiv defines it as follows:

$$ESGScore = \frac{\text{Companies with worse ESG category value } + \frac{\text{Companies with the same ESG category value}}{2}}{\text{Companies with a ESG category value}} \tag{4.1}$$

Following the rationale behind DEA analysis, this study wants to create a more reliable EI measure that can provide a measure that expresses EI based on other companies' implementation of EI. Substituting the ESG category value with the KEIPI indicator obtained previously, we obtain the final indicator, described as follows:

$$EiScore = \frac{\text{Companies with worse KEIPI indicator value } + \frac{\text{Companies with the same KEIPI indicator value}}{2}}{\text{Companies with a KEIPI indicator value}} \tag{4.2}$$

Control Variable

Two sets of different control variables were included in two separate models. The first set includes variables related to resource consumption in production. These variables are water withdrawal, total waste, energy used and the waste recycling ratio. Water withdrawal refers to the overall amount taken from any water source, whether directly withdrawn by the reporting organisation or through intermediaries like water utilities. It is measured in cubic meters. The second measure is the total amount of waste produced in tonnes, where total waste is the sum of non-hazardous and hazardous waste. Energy used is the direct and indirect energy consumption in gigajoules. The waste recycling ratio is calculated by dividing the amount of waste recycled by the total waste multiplied by 100. Any waste converted into energy through incineration or composting is considered recycled.

The second set includes productivity indicators of the first three previous variables. Productivity indicators are exactly the ones provided by Thomson Reuters' Eikon and are defined as the total amount of resources used or produced divided by the company revenue.

Econometric model

Using the dataset just described, this study analysed the influence of EI and productivity on GHG emissions using a multivariate linear regression model described as follows:

$$\text{Model (1)} GHG_{it} = \beta_0 + \beta_1 EFF_{it} + \beta_2 EiScore_{it} + \beta_3 EFF_{it} * EiScore_{it} + \varepsilon_{it} \tag{4.3}$$

$$\begin{aligned}\text{Model (2)} GHG_{it} = \beta_0 + \beta_1 EFF_{it} + \beta_2 EiScore_{it} + \beta_3 EFF_{it} * EiScore_{it} + \beta_4 Energy_{it} \\ + \beta_5 Water_{it} + \beta_6 Waste_{it} + \beta_7 WasteRecycle_{it} + \varepsilon_{it}\end{aligned} \tag{4.4}$$

$$\begin{aligned}\text{Model (3)} GHG_{it} = \beta_0 + \beta_1 EFF_{it} + \beta_2 EiScore_{it} + \beta_3 EFF_{it} * EiScore_{it} \\ + \beta_4 CO_2 Productivity_{it} + \beta_5 EnergyProductivity_{it} \\ + \beta_6 WaterProductivity_{it} + \beta_7 WasteProductivity_{it} + \varepsilon_{it}\end{aligned} \tag{4.5}$$

Where GHG is the Scope 1 emissions, EFF is the production efficiency, EI score is the environmental innovation score, and EFF*EI score is the interaction term between production efficiency and environmental innovation score. Model (2) adds to the model the use of resources, particularly energy used in production (Energy), Water withdrawal in production (Water), waste produced in production (Waste) and waste recycling as production input for production (Waste Recycle). Model (3) substitutes resources used with their productivity, defined as the total amount of resources used in production divided by the revenue. CO2 productivity is Scope 1 emissions divided by the firm revenues, Energy productivity is the energy used in production divided by the firm revenues, Water Productivity is the water withdrawal in production divided by the firm revenues, and Waste productivity is waste produced in production divided by the firm revenues. The measure was standardised before applying the linear regression model to determine the relative weight of each coefficient in determining the emission volume and avoid bias in the OLS standard errors. In addition, the first model is utilised for testing the previous hypotheses, whereas other models are employed as robustness checks to examine potential correlations with waste and material footprint, as well as resource productivity.

4.4 Result

The first stage of the study analysed the productivity of carbon-intensive firms in Western countries. Table 4.1 shows the mean efficiency results and the MI analyses' results on the productivity changes grouped by sector. Moreover, MI is further decomposed in its efficiency and technological change components.

The results from the defined production function reveal that during the analysed period,

Sector	EFF	EFF sd	MI	TC	EC
Energy	0.660	0.009	1.076	1.021	1.057
Industrials	0.656	0.004	0.999	0.986	1.015
Materials	0.646	0.003	1.009	0.985	1.026
Utilities	0.616	0.012	1.023	1.012	1.022

Table 4.1: The table shows efficiency score (EFF), MI and MI decomposition TC and TEC results of each sector for the period analysed. EFF is the mean value of bootstrap DEA, and EFF sd is the standard deviation of bootstrap DEA. MI in Malquist Index and TC and EC are MI decomposition components. TC represents technological progress, while EC represents technical efficiency change.

the most productive sector was the Energy sector (0.660), and the least productive was the Utilities sector (0.616). It is possible to notice that the differences among sectors are not substantial in production efficiency, meaning that all sectors have performed similarly on average. Regarding production increase, the Energy sector has the highest MI (1.076), while the Industrials sector has the lowest (0.999). As for production efficiency, the production increase was similar for all the sectors that had experienced only a slight rise except for the Utilities sector, which had occurred a regression. Regarding the technological and production components of MI, all sectors experienced an increase in production efficiency during the period, with the Energy sector confirming its leadership (1.057). Instead, only two sectors increased their technology (Energy, 1.021; Utilities, 1.012), while the other two experienced a slight regression (Industrials, 0.986; Materials, 0.985).

Table 4.2 shows the same information as table 4.1 year by year. All sectors increased

Sector	Year	EFF	EFF sd	MI	TC	EC
Energy	2015	0.633	0.010			
Energy	2016	0.605	0.009	0.877	0.878	1.020
Energy	2017	0.645	0.010	1.307	1.195	1.093
Energy	2018	0.693	0.010	1.146	1.062	1.079
Energy	2019	0.739	0.007	0.975	0.948	1.035
Industrials	2015	0.650	0.004			
Industrials	2016	0.636	0.005	0.986	1.019	0.969
Industrials	2017	0.648	0.004	1.014	0.996	1.019
Industrials	2018	0.661	0.004	1.019	0.999	1.021
Industrials	2019	0.686	0.003	0.977	0.929	1.052
Materials	2015	0.624	0.003			
Materials	2016	0.608	0.005	0.997	1.010	0.989
Materials	2017	0.656	0.003	1.059	1.002	1.058
Materials	2018	0.670	0.003	1.021	1.005	1.015
Materials	2019	0.675	0.002	0.960	0.922	1.043
Utilities	2015	0.602	0.012			
Utilities	2016	0.637	0.013	1.007	0.952	1.067
Utilities	2017	0.626	0.011	1.111	1.114	0.992
Utilities	2018	0.582	0.013	0.967	1.087	0.902
Utilities	2019	0.635	0.011	1.008	0.891	1.127

Table 4.2: The table shows efficiency score (EFF), MI and MI decomposition TC and TEC results of each sector for each year of the period analysed (2015 - 2019). EFF is the mean value of bootstrap DEA, and EFF sd is the standard deviation of bootstrap DEA. MI in Malquist Index and TC and EC are MI decomposition components. TC represents technological progress, while EC represents technical efficiency change.

their production efficiency during the years, excluding the Utilities sector, which had a fluctuating trend. The former sectors experienced decreased production efficiency in 2016 (0.605, 0.636, 0.608), while the latter had the opposite trend (0.637). This decreasing trend in productivity is also reflected in the MI of the sectors, which is below 1 for all sectors (0.877, 0.986, 0.997) except for the Utilities sector (1.007). This inverted trend for the latter sector is also present in 2019. It increased its productivity from the previous year (1.008) compared to all other sectors, which did not experience the same (0.975, 0.977, 0.960).

In the second stage of the study, the determinants of GHG emissions were analysed, using the production efficiency and the EI score and their interaction. Table 4.3 reports the results of the different models starting from the baseline model (1) in the first column, which includes the EI score, production efficiency, and the interaction between the EI score and productivity along with the sectoral and years control variables. Model (2) considers the determinants of GHG emission and the interaction terms. Finally, Model (3) includes resource productivity indicators instead of the GHG emissions determinants. The coefficients were standardised to determine each variable's relative weight in determining the emissions volume.

The study found in the model (1) that both production efficiency and EI are significant, but surprisingly the latter is positively correlated with GHG emissions while the former is negatively correlated (EI score: β = 0.177, p < 0.001; Prod eff: β = - 0.092, p < 0.001). These results are confirmed in model (2), with both being significant but with opposite signs (EI score: β = 0.180, p < 0.001; Prod eff: β = -0.077, p < 0.001). However, the moderation term is negative and significant (β = -0.053, p < 0.05). Model (3) confirms the negative and significant correlation of the interaction term (β = -0.143, p < 0.001). In this model, the EI score is still positive and significant (β = 0.066, p < 0.05), while production efficiency turns positive and significant (β = 0. 165, p < 0.001). In the last model (4), the latter variable returns negative and significant (β = -0.117, p < 0.001), while the former confirms its positive and significant effects (β = 0.100, p < 0.001). Despite the negative interaction term as in previous models, it is not significant.

4.5 Discussion

This paper analyses empirical evidence contributing to the debate about production efficiency, EI and their relationship with GHG emissions (Puertas & Marti, 2021). In the literature, the role of the former and the latter are analysed separately, particularly when applying DEA methodology (Łącka & Brzezicki, 2022). Production efficiency literature varies from sector to sector and at the analysis level (micro to macro). Although analysis methods are similar for all studies (Łącka & Brzezicki, 2022), the functional form of production highly differs based on the sector and the level investigated. To the best of this study's knowledge, it represents the first attempt to analyse the relationship between production efficiency and EI in influencing GHG emissions, especially at the micro level. Results are aligned with previous studies on productivity, confirming its negative correlation with GHG emissions and its positive impact on reducing carbon emissions (Picazo-

	Model (1)	Model (2)	Model (3)
Efficiency	-0.077***	0.165***	-0.117***
	(0.025)	(0.038)	(0.033)
EI score	0.180***	0.066***	0.100***
	(0.027)	(0.032)	(0.028)
Efficiency*EI score	-0.053*	-0.143***	-0.022
	(0.027)	(0.037)	(0.033)
Energy		0.895***	
		(0.034)	
Water		0.075	
		(0.039)	
Waste		-0.028	
		(0.028)	
Waste Recycle		-0.111***	
		(0.024)	
CO_2 Productivity			0.761***
			(0.036)
Energy Productivity			-0.294**
			(0.115)
Water Productivity			1.461***
			(0.351)
Waste Productivity			0.000
			(0.019)
Sector	Yes	Yes	Yes
Year	Yes	Yes	Yes
R^2	0.14	0.62	0.50
$Adjusted R^2$	0.13	0.61	0.49

Table 4.3: Model (1) is the baseline model, Model (2) includes the resources used in production, and Model (3) substitutes resources with their productivity. EFF is the production efficiency, EI score is the environmental innovation score, and EFF*EI score is the interaction term between production efficiency and environmental innovation score. Energy is the energy used in production, Water is the water withdrawal in production, Waste is waste produced in production, and Waste Recycle is the waste recycling as production input for production. CO2 productivity is Scope 1 emissions divided by the firm revenues, Energy productivity is the energy used in production divided by the firm revenues, Water Productivity is the water withdrawal in production divided by the firm revenues, and Waste productivity is waste produced in production divided by the firm revenues.

Tadeo et al., 2014). Thus, *H2* is confirmed. The results also show that EI positively correlates to GHG emissions in all the models, providing evidence against *H1*. This counterintuitive result has been partially confirmed in previous studies, highlighting that EI expressed as an increase in R&D expenditures has reduced GHG emissions only in certain countries (Fernàndez et al., 2018). Moreover, other studies have found that R&D expenses in some OECD countries are not achieving their intended objectives, especially in the energy sector, which is included in our research (Koçak & Ulucak, 2019). Another possible reason could be that the results of EI have not already paid off since they need time and resources to be completely implemented, and a longer time horizon is needed to reduce emissions (Bansal, 2005; Mongo et al., 2021).

The moderation effect needs to be analysed to derive conclusions about the role of EI and productivity. Figure 4.1 shows all marginal effects of EI and productivity on GHG emissions of the baseline model (1). As both variables are continuous and have been standardised beforehand, referring to this figure can provide more information in interpreting the moderation effect. When values exceed 0 for both variables, they exceed the average sample value. The impact of being above average differs for each variable - higher productivity leads to a positive impact by reducing emissions, while higher EI has the opposite effect. According to the figure, implementing an ambidextrous strategy that increases both variables equally can effectively decrease GHG emissions. The coloured areas in the figure improve the visualisation of the different combinations of EI and productivity. These areas also confirm that equivalent values of these variables are located within the green and blue regions, namely areas with a negative impact on GHG emissions. This confirms H3 and the beneficial effects of the ambidextrous approach on GHG reduction but also provides evidence in favour of H1 and against H2.

The decomposition of the MI in table 4.2 provides information to understand the differences in the strategies output on GHG emissions. During the period analysed, all sectors experienced an increase in production efficiency on average, while not all sectors had the same technological improvement. This study has analysed a set of sectors in which carbon-intensive resources (i.e. energy) are predominant. The innovation in those fields is cumulative, path-dependent and technology costs reduce with the cumulative deployment (Grubb et al., 2021). For this reason, some sectors have preferred to increase their production efficiency instead of using new technologies that are not cost-effective and require time to be implemented and pay off.

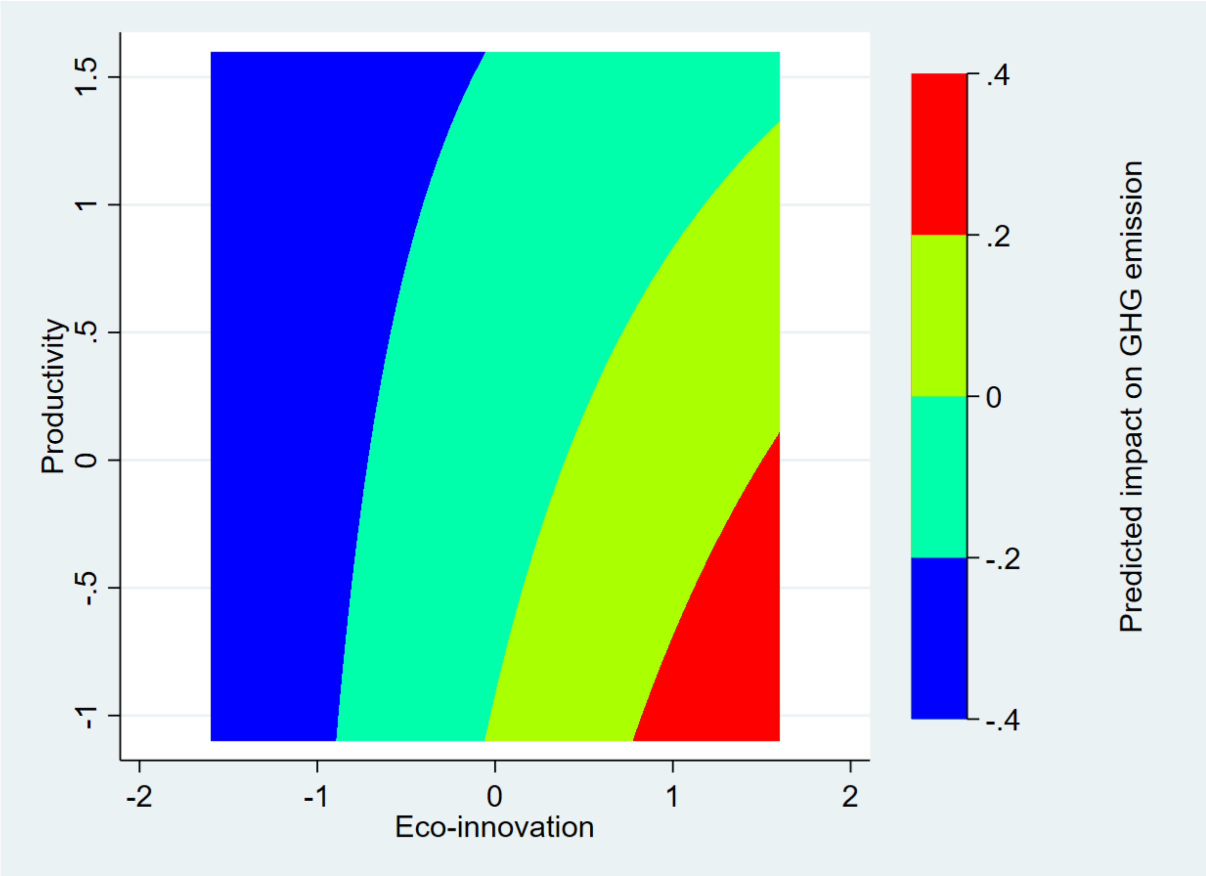

Figure 4.1: The figure shows the standardised marginal effect of EI and productivity on GHG emissions of the baseline model (1). EFF is represented by productivity, and Eco-innovation represents the EI score. Blue and green areas describe a negative impact (i.e. reduction) of the interaction on GHG emissions. In contrast, yellow and red areas describe a positive impact (i.e. increase) of the interaction on GHG emissions.

4.6 Conclusion

Using panel data of 428 companies classified as carbon-intensive from the Standards and Poor (S&P) 1500 index and the Eurostoxx 600 index from 2015 to 2019, this study aims to determine the role of productivity and EI on GHG emissions. In the first stage, the study derived the production efficiency and the increase in productivity using the DEA analysis and the MI, which are widely used in the literature. The second stage estimated the relationship between EI, productivity and their interaction using linear regression analysis with the OLS estimator.

The results for the first stage show that production efficiency was similar and the productivity increased for all the sectors during the period analysed, except for the Industrial sector, which experienced a decreased productivity. The technical efficiency increased while the technological change increased only for two sectors and decreased for the other two.

The results for the second stage show that production efficiency is negatively correlated with the increase of GHG emissions confirming H2, while EI is positively correlated and provides evidence against H1. The interaction term between the previous variables is negatively correlated with carbon emissions, confirming H3.

The negative impact of EI is due to the nature of the innovation in the sector analysed, which is cumulative, path-dependent and technology costs reduced with the cumulative deployment (Grubb et al., 2021). For this reason, some sectors have preferred to increase their production efficiency instead of using or developing new technologies that are not cost-effective and require time to be implemented and paid off. This is also confirmed by the fact that carbon-intense sectors used more energy than other sectors, and the most efficient way to reduce emissions is through energy efficiency (Picazo-Tadeo et al., 2014).

This study provides managerial implications. From this study, production efficiency has been shown to have a positive effect on reducing GHG emissions compared to EI, which is negatively related. Despite pursuing a strategy based on efficiency that might positively impact carbon emission with respect to one based on EI, an ambidextrous approach will be the one with the best possible outcome, especially in the long run. An efficiency-based strategy might benefit in the short term for EI since the latter requires more time and resources to be implemented. However, due to the synergistic interaction between production efficiency and EI, strategies that combine both seem to have a better payoff. Therefore, managers of carbon-intensive companies willing to reduce emissions may focus on increasing their productivity to impact the short-term and long-term EI strategies for the best results. To avoid failures in implementation, managers need to balance the resources allocated for the different strategies through constant reassessment. The balance between long-term and short-term objectives is essential to ensure the implementation of the strategies because they have different times to pay off.

Despite its contribution, this study is not without limitations. Although this study is the first to apply this methodology to this dataset, non-carbon-intensive firms were excluded from the analysis. Future research may analyse if there are differences between carbon-intensive and non-carbon-intensive sectors. The sample size is only limited to listed companies from Europe and US. Further research may analyse if the results hold in the broader dataset that also includes listed companies from other countries.

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Chapter 5

Appendix

.1 KEIPIs Description

In this appendix are reported the KEIPIs used in the study as described in Eikon. On the brackets, there is the correspondent DFO Code.

.1.1 Product Eco-innovation

Environmental Materials Sourcing (ENRRDP029) : Does the company claim to use environmental criteria (e.g., life cycle assessment) to source or eliminate materials?
Product Impact Minimization (ENPIO16V) : Does the company reports about take-back procedures and recycling programmes to reduce the potential risks of products entering the environment or does the company report about product features or services that will promote responsible and environmentally preferable use?
Resource Reduction Policy (ENRRD01V) : Does the company have a policy for reducing the use of natural resources or to lessen the environmental impact of its supply chain?
Eco-Design Products (ENPIDP069) : Does the company report on specific products which are designed for reuse, recycling or the reduction of environmental impacts? Products that have been specifically designed with the goal of being recycled, reused or which are disposed of without negatively impacting the environment. There must be some

discussion of environmental concerns during the product design

.1.2 Process Eco-innovation

Toxic Chemicals Reduction (ENRRDP031) : Does the company report on initiatives to reduce, reuse, substitute or phase out toxic chemicals or substances? In scope, the data includes chemicals, toxic materials, hazardous, PBT (persistent bio-accumulative toxic) and PVC (polyvinyl chloride)

Waste Reduction Initiatives (ENERDP062) : Does the company report on initiatives to recycle, reduce, reuse, substitute, treat or phase out total waste? Initiatives to reduce any type of waste generated by reporting organisation. Partnership with waste management companies to treat waste generated

Policy Energy Efficiency (ENRRDP0122) : Does the company have a policy to improve its energy efficiency? In scope are the various forms of processes/mechanisms/procedures to improve energy use in operation efficiently. System or a set of formal documented processes for efficient use of energy and driving continuous improvement

Policy Water Efficiency (ENRRDP0121) : Does the company have a policy to improve its water efficiency? In scope are the various forms of processes/mechanisms/procedures to improve water use in operation efficiently. System or a set of formal documented processes for efficient use of water and driving continuous improvement

Increasing in R&D expenditure : This KEIPI is calculated as the increase or decrease in R&D expenditure compared to the previous year. If an increase occurs in the year t, it takes the value of 1 and 0 otherwise.

.1.3 Organizational Eco-innovation

Environment Management Training (ENRRDP008) : Does the company train its employees on environmental issues? Employee environmental (resource reduction & emission reduction) related training provided by the company or external trainers. In focus include the code of conduct training encompasses environmental aspects

Policy Emissions (ENERDP0051) : Does the company train its employees on environmental issues? Employee environmental (resource reduction & emission reduction) related training provided by the company or external trainers. In focus include the code of conduct training encompasses environmental aspects

Environmental Partnerships (ENERDP070) : Does the company report on partnerships or initiatives with specialized NGOs, industry organizations, governmental or supra-governmental organizations, which are focused on improving environmental issues?

.2 Network measures

Network analysis examines the connections between nodes in a system. It helps to understand the connectivity patterns in supply chains, with each firm represented as a node. Centrality measures the relative importance of a node in the network based on its number of connections and distance.

.2.1 Influence

The level of centrality is determined by the number of edges that link to each node, providing an overview of a company's direct connections. The greater the number of connections a node has, the higher its centrality, bringing a company closer to the network's centre. Firms occupying a central position are more visible in the network (Freeman, 1978). If only one or a few firms take a high degree of centrality in a network, it is known as a centralised network (Kim et al., 2011).

To measure the supply network influence (*"Influence"*), this study uses the degree of centrality, defined as the number of links that a firm has with others, and it is defined as:

$$\text{Influence} = \text{Degree of Centrality} = \sum_{x} y_{xy} \tag{1}$$

where y_{xy} has value one if the x-th firm is connected to the y-th firm, 0 otherwise.

.2.2 Accessibility

As a measure to capture supply network flow accessibility ("Accessibility"), this study uses closeness centrality, defined as the inverse of the average length (geodesic distance) of the shortest paths to and from all the other firms in the network multiplied by the total number of nodes in the network (Freeman, 1978). Thus, closeness centrality is calculated as follows:

$$Accessibility_x = \frac{N-1}{\sum_y d(x,y)} \tag{2}$$

where $d(y,x)$ is the average length (geodesic distance) between firm x and y, where N is the number of nodes in the network.

Closeness centrality is determined by the distance between nodes, with a shorter distance indicating higher centrality. A node is considered central if it can easily connect to all other nodes. Nodes with high closeness centrality have greater autonomy, meaning they can act independently and are less reliant on other nodes. This implies a greater level of independence for a firm within a network.

.2.3 Flow Control

To measure the supply network flow control ("Control"), this study uses the betweenness centrality, defined as how often company i-th firm lies on the shortest path between any other two companies (Freeman, 1978) and calculated as:

$$FlowControl_x = \sum_{x \neq y \neq t} \frac{\sigma_{st}(x)}{\sigma_{st}} \tag{3}$$

Where σ_{st} is the number of shortest paths from the firm x to y and $\sigma_{st}(x)$ is the number of shortest paths that pass through firm x. For this study, it is used the directed version of this measure.

In network analysis, the betweenness centrality determines how frequently a node appears on the shortest path connecting pairs of nodes. If a node acts as the sole channel through which other nodes must pass to connect, it has a high betweenness centrality, signifying its importance in the network's interactions. A company with a high level of betweenness holds substantial potential for influencing or controlling the network (Marsden, 2002). Node i in this context served as a gatekeeper for the other nodes, and its betweenness centrality indicates its level of influence.

.2.4 Interconnectedness

It expresses how a node is central based on its connections' number of connections. Usually is calculated by using the eigenvector centrality (Freeman, 1978) or the Bonacich Power centrality (Bonacich, 1987). The second measure is preferred to the former because current literature has shown that excessive interconnectedness may negatively impact CEP (Gualandris et al., 2015). The reasons for this phenomenon are several: high coordination cost (Kim et al., 2011), blurred firm-supplier relationship (Lamming et al., 2004), and asymmetric economic power (Fontana & Egels-Zandén, 2019), to name a few. Compared to the eigenvector centrality, the Bonacich power can investigate this aspect by modifying the attenuation parameter β. To conclude, Bonacich Power is defined as:

$$Interconnectedness_x = \sum_y (\alpha - \beta C_{xy}) y_{xy} \tag{4}$$

where α is a normalized measure, β is the attenuation factor and x and y is a node. Some specifications need to be made about theβ Because it influenced BP results, selecting the right β has been a topic of discussion in the literature (Rodan, 2020). With a value of β equal to 0, the measure is equal to degree centrality, with a value of $\beta = 1/\lambda_{max}$ (where λ is the value used to define the eigenvector) is equal to the eigenvector centrality. Therefore, the range of options is two $-1 < \beta < 0$ or $0 < \beta 1/\lambda_{max}$. The difference between these two options is the final interpretation of the measure. Using the first range, it is considered not an advantage to be connected with nodes that are not well-connected, while the second range is considered advantageous to be connected with well-connected nodes. For our studies, the second range is considered more appropriate. The reason is simple: well-connected nodes are usually bigger firms with more financial resources and persuasive power to implement CEP.

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