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Moving towards a Circular Economy:

The effect of cooperation on eco-innovation
Evidence from German firms

- Master Thesis -

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V. List of Abbreviations

Circular Economy	CE
Community Innovation Survey	CIS
Eco-innovation	EI
Mannheim Innovation Panel	MIP
Non-eco-innovation	NEI
Product eco-innovation	PDEI
Product innovation	PDI
Product non-eco-innovation	PDNEI
Process eco-innovation	PCEI
Process innovation	PCI
Process non-eco-innovation	PCNEI
Research and development	R&D

Abstract

This paper aims to investigate how cooperation influences firms to conduct eco-innovations. The main research objective is to empirically ascertain the presence of a positive association between inter-firm cooperation and the development of eco-innovation. Our motivation to examine this relationship is driven by the inherent potential of eco-innovation to engender circular economic structures, thereby contributing to the creation of more sustainable economic systems.

After conceptualizing the relationship between circular economy, eco-innovation and innovation we conclude that the nature of eco-innovations reinforces the need for cooperation, making cooperation an essential requirement within the circular approach. While a substantial body of research has focused on identifying the drivers and impact of eco-innovation on firm performance, limited attention has been given to comprehensively understanding their development processes. Therefore, we empirically investigate the effect of cooperation on firms' behavior to engage in eco-innovation. We further advance the comprehension of the significance of cooperation within distinct types of eco-innovations. Through a differentiation between product and process eco-innovation, we establish a connection between the specific characteristics of these different eco-innovation types and their propensity to benefit from collaborative endeavors.

By applying a probit regression model with data from German firms, we were able to find evidence of the relationship between cooperation and eco-innovation. Our findings show that cooperation indeed promotes eco-innovation. Secondly, we were able to show that cooperation specifically promotes product eco-innovation. However, no evidence could be found on the positive effect of cooperation on process eco-innovation.

With these findings, we were able to expand the research on cooperation and innovation specifically in the realm of eco-innovation. Our findings offer new evidence for managers that cooperative efforts should be a core part of their innovation development, especially for eco-innovation. Our results also offer insights for policy makers as regulations are an important driver for eco-innovation, but we propose that they must be specifically designed to promote cooperation and incentivize industry-wide circularity projects.

1 Introduction

The phenomenon of the Circular Economy (CE) challenges the current status of the economy and its underlying assumptions (Boulding, 2017). Popular economic models like the value chain represent the linear thinking current businesses are built upon. The usual process within an industry or a chain of suppliers and consumers entails the linear order of production, usage and disregarding, which is neither economically nor environmentally sustainable (Pearce & Turner, 1990; Ul-Durar et al., 2023). The CE framework extends the traditional value chain and restructures it into different circles, where an economic good can either be disposed, recycled, remanufactured, or reused (Mihelcic et al., 2003). By creating closed loop systems, the environmental impact and material efficiency can be optimized (Preston, 2012). The transition towards an economic system founded on circularity necessitates innovation (de Jesus & Mendonça, 2018). Drawing upon Schumpeter's concept of "creative destruction" (1934, 1942), innovation drives the continuous creation and destruction of economic structures. Therefore, the pursue of CE requires innovation that specifically leads the economy in a circular direction. This type of progressive and sustainable innovation is commonly referred to as eco-innovation (EI) (de Jesus & Mendonça, 2018).

The field of EI studies commercial improvements that follow the goal of fewer adverse effects on the environment and more efficient resource usage (Díaz-García et al., 2015). Hence, EI holds the potential to engender the emergence of novel economic frameworks imperative for the realization of CE. Given the systemic changes required to attain circularity in the CE, previous research suggests that individual firm-wide projects alone may fall short of achieving this goal (De Marchi, 2012). The construction of closed loop systems, which prioritize material flows rather than ownership, is contingent upon collaborative efforts. Consequently, the development of EI necessitates inter-firm cooperation. The nature of EIs reinforces the need for cooperation, making cooperation an essential requirement within the circular approach. By recognizing the interdependencies and interconnectedness of stakeholders, cooperation becomes a fundamental aspect of fostering circularity and advancing sustainable practices (EMF, 2012; Ghisetti et al., 2015).

In this regard, the literature on innovation suggests that the technological complexity and uncertainty involved in the development of EI cannot be borne by a single organization (Lee et al., 2012; Powell et al., 1996; Teece, 1992). The engagement of multiple stakeholders not only promises greater leverage in innovation projects but also combining the capabilities and knowledge promises a better output in the development process.

The promotion of EI has garnered significant attention due to its societal significance. Hence, much of the research in this field has concentrated on understanding the driving factors behind firms' pursuit of EIs and investigating their potential to enhance firm performance. (Bitencourt et al., 2020; Hojnik & Ruzzier, 2016; Horbach et al., 2013; Sezen & Çankaya, 2013). Unfortunately, less research has focused on how to successfully develop EI. The systemic, credence and complex character of EI suggests that cooperation is just as important as for other types of innovation (De Marchi, 2012), however, there is still empirical evidence missing to support this connection. Extensive research has contributed to our understanding of the circumstances under which firms engage in inter-organizational cooperation and leverage external knowledge during the development and implementation of innovation projects. Scholars have shed light on the factors that influence firms' decisions to pursue collaborative efforts and tap into external knowledge sources for effective innovation outcomes, but EI exhibits specific characteristics that have not yet been considered unveiling a certain gap in the literature.

Despite the considerable interest in CE, EI, and the significance of cooperation within the innovation process, there remains a lack of comprehensive research that integrates these areas effectively. We address this gap by establishing a comprehensive understanding of the connection between the three fields of research. By synthesizing and structuring the pertinent literature on EI, we offer a valuable contribution to the existing knowledge on this subject matter. This endeavour allows to consolidate and organize the collective insights and findings from previous research, enabling a deeper understanding of the complexities and implications surrounding EI. Further, we present the research on the relationship between cooperation and innovation. By combining it with the knowledge on EI and their specific characteristics we are able to establish a conceptual relationship between cooperation and EI. This contextualization of both research fields facilitates a comprehensive comprehension of the imperative need for collaborative endeavors to address the unique challenges associated with EI, as well as elucidates the discernible distinctions inherent in diverse forms of innovation. While theoretical work argues for a positive effect of cooperation on EI (Chistov et al., 2021), there is little empirical evidence. Our research will decrease this gap by analysing if cooperation promotes EI.

We further improve the understanding of the importance of cooperation within the different types of EI. By differentiating between product and process eco-innovation we link the specific characteristics of different EI that profit from cooperation. We also discuss differences between EI and non-eco-innovation (NEI). This will give us insights into different requirements of the development between the innovation types. We further combine the eco/non-eco dimension and the product/process dimension by analysing differences between product eco-innovation (PDEI), process eco-innovation (PCEI), product non-eco-innovation (PDNEI) and process non-eco-innovation (PCNEI). Given the previously presented arguments and how we contribute to the knowledge of CE, EI and the importance of cooperation for the innovation process we address the following research question:

“Does cooperation enhance eco-innovation and
are there differences in this relationship depending
on the type of eco-innovation?”

Our empirical work is based on data from the Mannheim Innovation Panel (MIP) which is the German contribution to the European Commission's Community Innovation Surveys (CIS). It is designed to provide information related to the innovativeness of businesses in Germany and has been a proven data source for research on all kinds of innovation (Bammens & Hünermund, 2020; Horbach, 2014a; Lewandowska et al., 2022; Silva et al., 2021; Torres & Godinho, 2023).

Our regression analysis reveals compelling evidence that cooperation plays a significant role in promoting EI. Importantly, our findings indicate that the distinctive characteristics of EI render cooperation an even more indispensable component of the development process compared to NEI contexts. However, when examining the effects of different types of EI, our results are less conclusive.

Specifically, our analysis provides support for the positive impact of cooperation on product eco-innovation (PDEI). In contrast, we lack sufficient evidence to substantiate the influence of cooperation on process eco-innovation (PCEI). These findings highlight the nuanced nature of the relationship between cooperation and different forms of EI, necessitating further investigation to unravel the underlying dynamics and mechanisms involved.

The remainder of our paper is structured in the following way. Chapter 2 provides a comprehensive review of the literature on circular CE, EI, and the relationship between cooperation and innovation. This theoretical foundation forms the basis for our research. Next, we integrate existing findings from these three domains to derive three testable hypotheses, establishing the framework for our empirical analysis. This synthesis of literature contributes to the development of our research questions. Chapter 4 outlines our chosen methodology and research approach, detailing the selection and operationalization of our dependent, independent, and control variables. We convey a clear explanation of our research design. Moving forward, in chapter 6, we present the results of our analysis and report our findings. Chapter 7 encompasses a comprehensive discussion of our results, highlighting the contribution of our empirical work to the academic field. We also demonstrate practical insights for practitioners and policy makers based on our findings. In the concluding chapters, we summarize our work, acknowledging any limitations that should be considered when interpreting our results. Furthermore, we provide recommendations for future research, exploring potential avenues for further investigation in this domain.

2 Literature Review

2.1 Circular Economy

The human exploitation of natural resources is endangering global ecosystems. Several tipping points have already been reached, leading to irreversible environmental changes (Rockström et al., 2009). It is crucial to decouple economic growth and social development from resource exploitation and waste. This is one defining challenge of the 21st century, as economic development and rising living standards for a population of 10 billion by 2050 must be accommodated while also considering limited resources and sustainability (Pomázi, 2012). Due to the fact that traditional economic methods have limitations in solving the given situation, a more circular approach is gaining momentum.

The concept of a CE has emerged as a strategic approach that promotes closed-loop thinking within businesses, industrial organizations, and national agendas (Preston, 2012). This approach is inspired by natural ecosystems. It aims to shift away from a linear economy, which involves unidirectional extraction, production, distribution, consumption, and disposal activities (Ul-Durar et al., 2023). Instead, the CE advocates a regenerative economy that considers the entire life cycle of a product and consequently cooperation of participating players (Ghisetti et al., 2015). The CE prioritizes designing processes and products that minimize negative environmental and societal impacts, reduce the use of non-renewable resources, eliminate toxic and hazardous materials, increase product lifespan, and maximize opportunities for reusing products and recovering materials (Gueymard & Lopez, 2013). The CE also proposes models for creating value that support sustainable economic development, through loops of reuse, restoration, and renewability. This approach emphasizes functionality and service rather than ownership and material production (EMF, 2012).

Over the past few years, the concept of a CE has gained increasing attention from both scholars and practitioners, indicating a growing recognition of its potential benefits (Kirchherr et al., 2017). The augmentation of peer-reviewed articles on CE is indicative of the growing interest in this topic. Geissdoerfer et al. (2017) noted a substantial increase in publications, with over 100 articles published in 2016 compared to merely 30 in 2014. According to our own research on Web of Science, this number continued to grow with 708 published articles in 2021 and 651 published articles in 2022 (Web of Science, 2023a, 2023b). Meanwhile, there has been a surge in consultancy reports on CE, with consulting firms such as Accenture, Deloitte, Ernst & Young, and McKinsey & Company publishing reports on this subject in the last years (Enkvist et al., 2022; Fraser et al., 2023; Hetzer, 2022; Lacy et al., 2020). This trend reflects consultancies' endeavors to signal their proficiency in addressing trending topics to their clients.

Despite the high interest in CE, there is currently no comprehensive definition of this concept. Various contributions were made in order to create transparency regarding the current understanding of CE. Notably, prior research has made commendable attempts to survey the complexities associated with defining CE (Kirchherr et al., 2017; Murray et al., 2017; Zotti & Bigano, 2019)[1].

Early definitions determine CE as a mere combination of reducing, reusing, and recycling actions, without emphasizing the necessity of a systemic transformation (Kirchherr et al., 2017). Further limitations are found by Kirchherr et al. (2018) who point out that definitions of CE typically lack explicit connections to sustainable development. The primary objective of CE is frequently deemed to be economic well-being, followed by environmental conservation, with only scant attention devoted to the implications for social justice and intergenerational equity. Moreover, the role of business models and consumer behaviour as enablers of the CE is often overlooked, as they are not commonly highlighted or integrated into the current discourse and practices surrounding CE disregarding some exceptions, e.g. Nußholz (2017).

Although a broad definition, the definition by the European Commission (2015) remains a valuable and informative reference for social science applications as it avoids the limitations mentioned above. The European Commission defines CE as a system that maximizes the value of products, materials, and resources while minimizing waste generation.

2.2 Eco-innovation

In order to realize a CE, new or enhanced socio-technical innovations that conserve resources, mitigate environmental degradation, and/or enable recovery of value from substances already in circulation within the economy are necessary (de Jesus

[1] An overview of literature reviews is provided in Appendix 1

& Mendonça, 2018, p. 77). De Jesus and Mendonça (2018) express the relevance of a particular idea to the transformative process towards a more CE, as articulated by the original source in their call for a "new usage-production closed-loop system." As of yet, no unified term for innovations in the CE has emerged as the prevailing standard.

In the literature review, the terms EI, green innovation, environmental innovation, and sustainable innovation are often used interchangeably by researchers (Araújo & Franco, 2021; González-Moreno et al., 2019). It is worth noting that while the first three terms focus on ecological and environmental dimensions, sustainable innovation encompasses a wider concept, including an additional social dimension, as pointed out by Charter and Clark (2007) and Schiederig et al. (2012). Within the literature, these terms are commonly utilized to denote innovations that mitigate adverse environmental effects (Hojnik & Ruzzier, 2016). As the ecological and environmental dimensions are stressed in the further examination, we refer to CE innovations as EI. Regardless of the terminology employed, it is paramount that EI has emerged as a pressing managerial requirement and a critical determinant of sustainable performance and development (Kerdpitak et al., 2019). A literature review by de Jesus et al. (2018) shows that CE initiatives significantly drive EI. Further empirical studies confirmed the relationship between the CE and EIs but also suggested further investigation (González-Moreno et al., 2019).

EI determine a subset of innovations in the economy while sharing many characteristics with them (Wagner, 2008). However, EIs show distinct characteristics when compared with other types of innovations, as demonstrated by multiple empirical analyses (Horbach & Rammer, 2022). These unique features suggest that EIs require specific management and policy approaches to foster their development (Hojnik & Ruzzier, 2016). EI that reduces CO_2 emissions, such as those that decrease energy use in production processes and products or increase the use of renewable energy sources, are critical in addressing climate change (Horbach & Rammer, 2022). The groundwork was settled by Rennings (2000) by identifying three particularities of EI: first, EI can take on various forms, such as technological, organizational, social, or institutional, and can be developed by both for-profit and non-profit organizations, and traded or not traded on markets. Second, EI is situated at the intersection of innovation economics and environmental economics, requiring an interdisciplinary approach to analysis. Finally, EIs require a unique approach to policy design, one that reflects their distinctive features.

2.2.1 Definition

Defining EI proves to be a challenging task due to the lack of a widely agreed-upon definition among various research studies. Firstly, we will examine the general definition of innovation as provided by Crossan and Apaydin (2010, p. 1155) as: “production or adoption, assimilation, and exploitation of a value-added novelty in economic and social spheres; renewal and enlargement of products, services, and markets; development of new methods of production; and establishment of new management systems. It is both a process and an outcome”. By including both the process and the output, this definition goes beyond the creative process and requires innovation to add value to some economical party in a certain way.

To be considered an EI the process or outcome of an innovation needs to fulfill additional criteria. The Eco-Innovation Observatory (2012, p. 8) defines EI as the "introduction of any new or significantly improved product (good or service), process, organizational change or marketing solution that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole life-cycle." Kemp and Pearson (2007, p. 16) describe EI as "production, application or exploitation of a good, service, production process, organizational structure, or management or business method that is novel to the firm or user and which results, throughout its lifecycle, in a reduction of environmental risk, pollution and the negative impacts of resources use (including energy use) compared to relevant alternatives. Horbach et al. (2012, p. 119) refer to EIs as "product, process, marketing, and organizational innovations, leading to a noticeable reduction in environmental burdens. Positive environmental effects can be explicit goals or side effects of innovations. They can occur within the respective companies or through customer use of products or services."

While there are several other definitions, all recognize the environmental aspect and reflect the primary consequences of EI, namely, fewer adverse effects on the environment and more efficient resource usage (Díaz-García et al., 2015). However, the deployment of EI is not solely driven by the goal of reducing environmental burden, and it can take many forms, such as product, process, and organizational and marketing methods (de Jesus et al., 2018).

2.2.2 Antecedents and Drivers

Since EIs are tied to solving the environmental challenges of our planet naturally a lot of research has focused on their antecedents or drivers. Hojnik & Ruzzier (2016) describe drivers as stimuli that can either motivate or facilitate EI. These drivers may include factors such as regulatory pressure, expected benefits of implementation, profiling of the company as environmentally friendly, competitive pressure, customer demand, environmental management systems, financial resources, and technological capabilities. In a meta-study by Bitencourt et al. (2020) 10 constructs that are related to the promotion of EI have been identified. Drawing upon our own research, this following discourse explores the drivers of EI, encompassed by a comprehensive analysis of associated themes.

Environmental regulations, as external factors, have a significant impact on firms' investments in EI. The literature suggests that environmental regulation is a key driver of EI and can facilitate its diffusion, as stated by the Porter Hypothesis (Doran & Ryan, 2012; Horbach et al., 2012; Porter & Linde, 1995; Wagner & Llerena, 2011). However, Kesidou & Demirel (2012) argue that the stringency of regulations affects less innovative firms differently than more innovative ones. Moreover, certain types of EIs, such as those aimed at reducing air, water, or noise emissions, avoiding hazardous substances, and increasing the recyclability of products, may be more impacted by regulation (Horbach et al., 2012).

Firm size has been found to have a positive correlation with EI, attributed to the complexity of larger firms requiring organized and structured management to address environmental pressures and regulations (Buysse & Verbeke, 2003). Nonetheless, the impact of firm size on EI is a topic of debate in the literature. While some scholars suggest that size is a proxy for complementary assets and internal capacity to undertake EIs, others argue that firm size has no effect on a firm's probability of carrying out PDEI or PCEI. Revell & Rutherfoord (2003) suggest that SMEs are still hesitant to include environmental considerations in their practices, while others provide evidence that green initiatives among SMEs have proliferated (Revell et al., 2010) and that they have EI propensity (Aragón-Correa et al., 2008; Bos-Brouwers, 2010). Since most literature is focused on large mature firms, the effect of firm size on EI activities remains undetermined from a theoretical perspective (Horbach, 2008).

Similarly, *firm age* tends to promote EI as it is associated with technological maturity and capabilities (Carrillo-Hermosilla, Río González, et al., 2009). At the same time studies suggest that young and new firms may have advantages in innovation (Acs & Audretsch, 1990). They are potential candidates for offering solutions to new challenges, including environmental challenges. However, there are very few studies that address the innovation process of new ventures driven by environmental orientation. One exception is the study by Keskin et al. (2013).

Market turbulence/competition, reflecting the hostility of the business environment, creates a need for firms to differentiate themselves, leading to a drive for innovation (Hofstra & Huisingh, 2014). Moreover, external competition serves as a further driver for EI (Cai & Li, 2018). Intense market competition exerts pressure on companies to improve their innovation abilities (Li & Ye, 2011). Because of the innovation of new materials, technology, and equipment external pressure is applied by rival firms (Clark, 2005). The increasing demand for EI capabilities can be attributed to external competitive pressures that necessitate enhanced environmental performance and product quality (Hicks & Dietmar, 2007). Li and Ye (2011) examined the German industrial group Siemens and revealed that the leading role in highly energy-intensive industries through the development of energy-efficient products and solutions as well as renewable energy forced other firms to imitate the EI practices of Siemens to establish a good market image and gain more market share. Thus, external competitive pressures foster the development of EI.

With regards to a firm's *strategy* and its business logic, the importance of managerial concern in adopting and implementing environmental orientation is emphasized by Paraschiv et al. (2012), as it is found to be one of the most important drivers for the adoption of green practices in several industries (Qi et al., 2010). Firms undergoing EI projects need to integrate environmental aspects with the overall corporate strategy, and although EI combines environmental and techno-economic objectives, the former is not always a priority (Bélis-Bergouignan et al., 2012). The basis for a competitive strategy in EI is found in both cost-leadership and differentiation competitive strategies, where cost savings are an important motivation for EI initiatives such as PCEI and environmental research and development (R&D) (Demirel & Kesidou, 2011; Horbach et al., 2012; Pereira & Vence, 2012; Triguero et al., 2013), while differentiation is considered a motivation related to the adoption of EI initiatives, especially for PDEI (Cuerva et al., 2014). Through the adoption of proactive environmental strategies, companies can build a competitive advantage based on a green reputation (Tsai, 2002). Carrillo-Hermosilla et al. (2009) elaborate that firms located towards the end of the production process exhibit a greater propensity to react to the demands of environmentally-conscious end users when compared to companies situated at the outset of the production chain. As a consequence, reputational concerns have a higher significance if the market demand for PDEI is high (Tsai, 2002). It is observable that firms facing such demand seem to respond with innovations (Horbach & Rammer, 2022). Moreover, green organizational identity positively affects EI development (Chang & Chen, 2013).

Furthermore, *information sources* play a crucial role in EI, as they provide the necessary knowledge for driving changes in processes and products pointed out by Triguero et al. (2013).

Finally, *research and development activities*, representing firms' technological capabilities, are expected to have a positive relationship with EI, as R&D facilitates the technological adaptations required for cleaner technologies (Carrillo-Hermosilla et al., 2009). This is especially the case for local production systems like industrial districts, where innovation density, knowledge spillovers, and externalities are concentrated in a limited area (Mazzanti & Zoboli, 2009). As a result, being situated in an industrial district can also serve as a driving force for fostering EIs.

Bitencourt et al. (2020) also discuss *barriers* to EI, which restrict firms' actions in both internal and external contexts (Horbach et al., 2013). Barriers are likely to limit EI due to the associated risk related to consumer responses (Cuerva et al., 2014). Various factors have been identified in the literature as barriers to EI, including financial constraints (Cuerva et al., 2014), limited access to materials, lack of external financing, and uncertain demand (Nover, 2016). One way to decrease the barriers has been public support in the form of subsidies. They create incentives to invest in EI and help lessen the financial burden (Scarpellini et al., 2018).

Nonetheless, it is incumbent upon the firms themselves to strategize and surmount these barriers. Firms must cultivate distinct capabilities that are tailored to cater to the exigencies of EI, as highlighted by Cai and Zhou (2014). Pfeiffer & Rennings,

(2001) and Horbach (2014) highlight the importance of highly qualified personnel in EIs in order to overcome emergent barriers.

To organize the resources and capabilities of a firm *eco-management systems* are important. Implementing environmental management systems such as ISO14001 can reduce environmental impacts and increase efficiency (Demirel & Kesidou, 2011). Voluntary scheme certifications such as quality management systems can also help explain EI adoption (Leenders & Chandra, 2013). Managerial and organizational capabilities, training, information, and dissemination to improve human resources' absorptive capacity encourage and stimulate EIs (Horbach, 2008; Kesidou & Demirel, 2012; Mondejar et al., 2013).

Additional research shows that the relationship between EI and export-orientated firms just recently gained the attention of scholars. Their argumentation is based on institutional theory suggesting exporting firms tend to conform to global expectations for CSR and protection of the natural environment, as well as institutional pressures from distant countries. A few previous studies have shed some light on this issue (Shahzad et al., 2020; Tang et al., 2017). For example, Shahzad et al. (2020) investigated the impact of a country's export orientation on cleaner production in 63 developed and developing economies, finding that exporting can have a positive impact on the adoption of cleaner production practices.

Technological innovation is also essential for successful EI, particularly in local production systems like industrial districts, where innovation density, knowledge spillovers, and externalities are concentrated in a limited area (Mazzanti & Zoboli, 2009). As a result, being situated in an industrial district can also serve as a driving force for fostering EIs. Horbach (2014) argues that the empirical literature analyzing determinants of EI has neglected the inclusion of regional and location factors due to inadequate data. However, he emphasizes that external knowledge sources, such as proximity to research centres and universities, are more important for EIs than for other innovations. He finds that EIs are more likely in regions with high poverty rates and less dependent on urbanization advantages, thus presenting opportunities for under-developed regions to seek new business activities. Martin et al. (2013) also support the idea that *rurality* is important for EI due to firms' visibility within their local communities and their proximity to the impacts of climate change.

2.2.3 Consequences

There has also been a lot of research on the consequences of EI. A firm can profit from the introduction of EI through performance benefits. Firstly, EI can lead to higher economic performance through cost reduction, higher return on investment, increased profitability or greater productivity (Sezen & Çankaya, 2013). Secondly, given that a firm is under external pressure to operate ecologically for example through regulations, EI can help to improve its ecological performance. This is the case when an EI allows a firm to achieve lower adverse effects on the environment and a more efficient use of resources (Hojnik & Ruzzier, 2016; Sezen & Çankaya, 2013). Lastly, a firm can benefit from EI by increasing its social performance. This can be through moral considerations or social impact (Sezen & Çankaya, 2013). A firm can also indirectly profit from EI by increasing its reputation. For many consumers, sustainability plays as big role in the decision process. EI help firms improve their societal perception (Cretu & Brodie, 2007) and signals that environmental considerations have been made.

Some researchers have also focused on moderation effects on the relationship between EI and firm performance. The moderators can be categorized into cultural, economic and contextual EI types. From a cultural dimension, there is evidence that the relationship between EI and cooperation might vary between country and national culture (Cho et al., 2013; Gallego-Álvarez & Ortas, 2017; Morren & Grinstein, 2016). One important variable leading to differences is if the country's population tends to think more individualistically or collectivistically. The idea is that a population that identifies itself strongly as a group will have a better environmental performance because they tend to care more about others and the well-being of society as a whole (Morren & Grinstein, 2016) and that people from an individualistic country are more focused on personal gains (Ho et al., 2012; Morren & Grinstein, 2016). From an economic perspective, the structural differences of a nation play a role. Even though the economic growth of the past is how the overconsumption of our resources and pollution has come about, researchers have found that a high degree of economic development, a highly educated population and well-developed institutions are important for ecological performance (Sarasini, 2009). In this regard, the government has a significant role as a political entrepreneur (Johnson & Silveira, 2014). With the right framework and regulations policy makers can contribute to the environmental competitiveness of the firms within their nation. Lastly, there is also evidence that environmental performance depends on the EI type (Del Río et al., 2010; Hojnik & Ruzzier, 2016; Triguero et al., 2013).

It is worth noting that the literature highlights a gap regarding EI in the services sector. While much attention has been given to EI in the manufacturing sector, services have received little attention in previous research (Cainelli & Mazzanti, 2013).

2.3 Innovation

2.3.1 Closed Innovation

Closed innovation can be perceived as the classical concept of innovation. This concept is still relevant to this day and a lot of policy makers have based their laws on intellectual property on it. It is named closed because the innovation is solely created and implemented within one organization and therefore, the internal R&D department plays a crucial role. The organization is interested in getting a competitive advantage through innovation and sharing information externally could potentially jeopardize this competitive advantage. Especially in settings where a first-mover advantage is of importance.

There is one researcher in particular that was highly influential, when it comes to the concept of innovation. Schumpeter (1934, 1942) argued that the process of capitalism involves the continual creation and destruction of economic structures and that this dynamic process of "creative destruction" is the engine of economic growth and progress. Schumpeter believed that entrepreneurs were the key drivers in this process, as they were constantly introducing new products, processes, and business models that disrupted existing industries and created new ones. This was true for three reasons, each elucidating the significance of large corporate owners as the main entrepreneurs during that period (Schumpeter, 1942): He argued that firstly, the cost of R&D programs could only be borne by large companies. Secondly, these large and diversified companies could mitigate risks by innovating across a wide range of technological areas. Lastly, companies require a degree of market power to capitalize on the benefits of their innovations. Given that closed innovation was mostly done by large producers it is also referred to as “producer innovation” (Schumpeter, 1942).

2.3.2 Open Innovation

While Schumpeter's idea of creative destruction still is a helpful illustration of how innovation advances the economy, the structure of organizations and how they interact has changed a lot over the years. Even though the typical large-scale producer still exists today, a lot of companies have become complex horizontal and vertical constructs that cooperate with internal and external entities. Therefore, it has become hard to identify firm boundaries in a meaningful way (Teece, 1992).

Schumpeter's economic arguments of why innovation was mostly created in large-scale producers still hold today and closed innovation is still a viable development method, but emergent developments force companies to organize and interact in a different way. Baldwin and von Hippel (2011) argue that this evolution is due to the advancement in information technology. The communication and design costs of innovation have become so low that other processes than producer innovation have become viable. In other words, organizational alternatives to the traditional single entity with clear boundaries have become a better solution in certain business environments. More specifically Teece (1992) shows the advantages of strategic alliances compared to price (typical market settings) or internal organization in business environments characterized by rapid technological change and dispersed know-how. A company's unique competencies can be insufficient to develop a long-term competitive advantage in certain market settings (Powell et al., 1996), which is why partnerships, strategic alliances, joint ventures, and technology/patent sharing have become a viable alternative (Lee et al., 2012).

It is important to note though while there seems to be a clear link between the importance of collaborative efforts in industries with a high degree of technological complexity (Garud, 1994; Gnyawali & Park, 2009; Gomes-Casseres, 1994), it is not the technology per se that leads to the need for external knowledge. Padula and Dagnino (2007) show how changing and unstable environmental conditions, in general, can impact the cooperation strategy between competitors. Therefore, it can also be other destabilizing factors that lead companies to have to engage in collaborative efforts.

With more and more firms working collaboratively on innovation projects, researchers have shown how using external knowledge has become an integral part of a companies' business model. Chesbrough (2003) named this new paradigm open innovation, which was based on the fact that a lot of companies started using a wide range of external actors and sources for achieving and sustaining a competitive advantage.

It has become more evident that useful knowledge is widely distributed and that even the most capable R&D organizations must identify, connect to, and leverage external knowledge sources as a core innovation process (Chesbrough, 2003). A too strong internal focus could lead to missed opportunities (Laursen & Salter, 2006). The creation of innovation can be predicated upon either internal or external knowledge sources, while its execution can manifest through internal or external channels (Chesbrough, 2003, 2006).

Chesbrough (2006, p. 5) also explains why companies should be willing to share information and provide new technologies to other organizations and even competitors. The notion of spillover effects should be reframed from being perceived as a mere cost incurred in the course of conducting business, as traditionally held, to being leveraged as a means to augment the business model of a company. Instead of patents sitting on the shelves of a company to prevent competitors from using them, creating technologies for others can be part of a firm's business model.

In this regard, Wang and Hu (2020) emphasize the benefits of knowledge sharing along the supply chain and Lasagni (2012) demonstrates how relationships with relevant stakeholders in general can lead to a higher innovation performance. Interestingly, collaborative efforts between competitors seem to have a special position within an industry. According to the findings of Harbison and Pekar (1998), approximately half of the examined inter-organizational collaborations were observed to involve entities operating in direct competition with each other. This relationship manifests that competition and cooperation are not mutually exclusive (M. Bengtsson & Kock, 2000; Luo, 2004, 2005; Tsai, 2002). In connection with the already discussed unintended disadvantages of information exchange in the form of spillover effects, it seems counterintuitive that cooperation between competitors is so frequent. But Gnyawali and Park (2011) show with the example of Samsung and Sony how it can be beneficial for fierce rivals to work together. As previously discussed in this chapter, cooperation is particularly crucial in rapidly changing environments that necessitate technological innovation.

Further, certain scholars have directed their attention towards scrutinizing the transformations in value creation within specific industries related to innovation processes. A lot of business models are based on strong network effects, which means that the goal of innovation is to create the best possible value for all stakeholders involved. This also includes a strong shift towards the experience of the consumers, where an organization is not able to operate successfully by only considering its own goals (Lee et al., 2012). Rather than being confined to individual organizations or bilateral collaborations, the focus of innovation appears to have shifted towards the network in which a company is embedded. (Powell et al., 1996). Since a single company is not able to attain a competitive advantage from innovation by itself, the new important measurement becomes a company's role within a network (Ahuja, 2000). From a research perspective, the performance of different networks needs to be compared, as the innovation output of a firm acquires meaning and significance solely within the broader context of the network.

2.3.3 Product Innovation and Process Innovation

Research has shown that not all innovations exhibit the same characteristics depending on their distinct type. Innovation can have different determinants and impacts on firm performance (Jin et al., 2004). Therefore, the relationship between interorganizational cooperation and innovation might vary depending on the type of innovation. This chapter will give a categorization of the different innovation types and discuss how innovation can be structured.

Innovation entails the modification of one or more products or business processes, which commonly leads to the description of innovation based on its intended purpose or object (Schumpeter, 1934). Gaining insights into the object of an innovation provides valuable information for evaluating its purpose, inherent features, potential effects on the firm, and the specific types of innovation activities pertinent to its conceptualization and execution (Siguaw et al., 2006).

The Oslo Manual constitutes a set of guidelines developed by the Organization for Economic Co-operation and Development and the European Commission that provides internationally recognized standards for collecting and interpreting data on innovation activities. In the fourth and current edition, the Oslo Manual determines two major types of innovation by object: (1) innovations that change the firm's products (PDIs), and (2) innovations that change the firm's business processes (PCIs) (OECD & Eurostat, 2018). PDIs are categorized into two types, while PCIs are classified into six types.

PDIs encompass two fundamental types: goods and services (Gallouj, 2000). Goods refer to tangible objects and certain knowledge-based products that can be assigned ownership rights and transferred through market transactions (Cooper, 2005). Services, on the other hand, are intangible activities that are produced and consumed simultaneously, capable of altering the conditions (e.g., physical, psychological, etc.) of users (Miles, 2010). Active involvement of users through their time, availability, attention, transmission of information, or effort often becomes a necessary condition for the co-production of services by both users and the firm. As a result, the attributes or experience of a service can be influenced by user input (Miles, 2010). Additionally, services may also incorporate certain knowledge-capturing products within their scope. As a consequence, the Oslo Manual provides the following definition for PDI: "A product innovation is a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market." (OECD & Eurostat, 2018, p. 71)

Innovation activities involve all business functions within an organization (Amabile, 1996). Firms have the capacity to develop business process innovations targeting one or multiple functions within their operations (Gann & Salter, 2000). Business processes can be perceived as services for which the firm itself is the customer. It can be delivered internally or sourced externally. Business process innovations are concerned with enhancing and transforming the various functions within a firm. Management research has proposed various categorizations of business functions that differ in terms of defining core and supporting business functions. The core function of a firm entails the production of goods and services, while the remaining five functions encompass supportive activities that facilitate production and bring products to the market (Brown, 2008). Accordingly, in the fourth edition of the Oslo Manual, the term business process encompasses six business functions: (1) producing goods and services, as well as (2) supporting functions such as distribution and logistics, (3) marketing, sales and after-sales services, (4) information and communication technology (ICT) services, (5) administrative and management functions, and (6) product and business process development (OECD & Eurostat, 2018). Based on the foregoing, the Oslo Manual defines PCI as follows: "A business process innovation is a new or improved business process for one or more business functions that differ significantly from the firm’s previous business processes and that has been brought into use in the firm.” (OECD & Eurostat, 2018, p. 72)

In contrast to the distinction of innovation into two categories (PDI and PCI), previous innovation surveys that followed the third edition of the Oslo Manual collected data on multiple categories of innovation. For example, the European Community Innovation Survey (CIS) collected data in four categories (Eurostat, 2021). The category PDI maintained the same assessment as previously elaborated. However, business process innovation exhibits additional distinctions in the third version of the Oslo manual. A distinction is drawn between PCIs, organizational innovations, and marketing innovations (OECD & Statistical Office of the European Communities, 2005). This categorization offers a moderate level of comparability with the definition of business process innovation outlined in the fourth edition of the Oslo Manual. The reason for the adjustment is based on empirical research that has shown that business managers revealed difficulties differentiating between organizational and PCIs (OECD & Eurostat, 2018). Organizational innovations are therefore categorized within the specific domain of business processes (administration and management). This category includes activities that involve what was previously referred to as organizational innovation, such as strategic management (encompassing business practices and external relations) and human resource management (covering workplace organization) (OECD & Eurostat, 2018). It is important to note that the third edition of the Oslo manual introduced a distinct classification only between product or process innovators, which excluded firms solely focused on organizational or marketing innovations.

Next to the innovation categories of the Oslo Manual, there are also other ways to differentiate between certain types of innovation. There are many different concepts like radical vs incremental (Damanpour, 1996; Dewar & Dutton, 1986; Ettlie et al., 1984), competence-enhancing vs competence-destroying (Tushman & Anderson, 1986), architectural and generational (Henderson & Clark, 1990), disruptive (Christensen & Rosenbloom, 1995), core/peripheral (Abernathy & Clark, 1985; Tushman & Murmann, 1998) and modular innovation (C. Y. Baldwin & Clark, 2000). Gatignon et al. (2002) build a framework from these constructs and use a structural approach to differentiate between innovation based on their locus (core/peripheral), type (architectural or generational) and their characteristics (competence-enhancing/destroying, and incremental/radical).

Due to its international recognition and proven utilization in an academic environment, the Oslo Manual will serve as a sophisticated and streamlined framework throughout this thesis and we will follow the determinations and definitions of innovation categories proposed by the foregoing.

3 An Open Innovation Perspective on Eco-innovation

As elucidated by Schumpeter, innovations are the building blocks of new economic structures. In this process, the goal of any innovation is to achieve and maintain a competitive advantage. The differentiation of EIs lies in the distinctive approach employed to attain this competitive advantage, with a particular emphasis on environmental sustainability. While all innovation can ultimately impact a company's competitiveness, EI specifically seeks to reduce the environmental impact and minimize the use of natural resources (see chapter 2.2).

However, achieving a competitive advantage through EI is extremely challenging. One significant obstacle that contributes to this challenge is what Rennings (2000) refers to as the "double externality problem." On top of the knowledge spillovers, which were discussed in the previous chapter, EI additionally produces environmental positive externalities. This means the environmental value created through EI cannot directly be appropriated by the responsible firm. All other firms also profit without having to operate more responsibly themselves, which creates a disincentive for firms to invest in EI. From the possible market failure linked to these two externality dimensions, researchers have derived the importance of policy intervention for the introduction of EI. Several contributions have shown that regulatory frameworks are a key driver for EI and help to internalize or neutralize environmental externalities and to further push the introduction of EI through additional incentives (Cleff & Rennings, 1999; OECD, 2000; Porter & Linde, 1995; Stavins et al., 2002).

These peculiarities have implications for the development process of EI. According to De Marchi (2012) the systemic, credence and complex character of EI suggests a higher importance of cooperation for development compared to other types of innovation.

While the change in innovation paradigms has shown that cooperation has become more important for innovation in general, certain conditions can enhance the requirement for collaborative approaches. In essence, it is factors that destabilize a business environment, which makes cooperation essential (see chapter 2.3.2).

The presence of destabilizing factors of most EI is well-established and widely acknowledged in the existing scholarly literature. Firstly, there is a high degree of technological novelty including a requirement for new information and skills (De Marchi, 2012). Therefore, cooperation with suppliers plays a crucial role in the development of EI as it often necessitates alterations in the raw materials or components employed, integration with external partners in terms of logistics and technology, and product redesign. This cooperation ensures the availability of environmentally friendly inputs or components, which may not be easily accessible in the market (Allwood et al., 2011). It also facilitates the verification of whether these inputs or components meet the required standards or necessitate adjustments to the internal production process (Geffen & Rothenberg, 2000; Meyer & Hohmann, 2000; Seuring & Müller, 2008).

Secondly, the environmental aspect of a product or process often remains a hidden attribute, making it difficult to discern even after its purchase (Munch Andersen, 1999). Goods possessing such qualities were labelled "credence goods" by Darby and Karny (1973) due to their inherent value being hard to evaluate through regular use. In the context of product purchases, it is a rare occurrence to have the capacity to discern whether a given product was produced using a less environmentally polluting process or with raw materials that have a lower overall impact on the environment. This informational challenge impacts both consumer decisions when purchasing end-products and the procurement choices of companies when acquiring raw materials or components. Cooperation among stakeholders, including producers, regulators, and consumer advocates, can foster transparency and build trust. By openly sharing information about production processes, quality control measures, and third-party certifications, they can increase consumer confidence in the product or service (Chistov et al., 2021).

Lastly, while it is certain that the regulations and policies related to environmental sustainability are becoming more complex and stringent, it is not clear what exactly will be expected. Thus far, ambitious objectives such as carbon neutrality and the limitation of global warming have been established. However, the specific strategies and approaches that firms should adopt to accomplish these objectives remain uncertain. Cooperation can play a vital role in addressing uncertain regulations by facilitating information sharing, industry advocacy, regulatory intelligence, knowledge exchange, joint advocacy for clarity, collaborative compliance initiatives, and capacity building (N. J. Bengtsson, 2020). By working together, stakeholders can navigate regulatory uncertainties more effectively and contribute to the development of transparent, consistent, and fair regulatory frameworks.

One additional challenge encountered in the realm of the development of EI is the inherent interdependence among firms concerning their sustainable practices. This interdependence is imperative due to the overarching aim of EI to foster a more comprehensive impact on both society and the environment. While a lot can be done on an individual level, the concept of a CE shows the importance of a systemic approach (Allwood et al., 2011; Sumter et al., 2020). Shifting the focus to encompass material flows, supply chains, and even entire industries not only amplifies the potential impact, but also necessitates an examination of how value is generated through sustainable practices. A firm cannot achieve long-term success by solely focusing on its own goals. Instead, companies that prioritize the needs and expectations of all stakeholders, including employees, customers, suppliers, and communities, are more likely to achieve success and create a positive environmental impact (Carrillo-Hermosilla et al., 2010). By creating shared value (see chapter 2.3), companies can align their business goals with social and environmental goals, resulting in benefits for all stakeholders. This approach helps to build trust and reputation with customers, attracts and retains talent, and fosters long-term partnerships with suppliers and communities.

Considering the prior elaborated challenges, we believe that cooperation is a key element for the successful development and implementation of EI and therefore propose the following hypothesis:

Hypothesis 1:

Cooperation enhances eco-innovation

Different types of EI have distinct characteristics. Previous research has shown that the determinants of EI may vary depending on the type[2] (Del Río et al., 2010; Pujari et al., 2003). While the determinants mentioned in chapter 2.2 apply to all EI the extend and the importance can vary.

A PDEI is a PDI that has fewer adverse effects on the environment and more efficient resource usage (Díaz-García et al., 2015). PDEI are usually bought or consumed by end customers. Therefore, the demand side of the market is a key driver for PDEIs (Pujari, 2006). By leveraging cooperation with consumers, environmental organizations, supply chain partners or governmental organizations in the development process of PDEI is a great way to ensure the ecological consideration will have the desired impact. Especially proactively cooperating with government organizations is important to ensure the current and future regulations can be fulfilled.

These insights lead us to establish the following hypothesis:

Hypothesis 2:

Cooperation enhances product eco-innovation

PCEIs, which encompass improved production processes generating positive or less detrimental externalities on the environment (Rennings, 2000), exhibit distinct characteristics in terms of their introduction and drivers. In contrast to PDEIs that directly interact with consumers and consequently exhibit a positive association between a firm's reputation and the adoption of PDEIs, firms' motivations for introducing PCEIs are primarily internally driven (Rennings & Zwick, 2002; Triguero et al., 2013). Consequently, it is unsurprising that cost-saving plays a major role in motivating firms to adopt PCEIs (Cleff & Rennings, 1999). Technological capabilities serve as a pivotal driver for PCEIs (Triguero et al., 2013), and since these capabilities are deeply rooted in R&D, cooperation becomes imperative in high-technology industries for all types of innovation, including PCEIs (González-Moreno et al., 2019). This connection is further supported by Horbach's findings (2012), indicating the importance of cooperation with

[2] We apply the classification scheme for innovation of the Olso Manual (2018) and accordingly differ between PDEI and PCEI. However, we ackowlegde other classication possibilites (see chapter 2.3.3)

universities and research institutions, particularly for PCEIs. Moreover, González-Moreno (2019) highlights that in low-tech industries, establishing strong and frequent relationships with stakeholders holds special significance for the successful implementation of PCEIs.
Therefore, we set up the following hypothesis:

Hypothesis 3:
Cooperation enhances process eco-innovation

4 Methodology

4.1 Data Source

In order to test the relationship between EI and cooperation, data from MIP is utilized. The MIP is the German contribution to the European Commission's CIS. The CIS is designed to enable the analysis of innovation drivers or barriers, to provide information on the innovativeness of firms and economy sectors and to assess innovation outcomes in the European Union, European Free Trade Association and the candidate countries (Eurostat, 2021). The collection for the MIP started in 1993. In partnership with the Institute of Applied Social Science and Fraunhofer Institute for Systems and Innovation Research, on behalf of the Federal Ministry of Education and Research, the Centre for European Economic Research has been conducting an annual innovation survey to gather data on the innovation behaviour of German firms[3]. It encompasses various industries, including mining, manufacturing, energy and water supply, waste disposal, construction, business-related services, and distributive services. To allow projections for individual industries and size classes, the survey is representative of the German population of firms (Gottschalk, 2021). It is important to note that the participants of the CIS are generally owners or general managers of small or medium-sized enterprises, and innovation managers in larger firms. Therefore, the survey is designed to be straightforward to enable respondents of all types to furnish reliable answers (Horbach & Rammer, 2022). Several studies in the field of EI have been conducted utilizing the German CIS data, thereby establishing the panels' eligibility as a

[3] The innovation survey of the MIP is openly available for research upon request. More information on how to receive the data can be found on the following website: https://www.zew.de/forschung/mannheimer-innovationspanel-innovationsaktivitaeten-der-deutschen-wirtschaft

rigorous academic research environment that encompasses a wide range of research topics (Bammens & Hünermund, 2020; Horbach, 2014a; Lewandowska et al., 2022; Silva et al., 2021; Torres & Godinho, 2023).

The survey design is predicated upon a panel survey methodology, which includes the same firms each year and varies in sample size across different survey years. EIs are only queried in 2015 and 2021 that consequently form the basis for our further investigation. In 2015 and 2021, more than 5000 firms responded to the written questionnaire. Every two years, a random sample of newly founded firms is included in the survey to replace those that have left the market through closures or mergers. The MIP provides crucial information on the introduction of new products, services, and processes, as well as expenses related to innovation and approaches to achieving economic success with new products, services, and improved processes. Furthermore, the MIP collects information on several competition-related matters, which enables the study of various topics in industrial economics (Gottschalk, 2021). As a contributor to the CIS, the questionnaire of the MIP is grounded in the harmonized CIS questionnaire for the respective survey year. Furthermore, it applies the standard definitions for innovation of the Oslo Manual (Peters & Rammer, 2013).

The MIP sample is a stratified random sample that covers enterprises with five or more employees from a wide area of economic activities. The stratification of the sample is based on sector, size class, and region. The number of cells within the sample varies annually due to modifications in the sector coverage and classification schemes. After the original sample was drawn in 1993 the incorporated sectors experienced several adjustments. While some sectors were included such as retail trade, sale and repair of motor vehicles, renting activities and various business-related services, others were excluded due to the small demand for analysis in these sectors. Since 2011 the sectors of the samples remained unchanged which allows a comparison of the years 2015 and 2021 without validity issues related to the sampling model. The current survey encompasses the following 21 sectors: (1) food/tobacco, (2) textiles, (3) wood/paper, (4) chemicals, (5) plastics, (6) glass/ceramics, (7) metals, (8) electrical equipment, (9) machinery, (10) retail/automobile, (11) furniture/toys/medical/technology/maintenance, (12) energy/water, (13) wholesale, (14) transport equipment/postal service, (15) media services, (16) it/telecommunications, (17) banking/insurance, (18) technical services/R&D services, (19) consulting/advertisement, (20) firm-related services and (21) mining. In addition to the random sample, the MIP intentionally addresses a supplementary sample of firms that have obtained public funding for their R&D and innovation initiatives. This specific group of companies was selected from a comprehensive roster of recipients of public R&D grants provided by the Federal Ministry of Education and Research in Germany. The fundamental objective of incorporating publicly funded firms is to establish a database that can be utilized for assessment purposes. However, these firms are not taken into consideration for weighting purposes, unless a publicly funded enterprise was selected through random sampling to participate in the MIP (Peters & Rammer, 2013). Over time, the sample size of the MIP has been increased "to compensate for a somewhat falling response rate, to allow for a more detailed sector breakdown of the sample and to increase the drawing quota (gross sample as a percentage of the total population)" (Peters & Rammer, 2013, p. 138).

The innovation panel data is used both for point-in-time-related analysis of EI as well as for analysing innovation behaviour over time. Innovation indicators derived from panel data can potentially exhibit greater robustness against arbitrary fluctuations stemming from changes in the surveyed firms' sample, in comparison to cross-sectional surveys that are conducted only at certain intervals (Peters & Rammer, 2013). This tendency is particularly evident when the panel firms become accustomed to the essential concepts of the questionnaire, and the respondents remain the same over a specific period (Peters & Rammer, 2013). Notably, the innovation indicators that stem from the MIP demonstrate a relatively consistent trajectory, although adjustments to the survey methodology may result in a discontinuity in the series which will be further discussed in chapter 9. For the following analysis, factually anonymized data sets in the form of scientific use files were received. The term "factually anonymized" denotes that the dataset has been modified to an extent where the identification of the participants in question can only be achieved through a substantial investment of time, money, and effort, as mandated by German law. In practice, scientific use files preclude the identification of either companies or individuals. Consequently, no inferences can be drawn regarding the performance of a specific company or individual. (Gottschalk, 2021).

The measure of EI should be exogenous to a firm's activities related to other innovation activities. The survey design achieves this goal by locally distancing the question for general innovation and EI. Questions related to general innovations are positioned at the beginning of the survey in sections 3&4 in 2015 and in section 5 in 2021. Conversely, questions pertaining to EIs are allocated to section 13 in 2015 and section 10 in 2021. This deliberate arrangement ensures independent responses from the participating companies. The questions developed for the MIP distinguish two broad areas of EI (PDEIs and PCEIs). They ask respondents to rate their engagement in each type of EI as a factor for the innovation's contribution to environmental protection, employing a simple dichotomous scale with three response options (see Figure 1). The section dedicated to PCEI comprises nine questions, while the section for PDEI consists of four questions, making the section for PCEI larger in size.

Figure 1 – Questions to capture eco-innovation in the MIP in 2015 and 2021

During the last three years, did your enterprise introduce innovations with any of the following environmental benefits?

	Contribution to environmental protection		
	Yes, significant	Yes, insignificant	No
Reduced energy use per unit of output	o	o	o
Reduced material use / use of water per unit of output	o	o	o
Reduced CO ‚footprint’ (total CO production)	o	o	o
Reduced air pollution (i.e. SOx, NOx)	o	o	o
Reduced water or soil pollution	o	o	o
Reduced noise pollution	o	o	o
Replaced fossil energy sources by renewable energy sources	o	o	o
Replaced materials by less hazardous substitutes	o	o	o
Recycled waste, water, or materials for own use or sale	o	o	o
Environmental benefits obtained during the use of your products/services			
Reduced energy use or CO_2 ‘footprint’[4]	o	o	o
Reduced air, water, soil or noise pollution	o	o	o
Facilitated recycling of product after use	o	o	o
Extended product life through longer-lasting, more durable products	o	o	o

[4] CO_2 ‘footpint’ is only part of the 2021 survey

4.2 Variables

4.2.1 Dependent Variables

Ecoinnovation: The dependent variable *Ecoinnovation* captures the innovation behavior of firms as a set of dummy variables. Accordingly, the first hypothesis is built on the variable *Ecoinnovation*. *Ecoinnovation* is assigned a value of one if a firm introduced at least one PDEI or PCEI between 2012-2014 for the 2015 dataset and 2018-2020 for the 2021 dataset, with four types of PDEI and nine types of PCEI distinguished. This classification is based on a standard question used widely in the literature to analyze environmental innovation activities in firms, as previously demonstrated by several scholars (Ghisetti et al., 2015; Horbach, 2016; Horbach et al., 2012; Marzucchi & Montresor, 2017). If firms report that the respective type of EI makes a significant and insignificant contribution to protecting the environment are they considered eco-innovators. The PDEI category comprises energypd (reduced energy use or CO_2 footprint during product use), emissionpd (reduced emissions during product use), recyclingpd (facilitated recycling of product after use), and lifetimepd (extended product life through longer-lasting, more durable products). PCEIs consist of energypc (reduced energy use per unit of output), matwaterpc (reduced material and water use per unit of output), CO_2pc (reduced CO_2 emissions from business operations), airpc (reduced other air emissions from business operations), watersoilpc (reduced water or soil pollution from business operations), noisepc (reduced noise pollution from business operations), renewablepc (substitution of fossil energy sources by renewables), dangsubstpc (substitution of dangerous substances), and recyclingpc (recycling of waste, water or materials).

Product Ecoinnovation and Process Ecoinnovation: For the second hypothesis we create a subsection of *Ecoinnovation* by distinguishing PDEIs and PCEIs. The resulting variables *Product Ecoinnovation* and *Process Ecoinnovation* are based on the same data source as *Ecoinnovation* which encompasses companies that performed at least one respective type of innovation between 2018 and 2020. Both indicators are measured as dummy variables with number value one representing a positive reply. In accordance with the previous methodological approach innovations that exhibit a significant and insignificant contribution to protecting the environment are considered as PDEI and PCEI.

Nonecoinnovation: To assess innovation activities other than EI, we utilize the variable *Nonecoinnovation*. In instances where a firm has executed at least one NEI, but no significant EIs, it is classified as such. It serves as a counterpart to *Ecoinnovation*. Notably, it is important to bear in mind that the definition of PCI varies between the 2015 and 2021 datasets. As previously discussed in chapter 2.3.3, the revised definition encompasses business process innovations pertaining to novel or refined organizational and marketing methods[5].

Product Nonecoinnovation and Process Nonecoinnovation: The mirrored version of PDEI/PCEI. The variables *Product Nonecoinnovation* and *Process Nonecoinnovation* are based on the same data source as *Nonecoinnovation*. In accordance with the previous methodological approach explained for *Nonecoinnovation* the variable *Product Nonecoinnovation* encompasses firms that have executed at least one PDNEI, but no PDEIs. The same logic applies to *Process Nonecoinnovation*. The variables are binary. It is important to mention that the MIP changed the definitions of PDI and PCI in the survey expanding the range of considerable answers.

All Innovation: The variable *All Innovation* is a dummy variable. It denotes firms that have implemented any form of innovation including EIs. Thus, it is a combination of the aforementioned *Ecoinnovation* and *NonEcoinnovation*.

4.2.2 Independent Variable

Cooperation: The independent variable *Cooperation* indicates the cooperation activities of a firm for the last three years. A binary distinction is made between firms that engaged in cooperation and those that did not. Innovation co-operation is the process of actively engaging in collaborative innovation activities with other firms or institutions, with the mutual goal of advancing innovation efforts. It should be noted that such cooperation need not necessarily result in immediate commercial benefits for both partners and that it excludes mere contracting out of work without active participation and cooperation.

[5] More information in Appendix 2

4.2.3 Control Variables

Size: Several studies provide evidence that the size of a company has an impact on EIs (Hansen & Klewitz, 2012; Horbach, 2008; Schiederig et al., 2012). We measure a firm's size in terms of the enterprise's average number of employees (including marginally employed persons) over the last three years at the time of the survey. The categories are divided into three sections: 1=<50 employees, 2=50-249 employees, 3=250 employees.

Cost: Cost-leadership is an important driver of EI initially identified by Demiral & Kesidou (2011). The motivation to pursue EI due to cost advantages was later confirmed by multiple scholars (Horbach et al., 2012; Pereira & Vence, 2012; Triguero et al., 2013). By definition, EI aims to reduce the use of natural resources such as materials, energy and water. As a consequence, a firm lowers the costs of raw materials and energy through EI. The importance of costs for raw materials and energy is quantified by means of a scale ranging from 0 to 3, where 0 denotes negligible importance, 1 denotes low significance, 2 denotes moderate significance, and 3 denotes high significance, with respect to the impact of the escalation in energy and raw material prices.

Regulation: According to various studies, environmental regulations are a significant driver of EI. Legal requirements aimed at protecting the environment can encourage companies to develop innovative products and processes that are environmentally friendly. The studies conducted by Doran and Ryan (2012), Horbach et al. (2012), and Wagner and Llerena (2011) provide evidence to support this notion. We measure how important the fulfilment of legal requirements is for a certain company with numerical values ranging from 0 to 3. These values indicate the level of significance with 0 representing a negligible level of importance, while 1 signifies a low level of importance, a value of 2 suggests a moderate level of importance, and 3 indicates a high level of importance.

Subsidies: The availability of financing is considered a key driver of EIs (Cuerva et al., 2014). In their study on financing environmental innovation Johnson and Lybecker (2012) point out the significant role of public funding for the development of EI. The importance of public financial support is captured by a ranking from 0 to 3. A value of 0 equals no importance, a value of 1 minor, a value of 2 middle and a value of 3 high importance.

Competition: Competitive pressure has various origins (Clark, 2005). Therefore, we compile multiple competition variables of the MIP to create a holistic approach to market pressure. The variable is a sum of six market aspects that are responsible for external pressure. Firstly, (1) the rapid obsolescence of products and services and secondly (2) the ease with which competitors' products can substitute one's own products create external pressure. In addition, (3) the high threat of new competitors entering the market can be a source of competition, as well as (4) the unpredictable actions of competitors and (5) the prevalence of cut-throat competition in their relationships. Finally, (6) the fact that an increase in prices can result in a direct loss of customers poses a significant competitive challenge. All categories are measured by how often companies are exposed to a certain situation. The scale ranges from 0 (not the case), 1 (sometimes be the case), 2 (often be the case) to 3 (always be the case). In order to obtain the final composite variable, the individual categories are summed up, resulting in a numerical scale ranging from 0 to 18. A higher value on this scale reflects a correspondingly greater degree of competitive pressure within the market under consideration.

R&D: R&D can drive sustainability improvements and trigger environmental innovations (Blum-Kusterer & Hussain, 2001; Horbach, 2008; Segarra et al., 2011). Therefore, we create a dummy variable indicating whether a company conducts R&D activities or not.

Reputation: A green reputation can lead to a competitive advantage and thus motivate companies to conduct EI initiatives (Tsai, 2002). Our study quantifies the degree to which enhancing a company's reputation influences its ability to innovate, employing a four-point scale to measure the level of significance (ranging from 0, denoting no importance, to 3, indicating a highly important factor).

Academics: Several scholars highlight the importance of highly qualified personnel engaging in EIs (Horbach, 2014b; Pfeiffer & Rennings, 2001). To capture this driver of EI we measure for the respective year the proportion of all employees who have a university degree or other higher education qualification such as a degree from a university of applied science and a university of cooperative education. Due to data protection and confidentiality the dataset of MIP is anonymised before the use of external academic purposes. The variable of the proportion of academics underwent a grouping process which we will adopt. Instead of a value, a range is quoted within which the value for the proportion of highly educated employees lies (indicated by an ordinal variable). The grouping structure is as follows:

Figure 2 – Ordinal value range of academics in the MIP

Value given	0	1	2	3	4	5	6	7	8
Range of values in %	0	<5	<10	<15	<20	<30	<50	<75	≤100

Demand: Horbach and Rammer (2022) find indication that companies experiencing a high level of market demand for eco-friendly products are likely to respond by engaging in innovation. The variable is measured on a four-point scale, with respondents indicating the extent to which their companies face an increasing demand for products and services with positive impacts on climate protection. The applied rating scale ranges from 0 (none) to 3 (high). Given the novelty of this aspect of EI, the variable has been included only in the 2021 dataset and thus is only examined in the analysis of the respective year.

Export: The growing interest in the role of exports in driving EI is reflected in the control variable *Export* (Galbreath et al., 2021; Shahzad et al., 2020; Tang et al., 2017). To distinguish between firms that export and those that do not, we use a binary dummy variable where "1" represents exporters and "0" represents non-exporters. The reference year when the export activities are conducted is the year of the respective survey.

Year21: We address temporal variations in the combined dataset by including a dummy variable indication the year with 0 (=2015) and 1 (=2021).

4.3 Models

Based on the above elaborations, our final database encompasses firm-level data from various industries in Germany and facilitates projections for the German firm population. The database consists of three components: the 2015 dataset, the 2021 dataset, and a combined dataset incorporating data from both 2015 and 2021. The unit of analysis is the firm level. The datasets comprise information on whether a firm engages in EI, as well as its overall innovation activities. A further distinction is made between PDEI and PCEI. Additionally, information on a firm's cooperation behavior is included, along with measures of the competitive environment, regulatory factors related to environmental protection, the firm's exposure to rising raw material costs, and the firm's reputational concerns regarding eco-friendly behavior. Moreover, the datasets provide information on subsidies received by companies, their general R&D activities, and export behavior. Furthermore, the dataset contains information on the company's size and the proportion of highly educated personnel. The 2021 dataset possesses an extra component depicting the demand for eco-friendly products by customers. And finally, the combined dataset also includes a year variable.

Given that all dependent variables are binary, probit models are applied. For each innovation activity, the firm decides whether to undertake a specific innovation (Y = 1) or not (Y = 0). Firms i are affected by *Cooperation* and by different types *k* of innovations (*Ecoinnovation, All Innovation, Product Ecoinnovationn and Process Ecoinnovation*) while taking into account other factors driving firms' decision to innovate (x). Drawing from theoretical considerations, control variables are summarized by a vector x (*Size, Export, Competition, Regulation, Subsidies, Reputation, Cost, Academics, R&D, Demand*[6] *and Year21*[7]) which may influence a firm's decision to innovate. Therefore, we estimate the probability Prob(Y = 1| x) = F(x, β), where the β parameters represent the impact of changes in x on this probability (Greene, 2008, p. 772).

General probit regression model:

$$inn_{k,i} = f\,(Cooperation_i,\ \boldsymbol{x}_i)$$

The general regression model is adapted to examine the particular relationships of the individual hypotheses.

Probit regression model for testing Hypothesis 1:

$$\begin{aligned} Ecoinnovation_i = {} & \\ & f\,(\beta 0 + \beta 1\ Cooperation + \beta 2\ Size + \beta 3\ Export + \beta 4\ Competition + \\ & \beta 5\ Regulation + \beta 6\ Subsidies + \beta 7\ Reputation + \beta 8\ Cost + \\ & \beta 9\ Academics + \beta 10\ R\&D + \beta 11\ Demand^{8} + \beta 12\ Year^{9}) \end{aligned}$$

[6] Only for the 2021 dataset
[7] Only for the combined dataset
[8] Only for the 2021 dataset
[9] Only for the combined dataset

Probit regression model for testing Hypothesis 2:

$$Product\ Ecoinnovation_i =$$

$$f\,(\beta 0 + \beta 1\ Cooperation + \beta 2\ Size + \beta 3\ Export + \beta 4\ Competition + \beta 5\ Regulation + \beta 6\ Subsidies + \beta 7\ Reputation + \beta 8\ Cost + \beta 9\ Academics + \beta 10\ R\&D + \beta 11\ Demand^{10} + \beta 12\ Year^{11})$$

Probit regression model for testing Hypothesis 3:

$$Process\ Ecoinnovation_i =$$

$$f\,(\beta 0 + \beta 1\ Cooperation + \beta 2\ Size + \beta 3\ Export + \beta 4\ Competition + \beta 5\ Regulation + \beta 6\ Subsidies + \beta 7\ Reputation + \beta 8\ Cost + \beta 9\ Academics + \beta 10\ R\&D + \beta 11\ Demand^{12} + \beta 12\ Year^{13})$$

5 Descriptive Analysis

5.1 Data Structure[14]

For our study, we utilize data obtained from the MIP for the years 2015 and 2021. The combined sample comprises a total of 10,528 observations, with 5,445 observations recorded in 2015 and 5,083 observations in 2021. In the subsequent section, we provide a detailed description of the data structure of the combined dataset. The combined database reveals that more than half of the surveyed companies can be classified as innovators, accounting for 54.6% of the sample. However, the distribution is almost evenly split between innovators and non-innovators. Eco-innovators account for a group of 31.53% of the whole dataset with leads to the conclusion that a significant share of the German firm population already engages in innovation with a significant contribution to environmental protection.

Among the group of innovators, 57.75% are specifically categorized as eco-innovators, while noneco-innovators make up the minority at 43.15%. These findings suggest that companies exhibit an environmental consciousness and consider eco-friendly factors during the innovation process. Examining the results

[10] Only for the 2021 dataset
[11] Only for the combined dataset
[12] Only for the 2021 dataset
[13] Only for the combined dataset
[14] Please note that the values do not necessarily add up to 100% due to invalid responses and cross-sectional activities of the respondents that are not mutually exclusive , e.g. a respondent can perform product innovation and process innovation simultaneously by what the summed percentage exceeds the percentage of the respective type of innovation.

of the EI questions, it is evident that 20.17% of all firms within the survey's target population are product eco-innovators whereat 29.48% are process eco-innovators indicating a higher proportion of process eco-innovators compared to product eco-innovators. Within the different groups of innovation, PCI has a higher value than PDI, particularly within the realm of EI, accounting for 93.49% of reported eco-innovators that perform PCI. PDI, on the other hand, constitutes 63.95%. Interestingly, the results from Figure 3 indicate that when companies engage in innovation, they tend to pursue both product and process innovation simultaneously.

By dividing the different types of innovation into cooperators and non-cooperators, a consistent pattern emerges. Figure 4 showcases that companies primarily engage in innovation independently across all categories. This structure remains consistent across different categories, with over 80% of respondents classified as non-cooperators in each section (All Innovation: 81.63%, EI: 87.22%, and NEI: 87.74%), suggesting a slight but statistically insignificant inclination towards EIs. As a consequence, it can be said that companies that innovate tend not to be cooperators. However, once the innovators are compared to companies that do not innovate at all, only 2.47% of non-innovators exhibit cooperative behaviour, whereas, among innovators, the percentage of cooperators is significantly higher with 18.37% (All Innovation), 12.78% (EI) and 12.26% (NEI).[15] Conclusively, innovators demonstrate a greater propensity for cooperative behaviour compared to non-innovators. A significant difference between EI and NEI is not observable in the data structure.

[15] Differences in proportions between All Innovation and EI as well as NEI can be explained by the influence of invalid answers of the question on EI as described in chapter 4.1. Therefore, the proportion of cooperators among both, EI and NEI, appears to be smaller than the proportion among All Innovation. Nonetheless, the overall pattern remains consistent and does not affect the validity of the study.

Figure 3 – Share of firms reporting different types of innovation for process- and product innovators

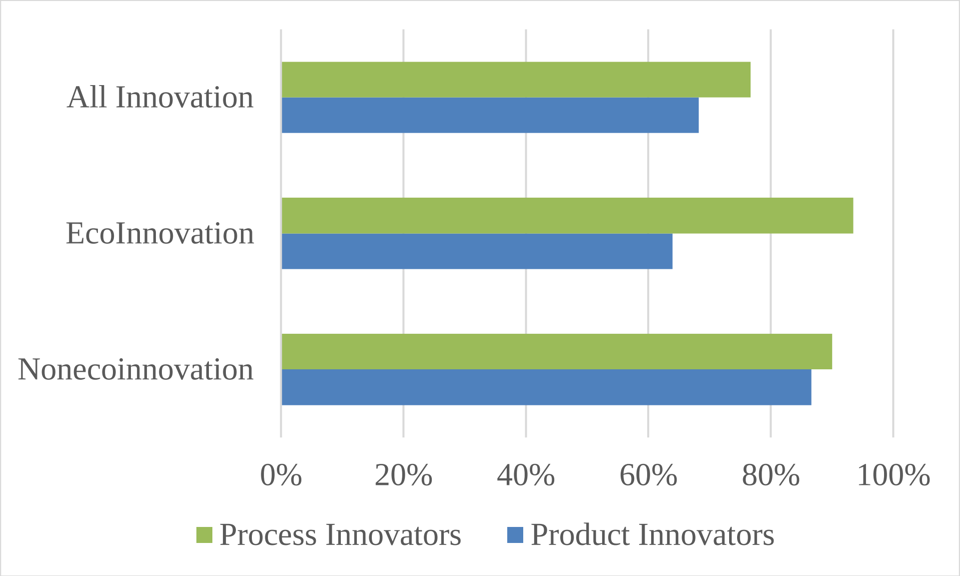
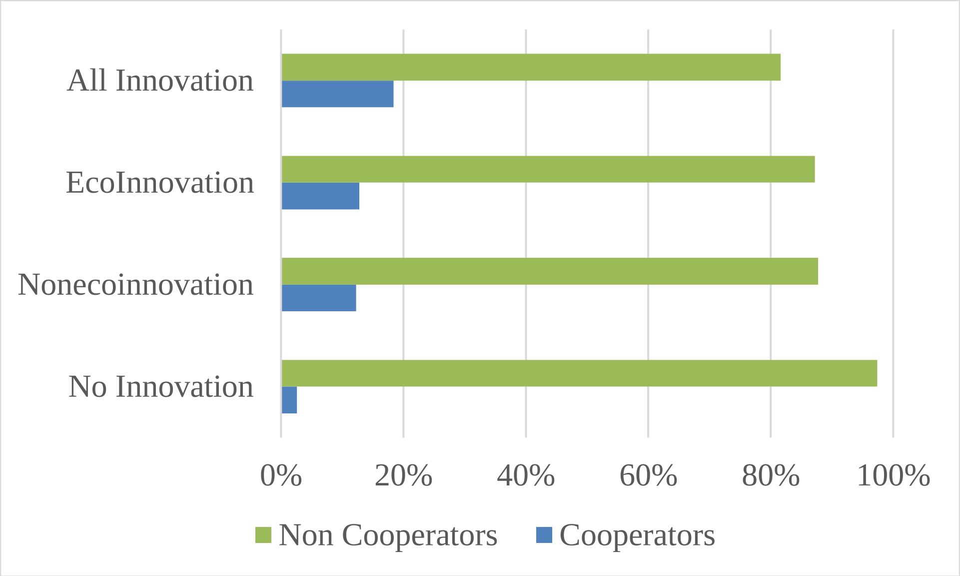


Figure 4 – Share of firms reporting different types of innovation for cooperators and non-cooperators



5.2 Descriptive Statistics

The following section showcases the descriptive statistics of the aforementioned variables, shedding light on their individual characteristics. A comprehensive statistical summary of all variables for Hypothesis 1 is found in Table 2, for Hypothesis 2 in Table 3 and for Hypothesis 3 in Table 4. It contains the statistical summary providing insights into their individual characteristics and a correlation matrix that unveils the interconnections and relationships among these variables based on the combined dataset, incorporating input from both 2015 and 2021. The descriptive analysis of distinctive characteristics and distributions of the variables in each respective year can be found in Appendix 3-5, alongside separate correlation matrices of the combined dataset dedicated to the other dependent variables which are applied for comparison in the econometric analysis in Appendix 6. This approach allows to provide a comprehensive understanding of the interrelationships and associations specific to each variable.

The analysis of the statistical summary yields four noteworthy observations. The first point to highlight is the number of valid datapoints among the number of observations. As mentioned before the combined database comprises a total of 10,528 observations. However, for the specific analyses of each hypothesis, the number of utilizable data points is significantly lower with: 5,044 (Hypothesis 1), 5,300 (Hypothesis 2) and 5,210 (Hypothesis 3). The phenomenon of careless or insufficient effort in responding is common, but may not affect the validity of the database after examining the correlation of the control variable for invalid data points (Curran, 2016). We observe no significant difference in the relationships among the variables strengthening the eligibility of the analyzed datasets. The second observation indicates that on average, companies tend not to engage in PDEI activities due to its low mean value of 0.282 (s.d.: 0.450). A comparable pattern is not evident for the other two dependent variables EI (mean: 0.473, s.d.: 0.499) and PCEI (mean: 0.426, s.d.: 0.495). Thirdly, it is important to note that the examined companies show a low engagement in *Cooperation* (mean: 0.115/0.118/0.117)[16] and *Subsidies* (mean: 0.514/0.521/0.515)[17] as well as moderately low *R&D* activities (mean: 0.285/286/289)[18]. Finally, in Table 2, the mean value of *Competition* appears to be low with 4.631 (s.d.: 3.681)[19] complementing a maximum of 18. However, due to the nature of this variable, the shown distribution does not necessarily indicate a low competitive environment. The variable is a sum of market aspects that are responsible for external pressure whereat a single factor constitutes a maximum of 3. Thus, a low accumulated number of 3 or higher can already relate to a highly competitive environment. The correlation matrices of Tables 2 to 4 show that the majority of the variables employed do not exhibit high correlations, but capture the different factors of each hypothesis successfully. We

[16] The numbers correspond to Table 2 to Table 4 in consecutive order
[17] The numbers correspond to Table 2 to Table 4 in consecutive order
[18] The numbers correspond to Table 2 to Table 4 in consecutive order
[19] Accordingly observed in Table 3 (mean: 4.614, s.d: 3.681) and Table 4 (mean: 4.625, s.d: 3.678)

stress that all three tables solely report pairwise correlations and thus ignore any potential impact of the other variables, which might result in some misleading correlations. For example, it should be noted that the correlation tables indicate negative correlations between *Competition* and each of the three dependent variables EI, PDEI, and PCEI. These negative correlations might not persist when accounting for the effects of the selected control variables. In order to test the robustness of this relationship, further analysis is required to assess the potential influence of other control variables. Moreover, we observe in all three tables moderately high correlations of the variable *Regulation* with the variables *Subsidies* (r=0.524, r=0.528, r=0.518), *Reputation* (r=0.524, r=0.529, r=0.525) and *Cost* (r=0.596, r=0.594, r=0.596)[20]. A further moderately high correlation can be noticed for the relationship between *Reputation* and *Cost* (r=0.556 (Table 2-4)).

Considering the identified moderate correlations, as well as the potential existence of other correlations, we proceed to compute the Variance Inflation Factors (VIFs) for all variables (see Table 1). This diagnostic analysis is conducted to assess the presence of potential multicollinearity among the variables. The VIFs for Hypotheses 1 and 2 range from 1.08 to 2.11, while for Hypothesis 3, there is a slight variation with a range of 1.08 to 2.12. All three hypotheses constitute a mean VIF of 1.59 as shown in Table 1. The mean value falls significantly below the moderate threshold of 5 as well as the critical threshold of 10, indicating that the level of correlation among the explanatory variables remains within an acceptable range (Bhandari, 2023). This suggests that we can reliably evaluate the individual contributions of each predictor in our three models.

Table 1 – Variance inflation factors for Hypothesis 1, 2 and 3

	Hyp 1		Hyp 2		Hyp 3	
Variable	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
Competition	2.11	0.473	2.11	0.475	2.12	0.471
Year	2.10	0.476	2.10	0.476	2.11	0.473
Cost	1.86	0.538	1.87	0.536	1.86	0.539
Regulation	1.85	0.540	1.85	0.540	1.85	0.541
Reputation	1.73	0.577	1.74	0.575	1.73	0.576
Subsidies	1.56	0.640	1.57	0.639	1.54	0.647
R&D	1.48	0.674	1.49	0.673	1.48	0.674
Export	1.28	0.784	1.28	0.779	1.28	0.782
Cooperation	1.27	0.785	1.27	0.785	1.27	0.788
Size	1.14	0.880	1.14	0.876	1.14	0.879
Academics	1.08	0.923	1.08	0.922	1.08	0.923
Mean VIF	1.59		1.59		1.59	

[20] The numbers correspond to Table 2 to Table 4 in consecutive order

Table 2 – Summary statistics and correlation matrix for Ecoinnovation in the combined dataset (Hypothesis 1)

	Variable	Obs	Mean	Std. dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Ecoinnovation	5,044	0.473	0.499	0	1	1.000											
2	Cooperation	5,044	0.115	0.319	0	1	0.142	1.000										
3	Size	5,044	1.419	0.636	1	3	0.148	0.134	1.000									
4	Export	5,044	0.435	0.496	0	1	0.174	0.216	0.256	1.000								
5	Regulation	5,044	1.009	1.333	0	3	0.156	0.093	0.201	0.153	1.000							
6	Competition	5,044	4.631	3.681	0	18	-0.224	-0.064	-0.004	0.043	0.167	1.000						
7	Subsidies	5,044	0.514	0.991	0	3	0.089	0.108	0.109	0.126	0.524	0.140	1.000					
8	Reputation	5,044	0.844	1.212	0	3	0.187	0.139	0.215	0.203	0.524	0.158	0.488	1.000				
9	Cost	5,044	1.263	1.384	0	3	0.238	0.117	0.176	0.199	0.596	0.161	0.485	0.556	1.000			
10	Academics	5,044	3.092	2.620	0	8	-0.006	0.185	-0.016	0.072	-0.037	-0.039	-0.022	0.021	-0.063	1.000		
11	R&D	5,044	0.285	0.451	0	1	0.154	0.431	0.225	0.388	0.181	0.065	0.123	0.249	0.189	0.215	1.000	
12	Year21	5,044	0.451	0.498	0	1	-0.345	-0.119	-0.050	-0.106	0.109	0.708	0.100	0.084	0.077	-0.012	-0.019	1.000

Table 3 – Summary statistics and correlation matrix for Product Ecoinnovation in the combined dataset (Hypothesis 2)

	Variable	Obs	Mean	Std. dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Product Ecoinnovation	5,300	0.282	0.450	0	1	1.000											
2	Cooperation	5,300	0.118	0.323	0	1	0.163	1.000										
3	Size	5,300	1.423	0.638	1	3	0.109	0.136	1.000									
4	Export	5,300	0.437	0.496	0	1	0.145	0.216	0.259	1.000								
5	Regulation	5,300	1.018	1.336	0	3	0.178	0.099	0.207	0.158	1.000							
6	Competition	5,300	4.614	3.681	0	18	-0.121	-0.070	-0.013	0.039	0.157	1.000						
7	Subsidies	5,300	0.521	0.994	0	3	0.121	0.108	0.111	0.129	0.528	0.134	1.000					
8	Reputation	5,300	0.857	1.216	0	3	0.215	0.144	0.219	0.207	0.529	0.151	0.488	1.000				
9	Cost	5,300	1.284	1.388	0	3	0.222	0.124	0.184	0.203	0.594	0.151	0.482	0.556	1.000			
10	Academics	5,300	3.097	2.616	0	8	0.031	0.189	-0.016	0.074	-0.036	-0.038	-0.022	0.021	-0.066	1.000		
11	R&D	5,300	0.286	0.452	0	1	0.173	0.436	0.224	0.387	0.185	0.058	0.122	0.249	0.191	0.215	1.000	
12	Year21	5,300	0.449	0.497	0	1	-0.202	-0.127	-0.062	-0.109	0.098	0.708	0.092	0.075	0.066	-0.013	-0.028	1.000

Table 4 – Summary statistics and correlation matrix for Process Ecoinnovation in the combined dataset (Hypothesis 3)

	Variable	Obs	Mean	Std. dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Process Ecoinnovation	5,210	0.426	0.495	0	1	1.000											
2	Cooperation	5,210	0.117	0.321	0	1	0.133	1.000										
3	Size	5,210	1.426	0.641	1	3	0.157	0.137	1.000									
4	Export	5,210	0.436	0.496	0	1	0.177	0.222	0.255	1.000								
5	Regulation	5,210	1.018	1.336	0	3	0.147	0.095	0.199	0.158	1.000							
6	Competition	5,210	4.625	3.678	0	18	-0.240	-0.064	-0.007	0.042	0.167	1.000						
7	Subsidies	5,210	0.515	0.991	0	3	0.082	0.105	0.110	0.128	0.518	0.140	1.000					
8	Reputation	5,210	0.854	1.217	0	3	0.173	0.145	0.217	0.208	0.525	0.153	0.484	1.000				
9	Cost	5,210	1.273	1.385	0	3	0.238	0.118	0.174	0.199	0.596	0.160	0.479	0.556	1.000			
10	Academics	5,210	3.101	2.617	0	8	-0.029	0.183	-0.017	0.072	-0.041	-0.043	-0.027	0.018	-0.067	1.000		
11	R&D	5,210	0.289	0.453	0	1	0.148	0.427	0.231	0.392	0.187	0.063	0.122	0.254	0.190	0.213	1.000	
12	Year21	5,210	0.450	0.497	0	1	-0.364	-0.123	-0.053	-0.108	0.109	0.709	0.101	0.079	0.076	-0.014	-0.022	1.000

6 Econometric Analysis

6.1 Main Analysis

All regression models are run in version 17 of the statistical software STATA. Due to the binary nature of all dependent variables and the independent variable *Cooperation* probit regression models are applied and analysed (see chapter 4.3). To ensure robustness, we investigate the model's performance using distinct datasets from the years 2015 and 2021, as well as a combined dataset that incorporates data from both years. By utilizing multiple datasets, we aim to capture the temporal dynamics and variations in the relationship between *Cooperation* and *Ecoinnovation*, *Product Ecoinnovation* as well as *Process Ecoinnovation*, thereby providing a comprehensive understanding of these associations.

6.1.1 Analysis Hypothesis 1

The regression model for Hypothesis 1 examines the relationship between *Ecoinnovation* and the independent variable *Cooperation* while also considering the impact of identified control variables (see chapter 4.2). Table 5 provides a detailed overview of the model used to test Hypothesis 1 as well as the corresponding outcomes derived from the investigation. Firstly, the model is tested for the marginal influence of *Cooperation* on *Ecoinnovation.* In the second step, the dependent variables *All Innovation* and *Nonecoinnovation* are studied by applying the same model as in step one in order to enable a further comparison of the different types of innovation.

In the combined dataset we find a positive and highly significant relationship ($p<0.01$) between *Cooperation* and *Ecoinnovation* ($\beta=0.182$, s.d.=0.070). Consequently, when *Cooperation* increases from 0 to 1 the z-score of *Ecoinnovation* increases by 18.2%. This positive effect leads to the conclusion that there is proof for the reinforcing relationship between *Cooperation* and *Ecoinnovation*. The chosen regression model demonstrates a satisfactory level of fit, with an overall R^2 value of 16.8%, indicating a reasonable degree of explanatory power. The empirical findings support Hypothesis 1, affirming the positive relationship between Cooperation and EI. Thus, it can be concluded that *Cooperation* plays a significant role in fostering and advancing *Ecoinnovation*.

Table 5 – Probit regression results: influence of Cooperation on Ecoinnovation (Hypothesis 1)

	Ecoinnovation		
DATASET	Combined	2015	2021
Cooperation	0.182***	0.191*	0.040
	(0.070)	(0.108)	(0.110)
Size	0.127***	0.221***	-0.117**
	(0.032)	(0.049)	(0.058)
Export	0.139***	0.195***	-0.040
	(0.043)	(0.060)	(0.074)
Competition	-0.018**	0.027	0.130***
	(0.008)	(0.036)	(0.046)
Regulation	0.034	0.101***	-0.088*
	(0.023)	(0.036)	(0.048)
Subsidies	-0.107***	-0.156***	0.148**
	(0.031)	(0.055)	(0.067)
Reputation	0.134***	0.287***	-0.169***
	(0.027)	(0.047)	(0.059)
Cost	0.252***	0.498***	-0.286***
	(0.023)	(0.036)	(0.047)
Academics	-0.011	-0.033***	0.056***
	(0.008)	(0.011)	(0.013)
R&D	0.177***	0.503***	0.298***
	(0.052)	(0.083)	(0.092)
Year21	-0.914***		
	(0.056)		
Constant	-0.186***	-0.710***	-1.348***
	(0.058)	(0.113)	(0.142)
Observations	5,044	2,767	2,767

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

However, when considering each year individually the results are not as clear. Despite the fact that the positive nature of the marginal effects is evident across all three datasets there exists a discernible variability in their significance. In 2015 the β for *Cooperation* is 0.191 (s.d.=0.108) but is moderately significant for $p<0.1$ and in 2021 the β for *Cooperation* is 0.040 (s.d.=0.110) and is not significant. Therefore, we conclude that the effect of *Cooperation* on *Ecoinnovation* in the combined analysis is mainly driven by data from 2015.

The analysis of all three datasets reveals consistent evidence supporting the notion that *Cooperation* positively influences *Ecoinnovation*. Nevertheless, it is important to note that while the results provide support for this relationship, some degree of ambiguity persists caused by deviation in the different years necessitating additional exploration and refinement. Further investigation shows the strong negative effect of *Year21* (β=-0.914, s.d.=0.056) on *Ecoinnovation* with a high significance of $p<0.01$ and hence reveals a large proportion of ecoinnovators in the

2015 dataset. A decrease in the proportion of ecoinnovators can be observed from the years 2015 to 2021, which might be caused by the expansion of the definition for the innovation variables of the MIP in 2019. A discussion of this development is elucidated in more detail in chapter 9.

Table 6 – Probit regression results: influence of Cooperation on All Innovation and Nonecoinnovation

	Combined		2015		2021	
VARIABLES	(1)	(2)	(1)	(2)	(1)	(2)
Cooperation	0.575***	0.072	0.574***	0.040	0.430***	0.317***
	(0.070)	(0.071)	(0.089)	(0.110)	(0.119)	(0.109)
Size	0.114***	-0.037	0.065	-0.117**	0.160***	0.011
	(0.030)	(0.035)	(0.040)	(0.058)	(0.046)	(0.048)
Export	0.132***	-0.003	0.185***	-0.040	0.053	0.034
	(0.039)	(0.047)	(0.053)	(0.074)	(0.059)	(0.064)
Competition	0.036***	0.038***	0.108***	0.130***	0.034***	0.021***
	(0.007)	(0.007)	(0.032)	(0.046)	(0.007)	(0.008)
Regulation	-0.005	-0.020	-0.011	-0.088*	0.005	-0.009
	(0.021)	(0.025)	(0.029)	(0.048)	(0.031)	(0.033)
Subsidies	-0.034	0.088***	-0.052	0.148**	-0.010	0.059
	(0.028)	(0.033)	(0.040)	(0.067)	(0.040)	(0.041)
Reputation	0.173***	0.010	0.129***	-0.169***	0.191***	0.073*
	(0.025)	(0.029)	(0.035)	(0.059)	(0.037)	(0.038)
Cost	0.065***	-0.114***	0.117***	-0.286***	-0.003	-0.004
	(0.021)	(0.025)	(0.028)	(0.047)	(0.031)	(0.033)
Academics	0.057***	0.041***	0.052***	0.056***	0.063***	0.039***
	(0.007)	(0.008)	(0.010)	(0.013)	(0.010)	(0.011)
R&D	0.897***	0.375***	1.063***	0.298***	0.716***	0.432***
	(0.048)	(0.054)	(0.068)	(0.092)	(0.069)	(0.070)
Demand					0.069***	0.042*
					(0.023)	(0.025)
Year21	0.167***	0.897***				
	(0.050)	(0.058)				
Constant	-1.001***	-1.464***	-1.156***	-1.348***	-0.864***	-0.768***
	(0.057)	(0.067)	(0.102)	(0.142)	(0.090)	(0.097)
Observations	6,042	5,044	3,179	2,767	2,850	2,264

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

All Innovation (1)
Noneconinnovation (2)

Looking at the combined data from Table 6, a strong and highly significant positive effect of *Cooperation* on *All Innovation* can be found. Specifically, when *Cooperation* increases from 0 to 1 the z-score of *All Innovation* increases by 57.5%. Analogous high significant and substantial impacts can be observed in both the 2015 dataset (β=0.574, s.d.=0.089, p<0.01) and the 2021 dataset (β=0.430, s.d.=0.119, p<0.01) which is to be expected from previous literature, since cooperation is important for the development of innovation in general (Chesbrough, 2003; Teece, 1992). The consistent patterns observed in the relationships between *Cooperation* and both *Innovation* and *Ecoinnovation* lend support to the notion that analogous effects are at play. This finding substantiates the proposition that insights derived from the study of cooperation and innovation can be extended to the realm of *Cooperation* and *Ecoinnovation*.

Moreover, *Nonecoinnovation* is not significantly affected by *Cooperation* in the combined dataset which stands in contrast to the significant influence of *Cooperation* on *Ecoinnovation*. These findings lead to the conclusion that *Cooperation* is more significant for *Ecoinnovation* than *Nonecoinnovation*. The same pattern is observable in the 2015 dataset and thus confirms this finding. Conversely, it is imperative to take into account that the opposite peculiarity is displayed in the 2021 dataset. *Cooperation* has no significant effect on *Ecoinnovation*, but it is highly significant ($p<0.01$) for *Nonecoinnovation* ($\beta=0.317$, s.d.=0.109). Consequently, the available evidence does not provide a distinct result. Regarding the control variables the analysis of the combined dataset reveals consistent findings with prior research, as *Size, Export, Reputation, Cost*, and *R&D* exhibit positive and highly significant effects ($p<0.01$) on *Ecoinnovation* (Demirel & Kesidou, 2011; Doran & Ryan, 2012; Horbach et al., 2012; Tsai, 2002). Surprisingly, *Competition* and *Subsidies* demonstrate negative impacts on *Ecoinnovation*, with statistical significance ($p<0.05$ and $p<0.01$, respectively). However, when comparing the results with the 2015 dataset, notable differences emerge, particularly in the significance and direction of the effects on *Competition*, *Regulation*, and *Academics*. The 2021 dataset diverges significantly from prior research, as only *Reputation* retains a significant effect on *Ecoinnovation*, contrary to the findings of previous scholars (Horbach & Rammer, 2022). For a further discussion of the control variables, we refer to Appendix 7.

6.1.2 Analysis Hypothesis 2

For Hypothesis 2 the probit regression model tests the relationship between *Product Ecoinnovation* and the independent variable *Cooperation.* Simultaneously, all pertinent control variables that have been identified are taken into consideration during the analysis (see chapter 4.2). Consecutively, we compare the effects of *Cooperation* on *Product Ecoinnovation* with the effect of *Cooperation* on *Product*

Nonecoinnovation. Our findings for Hypothesis 2 are reported in Table 7. The model is subject to examination using distinct datasets from the years 2015, 2021, and a combined dataset incorporating both years.

Table 7 – Probit regression results: influence of Cooperation on Product Ecoinnovation and Product Nonecoinnovation

	Combined		2015		2021	
VARIABLES	(1)	(2)	(1)	(2)	(1)	(2)
Cooperation	0.243***	0.066	0.205**	0.040	-0.016	0.274**
	(0.064)	(0.064)	(0.082)	(0.083)	(0.120)	(0.107)
Size	0.019	-0.021	-0.017	-0.006	0.051	-0.036
	(0.031)	(0.033)	(0.041)	(0.044)	(0.053)	(0.052)
Export	0.082*	0.076*	0.134**	0.105*	-0.019	0.028
	(0.043)	(0.046)	(0.057)	(0.062)	(0.070)	(0.069)
Competition	-0.008	0.037***	0.060*	0.083**	0.013	0.024***
	(0.008)	(0.008)	(0.035)	(0.038)	(0.009)	(0.009)
Regulation	0.060***	-0.041*	0.105***	-0.039	0.016	-0.064*
	(0.022)	(0.024)	(0.028)	(0.033)	(0.037)	(0.036)
Subsidies	-0.039	-0.009	0.015	-0.083*	-0.085*	0.029
	(0.029)	(0.031)	(0.039)	(0.048)	(0.047)	(0.044)
Reputation	0.155***	0.070**	0.235***	-0.042	0.090**	0.141***
	(0.025)	(0.027)	(0.034)	(0.039)	(0.042)	(0.040)
Cost	0.143***	-0.076***	0.235***	-0.086***	-0.032	-0.042
	(0.022)	(0.024)	(0.028)	(0.032)	(0.037)	(0.036)
Academics	0.003	0.050***	0.002	0.044***	-0.006	0.063***
	(0.008)	(0.008)	(0.011)	(0.011)	(0.012)	(0.012)
R&D	0.207***	0.612***	0.399***	0.550***	0.015	0.688***
	(0.050)	(0.050)	(0.068)	(0.072)	(0.078)	(0.072)
Demand					-0.022	0.097***
					(0.028)	(0.027)
Year21	-0.539***	0.080				
	(0.059)	(0.061)				
Constant	-0.810***	-1.326***	-1.216***	-1.316***	-1.031***	-1.417***
	(0.060)	(0.064)	(0.108)	(0.117)	(0.105)	(0.108)
Observations	5,300	5,300	2,918	2,918	2,369	2,369

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Product Ecoinnovation (1)
Product Nonecoinnovation (2)

In the combined dataset a positive and significant relationship (p<0.01) between *Cooperation* and *Product Ecoinnovation* (β=0.243, s.d.=0.064) is apparent providing evidence for Hypothesis 2. A one-unit increase in the independent variable *Cooperation* leads to a 24.3% increase in the z-score of *Product Ecoinnovation* when transitioning from a value of 0 to 1. The observed positive effect provides proof to support the hypothesis of a reinforcing relationship between *Cooperation* and *Product Ecoinnovation*, thereby substantiating the notion that *Cooperation* plays a crucial role in promoting and enhancing *Product*

Ecoinnovation. However, we exercise caution in interpreting the results due to a modest R^2 value of 10.5% for the selected regression model, suggesting a moderate level of explanatory capability, but still in an acceptable range. Based on these findings we ascertain evidence that *Cooperation* affects *Product Ecoinnovation* and hence, Hypothesis 2 is supported.

When examining the data for each individual year, the findings regarding the relationship between *Cooperation* and *Product Ecoinnovation* become less conclusive and more nuanced. In 2015 *Cooperation* (β=0.205, s.d.=0.082) has a positive effect on *Product Ecoinnovation* with a significance of $p<0.05$ in contrast to 2021 when the β for *Cooperation* is -0.016 and not significant. Consequently, this finding aligns with the previously established association that the combined analysis predominantly relies on the 2015 data to elucidate the impact of *Cooperation* on *Product Ecoinnovation*, considering that *Product Ecoinnovation* is encompassed within the broader concept of *Ecoinnovation*. We further investigate the ambiguity of the results for 2015 and 2021 by examining the variable *Year21*. In the combined dataset *Year21* has a high significance ($p<0.01$) and a strong negative effect (β=-0.539, s.d.=0.059) indicating a larger proportion of eco-innovators in 2015 than in 2021.

Furthermore, the combined dataset shows no statistically significant impact for the variables *Product Nonecoinnovation*. Comparing the influence of *Cooperation* on *Product Ecoinnovation* and *Product Nonecoinnovation* we observe in the combined database a significant positive effect for *Product Ecoinnovation* but not for *Product Nonecoinnovation*. These findings suggest that *Cooperation* has a stronger influence on *Product Ecoinnovation* than *Product Nonecoinnovation*. This conclusion is affirmed by the findings derived from the analysis of the 2015 dataset. Conversely, it has to be mentioned that the results of the 2021 dataset present a contrasting perspective. In 2021, the influence of *Cooperation* exerts a significant influence on *Product Nonecoinnovation* while displaying no significant effect on *Product Ecoinnovation* indicating further discrepancies between the two datasets. As a consequence, the existing evidence does not successfully yield a definitive result.

The combined dataset demonstrates significant positive effects of *Regulation*, *Reputation*, *Cost*, and *R&D* on *Product Ecoinnovation*, while *Export* exhibits a moderately significant effect. The 2015 and 2021 datasets show similar patterns with some deviations (see Appendix 7).

6.1.3 Analysis Hypothesis 3

A probit regression model is utilized to examine the relationship between *Cooperation* and *Process Ecoinnovation* while accounting for the control variables outlined in the previous chapter 4.2. The analysis assesses the impact of *Cooperation* on *Process Ecoinnovation* and compares these findings with *Process NonEcoinnovations*. The findings for Hypothesis 3 are reported in Table 8. For the combined dataset the selected regression model exhibits a commendable level of fit, as evidenced by an overall R^2 value of 17.9%. This indicates a reasonable degree of explanatory power, underscoring the model's effectiveness in capturing the variation in the dependent variable.

Given this strong relationship between *Cooperation* and *Ecoinnovation*, it is reasonable to anticipate a comparable impact for the specific innovation categories encompassed by the variable *Ecoinnovation*. After running a probit regression, interestingly this effect cannot be confirmed in the combined dataset for the relationship between *Cooperation* and *Process Ecoinnovation* as shown in Table 8. In the combined dataset, we observe an absence of statistical significance regarding the effect of *Cooperation* on *Process Ecoinnovation* (β=0.107, s.d.=0.067). Further, neither in 2015 (β=0.079, s.d.=0.095) nor in 2021 (β=-0.168, s.d.=0.119) a significant effect of *Cooperation* on *Process Ecoinnovation* is evident. Consequently, the findings clearly do not support Hypothesis 3, indicating a lack of proof suggesting that *Cooperation* has no significant influence on *Process Ecoinnovation.* These results suggest that there may be distinctive factors and complexities associated with *Process Ecoinnovation* that differentiate it from other types of EIs, warranting further investigation.

Table 8 – Probit regression results: influence of Cooperation on Process Ecoinnovation and Process Nonecoinnovation

	Combined		2015		2021	
VARIABLES	(1)	(2)	(1)	(2)	(1)	(2)
Cooperation	0.107	0.109	0.079	0.089	-0.168	0.296***
	(0.067)	(0.073)	(0.095)	(0.114)	(0.119)	(0.107)
Size	0.145***	0.035	0.215***	0.006	0.084*	0.046
	(0.032)	(0.036)	(0.045)	(0.060)	(0.050)	(0.047)
Export	0.153***	-0.069	0.179***	-0.208**	0.089	0.022
	(0.043)	(0.050)	(0.058)	(0.084)	(0.067)	(0.063)
Competition	-0.019**	0.036***	0.001	0.105**	0.006	0.021***
	(0.008)	(0.007)	(0.034)	(0.051)	(0.008)	(0.008)
Regulation	0.028	0.007	0.093***	-0.056	-0.017	0.021
	(0.022)	(0.025)	(0.032)	(0.048)	(0.035)	(0.032)
Subsidies	-0.097***	0.079**	-0.096**	0.087	-0.070	0.065
	(0.030)	(0.033)	(0.048)	(0.066)	(0.045)	(0.041)
Reputation	0.102***	0.064**	0.179***	-0.039	0.071*	0.095**
	(0.027)	(0.029)	(0.040)	(0.057)	(0.041)	(0.038)
Cost	0.260***	-0.082***	0.454***	-0.202***	0.011	-0.013
	(0.022)	(0.026)	(0.032)	(0.048)	(0.035)	(0.033)
Academics	-0.025***	0.044***	-0.051***	0.058***	-0.011	0.040***
	(0.008)	(0.008)	(0.010)	(0.014)	(0.012)	(0.011)
R&D	0.179***	0.365***	0.418***	0.332***	0.001	0.380***
	(0.051)	(0.055)	(0.076)	(0.098)	(0.075)	(0.069)
Demand					-0.022	0.052**
					(0.027)	(0.024)
Year21	-0.969***	1.128***				
	(0.057)	(0.061)				
Constant	-0.281***	-1.887***	-0.645***	-1.774***	-0.890***	-0.879***
	(0.058)	(0.073)	(0.106)	(0.156)	(0.101)	(0.096)
Observations	5,210	5,210	2,868	2,868	2,329	2,329

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Process Ecoinnovation (1)
Process Nonecoinnovation (2)

Particularly, the variable *Year21* has a very strong negative and highly significant effect on *Process Ecoinnovation* (β=-0.969, s.d.=0.057) indicating a low number of *Process Ecoinnovations* in 2021. In contrast, the β-value of *Year21* (β=1.128, s.d.=0.061) for *Process Nonecoinnovation* is strongly positive and highly significant (p<0.01) which leads to the conclusion that PCIs in 2021 were mainly PCNEIs. Furthermore, in 2021 *Cooperation* (β=0.296, s.d.=0.107) influences *Process Nonecoinnovation* significantly (p<0.01). As a result, it can be inferred that *Cooperation* has a stronger effect on *Process Nonecoinnovation* than on *Process Ecoinnovation* since the relationship between *Cooperation* and *Process Ecoinnovation* is not significant according to the results of Table 8. However, similar conclusions cannot be drawn from the 2015 and combined dataset thereby indicating insufficient evidence to support the aforementioned comparison. It is noteworthy that in the combined dataset all control variables except *Regulation* have a significant effect on *Process Ecoinnovation*.

6.2 Further Analysis

In this chapter, we introduce three new variables: *SumEcoinnovation* (Hypothesis 1), *SumProduct Ecoinnovation* (Hypothesis 2), and *SumProcess Ecoinnovation* (Hypothesis 3). In contrast to the binary approach adopted in the main analysis, for further examination, we apply a variable that aggregates all EI activities into one variable respectively. This allows for a deeper understanding of the regression patterns and the proposed relationships between environmental innovation EI, PDEI, PCEI, and cooperation. By incorporating non-probit analyses and employing a non-binary assessment of EI, PDEI, and PCEI, our study extends the earlier findings.

Based on the scoring system (see chapter 4.2.1) the measures for all different types of EI, PDEI, and PCEI are now summed up instead of exhibiting a binary nature. The scoring system differentiates between activities that have a significant impact (=2), those that have an insignificant impact (=1), and those that have no impact (=0). Accordingly, the variable *SumEcoinnovation* aggregates all different types of EIs of firms. As a result, the variable *SumEcoinnovation* ranges from 0 to 26, reflecting the cumulative extent of EI activities. Similarly, the variables *SumProduct Ecoinnovation* and *SumProcess Ecoinnovation* follow an identical assessment methodology, capturing the respective types of PDEI and PCEI. The maximum possible score for PDEI is 8, indicating the highest level of engagement in PDEI. Likewise, the maximum score for PCEI is 18, representing the maximum extent of involvement in PCEI.

To identify the appropriate regression model for analyzing the new dataset, we initially analyse the histograms of the variables (Appendix 9-11). Utilizing the combined dataset, we generate histograms for the new variables to provide insights into the distribution characteristics of new variables. Upon closer examination of the individual distributions, we observe two notable patterns. Firstly, the models exhibit zero inflation, which indicates an excess of zero counts in the count data model. However, it is important to note that in this context, there are no alternative processes or factors that could result in a zero outcome. Therefore, the issue of zero inflation will not be further explored in this analysis. Secondly, the observed distribution reveals overdispersion, characterized by a conditional variance that surpasses the conditional mean. To further assess the overdispersion, we scrutinize the mean values of the variables. It becomes evident that the mean values are significantly low for all three new variables. For instance, the mean of *SumEcoinnovation* is 2.779. Considering its maximum value of 26, this indicates a significantly low average. A similar pattern is observed for *SumProduct Ecoinnovation*, with a mean of 0.887 and a maximum value of 8, as well as for *SumProcess Ecoinnovation*, with a mean of 1.939 and a maximum value of 18 (see Table 9).

Table 9 – Summary statistics for SumEcoinnovation, SumProduct Ecoinnovation and SumProcess Ecoinnovation in the combined dataset

Variable	Obs	Mean	Std. dev.	Min	Max
SumEcoinnovation	5,044	2.779	4.477	0	26
SumProduct Ecoinnovation	5,300	0.887	1.739	0	8
SumProcess Ecoinnovation	5,210	1.939	3.198	0	18

Therefore, we proceed to investigate the overdispersion by examining the deviance and the Pearson residuals. To quantify the extent of overdispersion, we calculate the dispersion parameter, which is obtained by dividing the sum of square Pearson residuals by the degrees of freedom. The findings reveal a pronounced overdispersion in all three cases, with the highest value evident for SumEcoinnovation at 7.201. This indicates that the variance of the response is significantly greater than the mean and thus the dataset is over-dispersed.

Table 10 – Dispersion of Poisson model for SumEcoinnovation, SumProduct Ecoinnovation and SumProcess Ecoinnovation in the combined dataset

Variable	(1/df[21]) Deviance	(1/df[22]) Pearson
SumEcoinnovation	4.611	7.201
SumProduct Ecoinnovation	2.212	3.493
SumProcess Ecoinnovation	3.366	5.474

To address the issue of overdispersion observed in the data, we employ negative binomial regression, which is specifically designed for analyzing over-dispersed count data (Cameron & Trivedi, 2013). This modelling approach can be seen as a generalization of Poisson regression, as it shares the same mean structure but

[21] Degrees of freedom
[22] Degrees of freedom

incorporates an additional parameter to account for the overdispersion (Long & Freese, 2006). By utilizing negative binomial regression, we can effectively capture the inherent variability in the data and obtain more reliable estimates.

Table 11 reports the results for the negative binominal regression of Hypothesis 1, 2 and 3. The regression results for Hypothesis 1 reveal a moderately significant relationship ($p<0.1$) between *Cooperation* and *SumEcoinnovation*. If *Cooperation* changes from one to zero, the difference in the logs of expected counts of *SumEcoinnovation* is expected to change by 0.170, given the other predictor variables in the model are held. These results affirm Hypothesis 1 and thus provide proof for the influence of *Cooperation* on *Ecoinnovation.* The selected regression model shows a modest level of fit, indicated by a low overall R^2 value of 2.8%. This suggests a limited degree of explanatory power, emphasizing the need for caution in interpreting the results.

Providing support for Hypothesis 2, the further analysis validates the results obtained in the main analysis. The relationship between *Cooperation* and *Product Ecoinnovation* is found to be highly statistically significant ($p<0.01$), affirming the positive association between these variables. Holding the other predictor variables in the model constant, a change in *Cooperation* from one to zero is associated with an expected change of 0.332 in the logarithm of expected counts of *SumProduct Ecoinnovation*. The chosen regression model demonstrates a satisfactory level of fit, as supported by an overall R^2 value of 26.5%. This signifies a meaningful extent of explanatory power, highlighting the effectiveness of the model in capturing the variability observed in the dependent variable. These results provide additional validation to support Hypothesis 2, exhibiting the positive effect of *Cooperation* on *Product Ecoinnovation*.

The analysis of the relationship between *Cooperation* and *SumProcess Ecoinnovation* reveals that the findings are not statistically significant. This aligns with the results of the main analysis and indicates that there is no strong evidence to support Hypothesis 3, which suggests a relationship between *Cooperation* and *Process Ecoinnovation*.

Table 11 – Negative binomial regression results: influence of Cooperation on SumEcoinnovation, SumProduct Ecoinnovation and SumProcess Ecoinnovation

VARIABLES	(1)	(2)	(3)
Cooperation	0.170*	0.332***	0.054
	(0.088)	(0.105)	(0.087)
Size	0.067	-0.012	0.112***
	(0.042)	(0.052)	(0.041)
Export	0.138**	0.158**	0.146**
	(0.058)	(0.071)	(0.058)
Competition	-0.031***	-0.013	-0.035***
	(0.010)	(0.013)	(0.010)
Regulation	0.099***	0.091***	0.093***
	(0.028)	(0.034)	(0.028)
Subsidies	-0.082**	-0.051	-0.082**
	(0.038)	(0.046)	(0.037)
Reputation	0.191***	0.232***	0.160***
	(0.034)	(0.041)	(0.033)
Cost	0.220***	0.198***	0.224***
	(0.029)	(0.035)	(0.028)
Academics	-0.017	0.005	-0.027***
	(0.010)	(0.013)	(0.010)
RD	0.118*	0.150*	0.131**
	(0.067)	(0.082)	(0.066)
Year	-0.353***	-0.146	-0.522***
	(0.075)	(0.095)	(0.076)
lnalpha	1.004***	1.329***	0.947***
	(0.031)	(0.043)	(0.035)
Constant	0.561***	-0.752***	0.263***
	(0.079)	(0.099)	(0.079)
Observations	5,044	5,300	5,210
Standard errors in parentheses			
*** p<0.01, ** p<0.05, * p<0.1			
SumEcoinnovation	(1)		
SumProduct Ecoinnovation	(2)		
SumProcess Ecoinnovation	(3)		

7 Discussion

7.1 Contributions to Previous Literature

In the context of achieving a sustainable economy, we analysed the relationship between cooperation and innovation. While the positive influence of cooperation on the innovation process at large has been firmly established, the understanding of its intricate relationship within the realm of EI remains limited. EI follows a specific goal to improve firm performance by optimizing adverse effects and material efficiency (Díaz-García et al., 2015). Therefore, they have specific characteristics that need to be considered. Even though some scholars have discussed the importance of cooperation and external knowledge for the creation of EI (Araújo & Franco, 2021; Chistov et al., 2021), they do not consider the overarching goals of creating systemic change and circularity within the economy. Consequently, the existing body of knowledge lacks an understanding of the potential contextual factors that may influence the association between cooperation and EI. Particularly, limited research has been conducted on how the significance of cooperation may differ based on the type of innovation.

To build our argumentation, we combine the previous research on CE, EI and the relationship between cooperation and innovation. Within this discussion, we also mention different innovation types and categorizations of innovation to clearly understand when and why EI profits from cooperation. By structuring the literature on the three research fields we also gather further clarity on the interdependence of the theoretical constructs.

The findings of this study provide empirical evidence for the foregoing conceptual work connecting the concept of open innovation with the theory of EI. In particular, it emphasizes the relationship of cooperation with the importance of developing new or improved socio-technical innovations that mitigate environmental degradation, promote value conservation, and enable resource recovery within the economic system. Consequently, our results confirm Hypothesis 1 stating the positive influence of cooperation on EI. This finding aligns with the argument presented by Rennings (2000) regarding the distinct characteristics of EI and the need for specific management and policy approaches. Rennings (2000) highlights the "double externality problem" associated with EI, where positive environmental externalities generated by such innovations cannot be directly captured by individual firms. The necessity of collaborative efforts is implied to overcome this challenge. Cooperation allows firms to share knowledge, resources, and expertise, fostering collective action in addressing environmental issues (Gnyawali & Park, 2009). Thus, our study supports the idea that cooperation plays a crucial role in the successful development and implementation of EIs, in accordance with our theoretical work combining EI and cooperation. The systemic, credence, and complex nature of EI, as highlighted by De Marchi (2012), further underscores the significance of cooperation in this context. Our findings reinforce the notion that EI requires a systemic approach and a shift from individual firm-level initiatives to industry-wide cooperation (Carrillo-Hermosilla et al., 2010). The concept of a CE emphasizes the importance of considering material flows, supply chains, and whole industries in driving sustainable practices (Allwood et al., 2011; Sumter et al., 2020; Wang & Hu, 2020). Companies that prioritize the needs and expectations of all stakeholders, including employees, customers, suppliers, and communities, are more likely to achieve success in EI.

Our research demonstrates that competition has a negative impact on the progress of EI, indicating that competition and cooperation are not mutually exclusive (M. Bengtsson & Kock, 2000; Luo, 2004, 2005; Tsai, 2002). While it may seem counterintuitive, considering the unintended drawbacks associated with sharing information among competitors, cooperation among rivals is quite prevalent. However, as discussed earlier, it is in dynamic and rapidly changing environments, where technological innovation is crucial, that cooperation becomes particularly significant. Working alone in highly competitive settings tends to result in suboptimal outcomes for EI.

The high degree of technological novelty regarding EI demands the integration of new information and skills, which often requires cooperation with suppliers and external partners (De Marchi, 2012). This collaborative approach ensures access to environmentally friendly inputs and facilitates product redesign to meet sustainability criteria. It also streamlines the verification process for compliance with environmental standards, enabling firms to develop and implement eco-friendly practices more effectively. Contrary to the assertions put forth by several previous studies, our findings did not reveal a significant impact of regulation on EI (Doran & Ryan, 2012; Horbach et al., 2012; Porter & Linde, 1995; Wagner & Llerena, 2011). While regulatory frameworks have often been posited as a catalyst for promoting environmentally friendly innovation, our empirical analysis did not definitely support this notion. The results suggest that the relationship between regulation and EI may be more complex and context-dependent than previously assumed. Previous research has emphasized the role of regulations in stimulating EI by imposing constraints on firms and incentivizing them to develop sustainable practices and technologies (Porter & Linde, 1995). However, our study's findings challenge this conventional wisdom, indicating that the presence of regulatory measures alone may not be sufficient to drive EI. It is plausible that other factors, such as the specific design and implementation of regulatory policies, industry characteristics, and firm-level attributes, interact with regulations in shaping EI outcomes.

The positive relationship between cooperation and general innovation has been well-established in previous studies (Belderbos et al., 2004; Chesbrough, 2003). Our findings align with this existing literature, emphasizing the benefits of collaborative efforts in promoting creativity, knowledge sharing, and resource pooling. Through cooperative relationships, firms can access external expertise, gain diverse perspectives, and combine complementary capabilities. These cooperations facilitate the exchange of ideas, joint problem-solving, and the generation of innovative solutions that may not have been achievable through individual endeavours alone. This finding not only validates our study but also underscores the role of EI within the broader context of general innovation. Our results reveal a positive relationship between cooperation and both EI and general innovation.

Moreover, the findings suggest that cooperation is more important for companies to perform EI than NEI. The study elucidates the significant positive influence of cooperation on EI contrary to the relationship between cooperation and NEI where no significance could be found. We conclude that cooperation is crucial for addressing the challenges specific to EI, including the double externality problem, informational challenges related to credence goods, and uncertainties in environmental regulations (N. J. Bengtsson, 2020; Darby & Karni, 1973; Rennings, 2000). This aligns with the understanding that EIs often involve technological novelty, require cooperation with suppliers, and necessitate transparency and trust-building among stakeholders (De Marchi, 2012; Geffen & Rothenberg, 2000; Meyer & Hohmann, 2000).

Additionally, the idea that cooperation is more important for EI than NEI suggests an increasing influence of environmental factors on innovation research. Our study's findings indicate that the positive impact of cooperation on innovation extends beyond EI and holds implications for innovation in general. The mechanisms through which cooperation facilitates general innovation are likely similar to those observed in the context of EI. Collaborative efforts allow firms to leverage external knowledge, engage in open innovation practices, and capitalize on opportunities arising from synergistic interactions with partners. Furthermore, the positive relationship between cooperation and general innovation can be attributed to knowledge and expertise spillover effects. Through cooperation, firms not only benefit from their partners' knowledge but also contribute to the accumulation of knowledge within the collaborative network (Powell et al., 1996). This knowledge spillover effect creates a virtuous cycle, where firms involved in collaborative relationships continuously enhance their innovative capabilities through shared learning and the exchange of best practices.

Previous research has also shown that the determinants and impacts on firm performance vary depending on the innovation type (Jin et al., 2004). This suggests that there might be differences in the development process depending on the innovation type and that therefore the relationship between cooperation and innovation might also vary. The specific determinants of EI also point in this direction (Del Río et al., 2010). To test this matter we followed the standard in the innovation research field and accordingly categorized EI of our data into PDEI and PCEI (OECD & Eurostat, 2018).

Both in our main and further analysis we were able to find proof for the legitimacy of our Hypothesis 2 that cooperation enhances PDEI. With these results, we were able to contribute empirical evidence and confirm the previous literature on the topic of PDEI. Since PDEIs are developed for an end-consumer, closeness to relevant stakeholders is a key determinant of their success. Our research confirms that cooperation with consumers, environmental organizations, supply chain partners, and governmental organizations is a great tool for firms to create the desired impact with their PDEIs. Our findings even indicate that cooperation may hold greater importance to PDEI than PDNEI. Nevertheless, it is important to note that the overall understanding of this relationship remains inconclusive, and a definitive conclusion cannot be drawn at this stage.

Surprisingly, neither did we find support in our main analysis nor in our further analysis for Hypothesis 3. Derived from previous research we argued that cooperation also enhances PCEI. PCEIs usually do not have a direct connection to consumers, which is why firms are more internally motivated when it comes to their introduction (Triguero et al., 2013). Therefore, what drives PCEI comes from the supply side of the market, where cost savings are the main incentive (Cleff & Rennings, 1999).

We still believe that our original reasoning behind Hypothesis 3 holds. Based on innovation literature cooperation is especially important in business environments dealing with a lot of uncertainty (Padula & Dagnino, 2007), which usually entails a high technological complexity (Garud, 1994; Gnyawali & Park, 2009; Gomes-Casseres, 1994). High technological complexity and uncertainty are exactly what can be expected from improvements in the production process that have the goal to reduce the environmental impact or to improve material efficiency. Also, a lot of linkages between suppliers and consumers are built on interdependent systems. Considering the production process of all firms within an industry or specific material flows promises greater results. Improving the ecological impact of a production step individually might not be efficient or even counterproductive. Hence, irrespective of our findings, it can be anticipated that a favourable promotion of PCEI through cooperation exists.

One reason for the unexpected results could have to do with regulations. Previous research clearly shows that regulations are an important driver for EI (Doran & Ryan, 2012; Horbach et al., 2012; Porter & Linde, 1995; Wagner & Llerena, 2011), but the importance of their alignment with the desired sustainability goals might not have been considered. Many of the regulations and laws regarding innovation are built on the traditional picture of a closed innovation process. Especially laws that protect intellectual property might create the wrong incentives for a firm to develop an EI individually (Teece, 1992). In addition, newer regulations trying to enable firms to operate more sustainable could be focusing too heavily on individual performance instead of supporting circularity. Regulations that prioritize individual performance like firm-level ESG reporting might fail to consider the broader systems and interconnectedness of economic activities. A circular approach and cooperation between firms often require a holistic perspective to address the complex challenges of sustainability and resource management (Ghisetti et al., 2015).

This is in line with our findings about the impact of regulations on EI. Specifically designing and implementing ecological policies that promote cooperation and push circularity, could lead to different results on the relationship between cooperation and PCEI in the future.

Altogether, our study contributes to the existing literature by providing empirical evidence supporting Hypothesis 1 stating that cooperation is positively associated with EI. Cooperation emerges as a crucial element in the development process of innovation, facilitating the exchange of knowledge, resources, and ideas that enable firms to create and implement novel solutions. The findings highlight the importance of fostering cooperative relationships to enhance both EI and general innovation processes. Regarding the difference in the relationship between cooperation and EI depending on the innovation type, we cannot make any clear statements. We found evidence that supports Hypothesis 2 stating that cooperation promotes PDEI, but have no proof about PCEI. Although our belief persists that cooperation positively influences both types of EI, definitive assertions regarding this relationship cannot be made with certainty.

7.2 Implications for Managers

Our study brings a valuable contribution to the existing literature by providing compelling evidence that highlights the important role of cooperation in fostering EI. Beyond its academic significance, our findings also hold significant managerial implications, underlining the practical relevance of our research. By shedding light on the positive influence of cooperation on EI, we offer managers a clear understanding of the strategic importance of cooperative relationships in driving sustainable and environmentally friendly practices within their organizations.

Firstly, we recommend managers to recognize the positive effect that cooperation can have on the innovation process in general, including EI. Cooperation allows firms to share knowledge, resources, and expertise, fostering collective action in addressing environmental issues. It enables the development and implementation of eco-friendly practices and technologies. Our results and previous research suggest that developing EI can even profit more from cooperation than NEI. Especially when the necessary infrastructure and capabilities to freely cooperate with other firms are a core part of a firm's business model (Chesbrough, 2003, 2006).

Additionally, it is important for managers to acknowledge that different types of EI, such as PDEI and PCEI, may require distinct approaches. Cooperation has been found to promote PDEI, which involves developing eco-friendly products for end-consumers. However, the impact of cooperation on PCEI, which focuses on improving production processes for cost savings and environmental efficiency, requires further exploration. We must also mention that our results clearly show that EI can also be developed without cooperation. The number of EIs that were developed internally suggests there is also enough potential for ecological improvement on an individual firm basis. Nonetheless, in the long run, pursuing industry-wide projects with the goal of improving circularity appears to be more promising. Cooperative efforts allow to share development costs and a proactive engagement with policy makers ensures an alignment with current and future regulations. Especially since policy makers have shown that more and more sustainability policies will be introduced in the future.

While regulations have often been considered a catalyst for promoting environmentally friendly innovation (Doran & Ryan, 2012; Horbach et al., 2012; Wagner & Llerena, 2011), it is in the interest of managers to understand that the relationship between regulation and EI is complex and context-dependent. The presence of regulatory measures alone may not be sufficient to drive EI. Factors such as the design and implementation of regulations, industry characteristics, and firm-level attributes interact with regulations in shaping EI outcomes.

Cooperation is particularly important in dynamic and rapidly changing environments where technological innovation is crucial. It is a way to ensure the best knowledge is available as well as a way to lower the uncertainty around the success of EI. The complexity involved with developing EI gives a further reason to cooperate. Our study helps managers to understand the systemic and complex nature of EI. Cooperation is essential in addressing challenges specific to EI, such as the double externality problem and uncertainties in environmental regulations. Cooperation with suppliers, environmental organizations, and other stakeholders facilitates access to environmentally friendly inputs, product redesign, and compliance with sustainability criteria. Managing EIs requires a systemic perspective and a shift from individual firm-level initiatives to industry-wide cooperation. The concept of a CE emphasizes considering material flows, supply chains, and whole industries in driving sustainable practices. Our findings suggest that companies that prioritize the needs and expectations of all stakeholders are more likely to succeed in EI.

Overall, our findings imply that organizations benefit from a collaborative culture, embrace a systemic perspective, and recognize the diverse factors influencing EI. By understanding the relationship between cooperation and innovation, and considering the specific characteristics of EI, managers can effectively drive sustainable practices and contribute to a sustainable economy.

7.3 Implications for Policy Makers

While previous research has shown that regulations are an important driver for EI, our findings do not show this effect definitely. Instead, our results indicate that the relationship between regulations and EI may be more complex and context-dependent than previously assumed. It is plausible that the specific design and implementation of regulatory policies have different effects depending on the industry characteristics and firm-level attributes.

Teece (1992) propose that this might be a systemic issue and that an outdated understanding of innovation is still represented in regulations like intellectual property laws. An overprotection of the closed innovation process driven by misguided incentives might have led to either a suboptimal innovation or the firm's decision to keep a patent for itself. Of course, the original legitimization of creating a regulatory environment, where firms can profit from a temporary monopoly position should not be forgotten. However, intellectual property laws and other regulations should be reviewed to avoid overprotection of closed innovation processes and to incentivize cooperation for improved EI outcomes. Policy makers should facilitate mechanisms for knowledge sharing, cooperation, and learning among firms and stakeholders. Cooperative relationships allow firms to leverage external expertise, engage in open innovation practices, and benefit from knowledge spillover effects. Policies should encourage the exchange of ideas, joint problem-solving, and the generation of innovative solutions through collaborative networks. Consequently, the current regulations should be reconsidered.

In this sense, regulations should reflect the importance of cooperation. Especially when it comes to achieving sustainability goals. Our study suggests that policy makers are invited to contemplate the specific design and implementation of regulatory policies to ensure alignment with sustainability goals and support industry-wide cooperation. Eco-friendly regulations should primarily focus on environmental protection activities such as prohibiting pollution and material inefficiencies on a firm-level. By incentivizing cooperation and industry-wide circularity projects a systemic change can be achieved. Policies should encourage holistic thinking, considering material flows, supply chains, and whole industries in driving sustainable practices. Our findings call for a careful reevaluation and reflection on existing regulations to ensure they align with the evolving understanding of innovation and promote cooperation as a catalyst for achieving sustainable and impactful outcomes. Policy makers are encouraged to create an environment that supports firms to prioritize the needs and expectations of all stakeholders, including employees, customers, suppliers, and communities. Supporting EI requires transparency, trust-building, and collaborative efforts with suppliers and external partners. Policies should facilitate access to environmentally friendly inputs, streamline verification processes for compliance with environmental standards, and promote the adoption of eco-friendly practices and technologies.

8 Conclusion

The main objective of this thesis was to find empirical evidence on the relationship between cooperation and EI. The motivation behind this study comes from the rising interest in the CE and how humanity’s sustainability challenges can be dealt with. To achieve an economy based on circularity EIs are required.

The main result from our analysis is that cooperation indeed promotes EI. We also found proof that this relationship holds specifically for PDEI, but we did not find any evidence for PCEI. With these results, we are able to partly answer the research question, but further research is necessary on the specific types of EI.

Our thesis expands the research on the relationship between cooperation and innovation by finding proof for EIs and considering their specific characteristics, such as the "double externality problem," technological novelty, informational asymmetry, and regulatory uncertainties. Cooperation emerges as a crucial element in promoting sustainable and environmentally responsible practices. Policy makers, industry practitioners, and researchers should recognize and harness the power of cooperation as a strategic tool for advancing EI and achieving a more sustainable future.

The finding that cooperation promotes both EI and general innovation underscores the strategic importance of fostering collaborative networks and partnerships. Policy makers and practitioners should recognize that encouraging and facilitating cooperation among firms can have wide-ranging benefits beyond environmental sustainability. Collaborative initiatives, such as research and development consortia, joint ventures, and strategic alliances, can foster innovation ecosystems that drive economic growth, enhance competitiveness, and address complex societal challenges.

9 Limitations

Despite the measures taken to provide valuable contributions to previous literature and implications for managers and policy makers with our analysis, the following limitations must be considered.

Secondary data from the MIP which is the German contribution to the CIS was utilized in this study. While the diverse composition of the participants in the survey minimizes a sample selection bias and the sample is representative for German firms, it is based on self-reporting. This means the variables we chose for our model might be encompassed by a certain degree of subjectivity. In particular, we would like to emphasize the fact that the participant decides what contributions to environmental protection of their innovations are deemed significant or not. Due to the sample size of over 10.000 observations, this effect is expected to be mitigated and the validity of the study is not affected. Additionally, further consideration regarding the geographical restrictions of the MIP dataset must be employed. The dataset solely contains information on German firms. This means we do not account for possible geographical differences. Despite the fact that the dataset is diverse in various factors such as industries, size or exporting behaviour, concerns about locational disparities are hereby addressed.

An additional limiting factor to our study is potential time-contextual influences. By utilizing data on EI from 2015 and 2021 we partly address time-specific effects. The application of the combined dataset helps us to avoid those effects to a certain extent. The presence of dissimilarities within the dataset can be effectively addressed through an analysis of the outcomes derived from the combination of data from both years. However, to enhance the robustness and credibility of the findings, a greater number of years should be incorporated. Thus, in order to establish a comprehensive proposition regarding the influence of cooperation on EI, it is imperative to observe and analyze the phenomenon over multiple years.

In particular, in this context, we elucidate the change of definition for PDI and PCI. Since the MIP follows the definitions of the Oslo Manual, the change in the categorization of innovation made in 2018 was adopted (OECD & Eurostat, 2018). As a result, the study seemingly maintained consistency in the two categories of innovation, namely PDI and business process innovation, but starting in 2018, two further dimensions of PCI were introduced, encompassing additionally marketing and organizational innovation. This inclusion could potentially explain the observed shift in the proportions of EI and NEI among general innovation.

Also, we must mention the limitations of our chosen statistical model. While the probit regression model is appropriate for binary outcomes, it provides estimates of coefficients that represent the change in the probability of the event occurring associated with a one-unit change in the predictor. To address the potential limitations associated with the results derived from probit regression, we employ an additional statistical technique by utilizing negative binomial regression. By incorporating this complementary approach, we aim to bolster the robustness and enhance the validity of our findings. Negative binomial regression provides several advantages in this context. Firstly, it relaxes the assumption of linearity inherent in probit regression by accommodating nonlinear relationships between predictor variables and the binary response. This flexibility allows for a more accurate representation of the underlying data structure, especially when nonlinear associations exist. Furthermore, negative binomial regression offers increased resilience to outliers, which can exert a disproportionate influence on probit regression estimates. By employing a probability distribution that accounts for overdispersion, this approach is better suited to handle extreme observations, minimizing the potential for biased results. By integrating negative binomial regression alongside probit regression, we are able to mitigate the limitations inherent in the latter approach, while simultaneously capitalizing on the unique strengths of both techniques. This dual-model strategy not only bolsters the validity of our findings but also provides a more comprehensive analysis, strengthening the robustness of our conclusions.

Lastly, endogeneity poses a significant challenge in empirical research, and its presence can undermine the validity and reliability of the results. Due to our current data availability, the potential for endogeneity and its associated concerns of omitted variables and reverse causality must be addressed in future research to ensure the robustness and accuracy of our findings.

10 Recommendations for Further Research

While our study provides valuable insights into the role of cooperation in promoting EI, there are several opportunities for further research. We identified five directions to extend our study to provide more insights into an open innovation perspective on EI.

Firstly, additional evidence could be gained by examining different time and location-related dimensions. To enhance the research, we propose expanding the research by analysing data from different locations and spanning multiple years. This approach allows to add more evidence to the general understanding of the phenomenon, considering geographical differences and temporal trends. By investigating the same phenomenon in a different scope, the generalizability of the findings can be improved, and potential biases can be mitigated.

Further investigation is also recommended in order to explore the specific mechanisms and processes through which cooperation influences EI outcomes. Even though a lot can be learned from the binary variables we chose, more complex ones can include more qualitative information about the cooperation setting. If the dataset allows it in the future, this will help to delve deeper into the specific mechanisms and contextual factors that influence this relationship. For instance, exploring the role of trust, knowledge-sharing mechanisms, and the impact of different collaborative structures on innovation outcomes would enhance our understanding of the complexities involved in collaborative innovation processes. This would also enable better comparisons between eco and non-eco and the interpretation of the magnitude between the two categories.

Additionally, the examination of different types of cooperations, such as inter-firm partnerships, industry consortia, and public-private cooperations, would provide a more nuanced understanding of the diverse collaborative approaches that drive EI. With more complex variables the effects of cooperation length, and intensity of the relationship could be discussed.

Further, the innovation type analysis was based on the variable that categorized EI into PDI and PCI. In order to capture the complexity of innovation types we propose to further investigate applying another differentiation approach, such as analysing the different effects of cooperation for incremental and radical innovation. However, due to a lack of evidence in our analysis, we also encourage researchers to revisit the relationship between cooperation and PCEI as well as the relationship between cooperation and PCNEI to create a deeper and more nuanced understanding of this topic.

While it was not the focus of our research, we also found some surprising data on one of our control variables. The lack of a significant relationship between regulation and EI in our study underscores the need for further investigation and nuanced analyses of the regulatory environment's impact on innovation processes. It suggests that a more comprehensive understanding of the mechanisms through which regulations influence EI is required. Future research endeavors should consider exploring additional contextual factors and potential mediators or moderators that may help elucidate the intricate relationship between regulation and EI.

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12 Appendix

Appendix 1 – Previous reviews of the circular economy concept

Number	Study	Focus
1	Ghisellini et al. (2016)	Summary of 155 articles on CE
2	Lieder and Rashid (2016)	Summary of CE literature on the manufacturing industry
3	Blomsma and Brennan (2017)	Explanation of the emergence of the CE concept
4	Sauvé et al. (2016)	Comparison of CE concept, environmental sciences and sustainable development
5	Murray et al. (2017)	Comparison of CE concept and sustainable business
6	Geissdoerfer et al. (2017)	Comparison of CE concept and sustainability
7	Lewandowski (2016)	Conceptualization of circular business models

(Kirchherr et al., 2017)

Appendix 2 – Change of definitions on Product Innovation and Process Innovation

In 2018, a modification was introduced to the Oslo Manual, leading to adjustments in the definitions of innovative products, services, production processes, and service delivery methods (OECD & Eurostat, 2018). As a result, beginning with the 2019 survey cycle, the classification of innovation expands to encompass customer benefits and the design of product/service innovations. Additionally, innovations in organizational and management methods, as well as marketing methods, are now included as PCI innovations. The extent of these innovations will be captured using a questionnaire, effective from 2019.

<u>Definition of product innovation until 2018:</u>

"A PDI is a product or service whose components or basic characteristics (technical features, integrated software, usage properties, user-friendliness, availability) are either new or noticeably improved. The innovation must be new for your company, it does not necessarily have to be a market novelty. It is irrelevant who developed the innovation. Purely aesthetic modifications of products (e.g. colouring, styling) are not PDI. The mere sale of innovations developed and produced by other companies is also not a PDI." (OECD & Eurostat, 2018, p. 31)

<u>Definition of process innovation until 2018:</u>

"A PCI is a new or significantly improved production/process technology or a new or significantly improved process for service provision, logistics/distribution, supporting activities (e.g. information technology, office technology) or for enabling product/service innovations. The result should have a noticeable impact on cost or quality. The innovation must be new to your company, but it does not necessarily have to have been introduced first by your company. It does not matter who developed the innovation. Purely organizational changes or the introduction of new management methods are not process innovations.” (OECD & Eurostat, 2018, p. 32)

<u>Definition of product innovation as of 2019:</u>

“PDIs are new or improved products or services whose components or basic characteristics (technical features, integrated software, application properties, user-friendliness, availability, customer benefits, design) differ noticeably from the products and services previously offered by your company. The innovation must be new for your company, it does not necessarily have to be a market novelty. It is irrelevant who developed the innovation. The mere sale of innovations produced by other companies is not a PDI.” (OECD & Eurostat, 2018, p. 71)

<u>Definition of process innovation as of 2019:</u>

“PCIs are new or improved processes and methods that have a noticeable positive impact on costs or quality. Process/procedure innovations can relate to manufacturing/processing techniques, service delivery methods, logistics and distribution methods, information technology, support activities (e.g., office technology, administrative procedures), organizational and management methods, and marketing methods. The innovation must be new to your company, but it does not necessarily have to have been introduced first by your company. It does not matter who developed the innovation.” (OECD & Eurostat, 2018, p. 72)

Appendix 3 – Summary statistics and correlation matrix of Ecoinnovation in the 2015 and 2021 dataset

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11
1	Ecoinnovation	2767	0.629	0.483	0	1	1.000										
2	Cooperation	2767	0.149	0.356	0	1	0.180	1.000									
3	Size	2767	1.448	0.656	1	3	0.208	0.160	1.000								
4	Export	2767	0.482	0.500	0	1	0.235	0.263	0.240	1.000							
5	Competition	2767	2.267	0.773	0	3	0.088	0.013	0.031	0.103	1.000						
6	Regulation	2767	0.766	1.150	0	3	0.345	0.121	0.199	0.156	0.063	1.000					
7	Subsidies	2767	0.359	0.778	0	3	0.250	0.157	0.134	0.137	0.041	0.531	1.000				
8	Reputation	2767	0.613	0.939	0	3	0.388	0.183	0.242	0.225	0.090	0.505	0.484	1.000			
9	Cost	2767	0.995	1.188	0	3	0.483	0.161	0.205	0.222	0.112	0.569	0.490	0.575	1.000		
10	Academics	2767	3.121	2.621	0	8	-0.008	0.244	0.007	0.097	-0.078	-0.013	0.032	0.051	-0.011	1.000	
11	RD	2767	0.292	0.455	0	1	0.268	0.532	0.229	0.375	0.048	0.157	0.141	0.265	0.209	0.245	1.000

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Ecoinnovation	2264	0.284	0.451	0	1	1.000											
2	Cooperation	2264	0.073	0.261	0	1	-0.019	1.000										
3	Size	2264	1.386	0.610	1	3	0.042	0.075	1.000									
4	Export	2264	0.379	0.485	0	1	0.029	0.112	0.270	1.000								
5	Competition	2264	7.506	3.766	0	18	0.026	0.050	0.063	0.236	1.000							
6	Regulation	2264	1.005	1.167	0	3	0.021	0.089	0.222	0.179	0.177	1.000						
7	Subsidies	2264	0.527	0.844	0	3	-0.003	0.083	0.095	0.140	0.136	0.535	1.000					
8	Reputation	2264	0.778	0.979	0	3	0.045	0.109	0.205	0.221	0.195	0.571	0.537	1.000				
9	Cost	2264	1.171	1.183	0	3	0.020	0.061	0.135	0.188	0.217	0.638	0.541	0.578	1.000			
10	Academics	2264	3.063	2.618	0	8	-0.015	0.091	-0.050	0.039	-0.045	-0.058	-0.079	-0.013	-0.142	1.000		
11	RD	2264	0.277	0.447	0	1	0.009	0.273	0.215	0.405	0.160	0.201	0.111	0.248	0.159	0.177	1.000	
12	Demand	2264	1.178	1.217	0	3	0.020	0.059	0.194	0.154	0.235	0.312	0.282	0.392	0.280	0.006	0.158	1.000

Appendix 4 – Summary statistics and correlation matrix of Product Ecoinnovation in the 2015 and 2021 dataset

2015	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11
1	Product Ecoinnovation	2918	0.365	0.481	0	1	1.000										
2	Cooperation	2918	0.156	0.363	0	1	0.207	1.000									
3	Size	2918	1.459	0.659	1	3	0.142	0.163	1.000								
4	Export	2918	0.486	0.500	0	1	0.201	0.260	0.245	1.000							
5	Competition	2918	2.261	0.772	0	3	0.079	0.010	0.026	0.106	1.000						
6	Regulation	2918	0.786	1.161	0	3	0.322	0.129	0.206	0.161	0.063	1.000					
7	Subsidies	2918	0.371	0.789	0	3	0.265	0.153	0.137	0.143	0.038	0.537	1.000				
8	Reputation	2918	0.632	0.946	0	3	0.381	0.191	0.242	0.226	0.087	0.511	0.489	1.000			
9	Cost	2918	1.025	1.195	0	3	0.392	0.168	0.215	0.225	0.106	0.566	0.491	0.575	1.000		
10	Academics	2918	3.128	2.610	0	8	0.053	0.248	0.005	0.096	-0.077	-0.014	0.024	0.049	-0.016	1.000	
11	RD	2918	0.297	0.457	0	1	0.272	0.534	0.227	0.374	0.048	0.164	0.136	0.267	0.212	0.245	1.000

2021	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Product Ecoinnovation	2369	0.182	0.386	0	1	1.000											
2	Cooperation	2369	0.073	0.261	0	1	0.001	1.000										
3	Size	2369	1.381	0.607	1	3	0.028	0.069	1.000									
4	Export	2369	0.379	0.485	0	1	0.010	0.114	0.267	1.000								
5	Competition	2369	7.499	3.777	0	18	0.031	0.051	0.063	0.231	1.000							
6	Regulation	2369	1.002	1.166	0	3	0.012	0.088	0.231	0.180	0.172	1.000						
7	Subsidies	2369	0.526	0.839	0	3	-0.021	0.088	0.099	0.138	0.135	0.537	1.000					
8	Reputation	2369	0.783	0.985	0	3	0.032	0.113	0.206	0.225	0.196	0.571	0.532	1.000				
9	Cost	2369	1.177	1.186	0	3	-0.002	0.063	0.139	0.192	0.214	0.639	0.536	0.577	1.000			
10	Academics	2369	3.065	2.621	0	8	-0.007	0.094	-0.049	0.045	-0.041	-0.055	-0.073	-0.008	-0.142	1.000		
11	RD	2369	0.273	0.446	0	1	0.015	0.278	0.215	0.402	0.159	0.205	0.116	0.249	0.163	0.175	1.000	
12	Demand	2369	1.182	1.220	0	3	0.001	0.058	0.200	0.159	0.235	0.314	0.272	0.398	0.281	0.007	0.160	1.000

Appendix 5 – Summary statistics and correlation matrix of Process Ecoinnovation in the 2015 and 2021 dataset

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11
1	Process Ecoinnovation	2868	0.589	0.492	0	1	1.000										
2	Cooperation	2868	0.152	0.359	0	1	0.155	1.000									
3	Size	2868	1.456	0.661	1	3	0.212	0.164	1.000								
4	Export	2868	0.484	0.500	0	1	0.221	0.269	0.242	1.000							
5	Competition	2868	2.267	0.773	0	3	0.078	0.016	0.035	0.105	1.000						
6	Regulation	2868	0.774	1.153	0	3	0.336	0.123	0.198	0.166	0.065	1.000					
7	Subsidies	2868	0.358	0.775	0	3	0.242	0.154	0.133	0.141	0.044	0.526	1.000				
8	Reputation	2868	0.626	0.949	0	3	0.363	0.189	0.243	0.233	0.094	0.506	0.480	1.000			
9	Cost	2868	1.006	1.189	0	3	0.472	0.164	0.204	0.226	0.116	0.568	0.483	0.580	1.000		
10	Academics	2868	3.135	2.618	0	8	-0.048	0.240	0.003	0.096	-0.082	-0.017	0.024	0.047	-0.017	1.000	
11	RD	2868	0.298	0.457	0	1	0.241	0.526	0.236	0.382	0.052	0.167	0.144	0.273	0.213	0.242	1.000

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Process Ecoinnovation	2329	0.228	0.420	0	1	1.000											
2	Cooperation	2329	0.073	0.261	0	1	-0.023	1.000										
3	Size	2329	1.389	0.613	1	3	0.047	0.076	1.000									
4	Export	2329	0.378	0.485	0	1	0.042	0.116	0.265	1.000								
5	Competition	2329	7.514	3.762	0	18	0.024	0.057	0.060	0.239	1.000							
6	Regulation	2329	1.015	1.170	0	3	0.008	0.092	0.224	0.180	0.176	1.000						
7	Subsidies	2329	0.529	0.844	0	3	-0.013	0.079	0.095	0.141	0.135	0.528	1.000					
8	Reputation	2329	0.782	0.980	0	3	0.032	0.116	0.208	0.221	0.194	0.569	0.536	1.000				
9	Cost	2329	1.177	1.183	0	3	0.017	0.062	0.134	0.187	0.215	0.639	0.542	0.575	1.000			
10	Academics	2329	3.065	2.616	0	8	-0.022	0.090	-0.048	0.039	-0.050	-0.061	-0.080	-0.017	-0.142	1.000		
11	RD	2329	0.279	0.448	0	1	0.016	0.269	0.220	0.404	0.159	0.207	0.110	0.250	0.162	0.176	1.000	
12	Demand	2329	1.187	1.220	0	3	0.001	0.063	0.190	0.155	0.239	0.313	0.280	0.392	0.277	0.000	0.160	1.000

Appendix 6 – Summary statistics and correlation matrix of All Innovation, Nonecoinnovation, Product Nonecoinnovation and Process Nonecoinnovation in the combined Dataset

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	AllInnovation	6042	0.538	0.499	0	1	1.000											
2	Cooperation	6042	0.119	0.324	0	1	0.251	1.000										
3	Size	6042	1.429	0.643	1	3	0.160	0.136	1.000									
4	Export	6042	0.436	0.496	0	1	0.221	0.207	0.258	1.000								
5	Competition	6042	4.770	3.759	0	18	0.163	-0.076	-0.009	0.043	1.000							
6	Regulation	6042	0.896	1.172	0	3	0.168	0.094	0.207	0.156	0.158	1.000						
7	Subsidies	6042	0.450	0.820	0	3	0.134	0.109	0.115	0.121	0.140	0.541	1.000					
8	Reputation	6042	0.715	0.975	0	3	0.250	0.144	0.226	0.214	0.160	0.543	0.511	1.000				
9	Cost	6042	1.101	1.191	0	3	0.194	0.113	0.181	0.197	0.158	0.603	0.514	0.583	1.000			
10	Academics	6042	3.119	2.614	0	8	0.175	0.183	-0.020	0.075	-0.041	-0.040	-0.030	0.021	-0.076	1.000		
11	RD	6042	0.289	0.453	0	1	0.403	0.416	0.233	0.388	0.063	0.177	0.121	0.252	0.186	0.213	1.000	
12	Year	6042	0.474	0.499	0	1	0.101	-0.135	-0.063	-0.107	0.706	0.095	0.097	0.072	0.061	-0.016	-0.025	1.000

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Nonecoinnovation	5044	0.250	0.433	0	1	1.000											
2	Cooperation	5044	0.115	0.319	0	1	0.022	1.000										
3	Size	5044	1.419	0.636	1	3	-0.012	0.134	1.000									
4	Export	5044	0.435	0.496	0	1	0.012	0.216	0.256	1.000								
5	Competition	5044	4.631	3.681	0	18	0.313	-0.064	-0.004	0.043	1.000							
6	Regulation	5044	0.873	1.164	0	3	0.032	0.094	0.202	0.154	0.160	1.000						
7	Subsidies	5044	0.435	0.812	0	3	0.057	0.112	0.109	0.126	0.142	0.538	1.000					
8	Reputation	5044	0.687	0.961	0	3	0.050	0.141	0.221	0.213	0.162	0.539	0.514	1.000				
9	Cost	5044	1.074	1.188	0	3	-0.004	0.112	0.171	0.198	0.163	0.603	0.518	0.579	1.000			
10	Academics	5044	3.092	2.620	0	8	0.092	0.185	-0.016	0.072	-0.039	-0.035	-0.022	0.020	-0.070	1.000		
11	RD	5044	0.285	0.451	0	1	0.123	0.431	0.225	0.388	0.065	0.174	0.124	0.255	0.186	0.215	1.000	
12	Year	5044	0.451	0.498	0	1	0.361	-0.119	-0.050	-0.106	0.708	0.102	0.103	0.085	0.073	-0.012	-0.019	1.000

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Product Nonecoinnovation	5300	0.213	0.409	0	1	1.000											
2	Cooperation	5300	0.118	0.323	0	1	0.109	1.000										
3	Size	5300	1.423	0.638	1	3	0.030	0.136	1.000									
4	Export	5300	0.437	0.496	0	1	0.103	0.216	0.259	1.000								
5	Competition	5300	4.614	3.681	0	18	0.114	-0.070	-0.013	0.039	1.000							
6	Regulation	5300	0.882	1.168	0	3	0.006	0.099	0.209	0.158	0.151	1.000						
7	Subsidies	5300	0.441	0.816	0	3	0.009	0.112	0.113	0.129	0.135	0.541	1.000					
8	Reputation	5300	0.699	0.966	0	3	0.064	0.147	0.221	0.216	0.156	0.541	0.513	1.000				
9	Cost	5300	1.092	1.193	0	3	-0.006	0.119	0.179	0.202	0.154	0.601	0.515	0.578	1.000			
10	Academics	5300	3.097	2.616	0	8	0.140	0.189	-0.016	0.074	-0.038	-0.034	-0.023	0.022	-0.073	1.000		
11	RD	5300	0.286	0.452	0	1	0.240	0.436	0.224	0.387	0.058	0.178	0.123	0.256	0.188	0.215	1.000	
12	Year	5300	0.449	0.497	0	1	0.080	-0.127	-0.062	-0.109	0.708	0.091	0.094	0.076	0.062	-0.013	-0.028	1.000

	Variable	Obs	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12
1	Process Nonecoinnovation	5210	0.225	0.417	0	1	1.000											
2	Cooperation	5210	0.117	0.321	0	1	0.019	1.000										
3	Size	5210	1.426	0.641	1	3	0.017	0.137	1.000									
4	Export	5210	0.436	0.496	0	1	0.007	0.222	0.255	1.000								
5	Competition	5210	4.625	3.678	0	18	0.356	-0.064	-0.007	0.042	1.000							
6	Regulation	5210	0.882	1.167	0	3	0.088	0.096	0.201	0.160	0.160	1.000						
7	Subsidies	5210	0.435	0.811	0	3	0.097	0.108	0.109	0.128	0.143	0.532	1.000					
8	Reputation	5210	0.695	0.966	0	3	0.106	0.147	0.223	0.218	0.157	0.538	0.510	1.000				
9	Cost	5210	1.082	1.189	0	3	0.050	0.115	0.170	0.200	0.161	0.603	0.514	0.580	1.000			
10	Academics	5210	3.101	2.617	0	8	0.080	0.183	-0.017	0.072	-0.043	-0.039	-0.027	0.017	-0.073	1.000		
11	RD	5210	0.289	0.453	0	1	0.124	0.427	0.231	0.392	0.063	0.181	0.124	0.260	0.189	0.213	1.000	
12	Year	5210	0.450	0.497	0	1	0.414	-0.123	-0.053	-0.108	0.709	0.102	0.105	0.079	0.071	-0.014	-0.022	1.000

Appendix 7 – Discussion of control variables in the main analysis

The model for Hypothesis 1 shows that the effects of most of the control variables in the combined dataset are consistent with previous research (Bitencourt et al., 2020). Firm *Size* (β=0.127, s.d.=0.032), *Export* (β=0.139, s.d.=0.043), *Reputation* (β=0.134, s.d.=0.027), *Cost* (β=0.252, s.d.=0.023) and *R&D* (β=0.177, s.d.=0.052) all have a positive effect on *Ecoinnovation* and are highly significant ($p<0.01$).

Surprisingly, *Competition* (β=-0.018, s.d.=0.008) significantly ($p<0.05$) effect *Ecoinnocation* negatively. Similarly, *Subsidies* (β=-0.107, s.d.=0.031) also show a negative impact on *Ecoinnovation* indicating a statistically significant relationship with a high level of significance at $p<0.01$. The effect of *Academics* (β=-0.011, s.d.=0.008) and *Regulation* (β=0.034, s.d.=0.023) on *Ecoinnovation* is not significant.

Compared to the results of the 2015 data set we mainly observe a similar pattern. We elucidate two major differences. First, in the 2015 dataset, it is noteworthy that the variable *Competition* (β=0.027, s.d.=0.031) lacks statistical significance in its relationship with *Ecoinnovation* in contrast to the combined dataset where a significant effect is observed. Furthermore, the effect in 2015 shows a positive direction, whereas the combined dataset indicates a negative effect. Secondly, the variables *Regulation* (β=0.101, s.d.=0.036) and *Academics* (β=-0.033, s.d.=0.011) exhibit a high level of significance in the 2015 dataset, whereas in the combined dataset there is no significance. This indicates that the results from the year 2015 align more closely with previous research compared to the combined dataset. Hence, the findings from the 2015 dataset offer stronger support for the existing body of research, while highlighting deviations in the combined dataset. (Demirel & Kesidou, 2011; Doran & Ryan, 2012; Horbach et al., 2012; Tsai, 2002).

The findings of the 2021 dataset suggest that except *Reputation* (β=-0.078, s.d.=0.040, $p<0.05$) all other variables have no significant effect on *Ecoinnovation* which is completely contrary to the results of 2015, the combined dataset and prior research. Even the variable *Demand* which is only captured in 2021 has no significant effect and therefore opposes the findings of previous scholars (Horbach & Rammer, 2022).

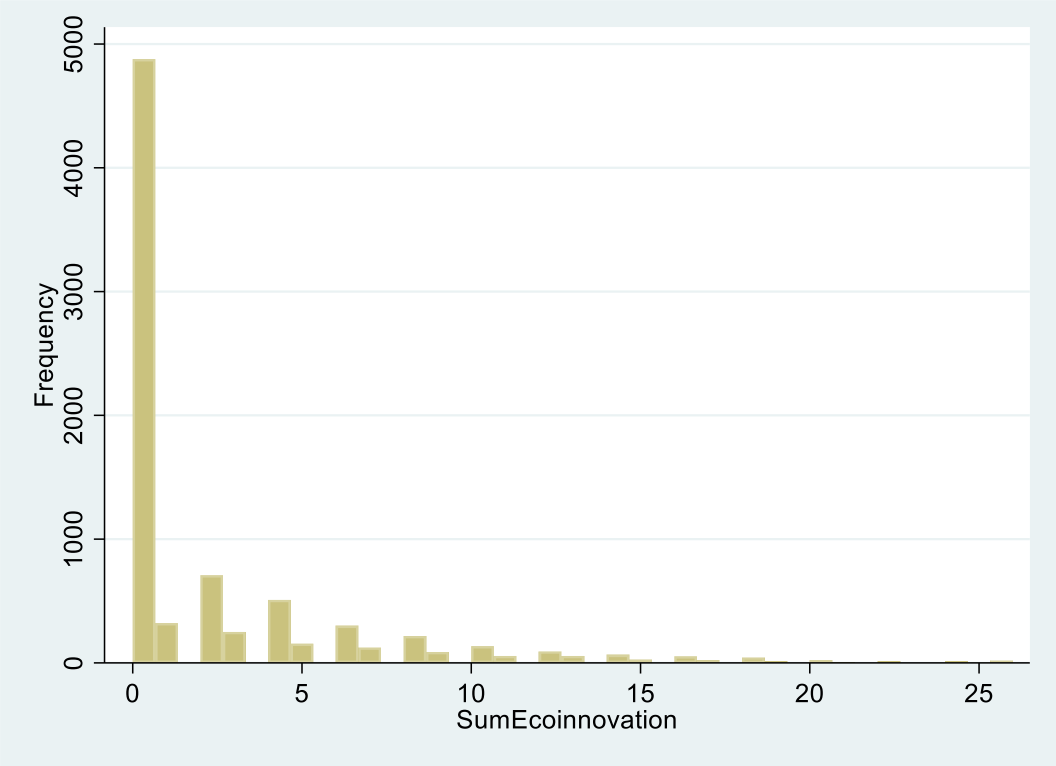
For Hypothesis 2 the combined dataset displays a positive and highly significant effect ($p<0.01$) of the control variables *Regulation* (β=0.060, s.d.=0.022), *Reputation* (β=0.155, s.d.=0.025), *Cost* (β=0.143, s.d.=0.022) and *R&D* (β=0.207, s.d.=0.050). *Export* (β=0.082, s.d.=0.043) expresses a moderately significant effect ($p<0.01$) on *Product Ecoinnovation*. *Size* (β=0.019, s.d.=0.031), *Competition* (β=-0.008, s.d.=0.008), *Subsidies* (β=-0.039, s.d.=0.029) and *Academics* (β=0.003, s.d.=0.008) were not significant for *Product Ecoinnovation*. The 2015 dataset follows a similar pattern with one slight deviation. The control variable *Cooperation* (β=0.060, s.d.=0.035) reveals a moderately significant impact ($p<0.1$) on *Product Ecoinnovation* in 2015 in contrast to a no significant effect in the combined dataset. On the contrary, the 2021 dataset exhibits divergent results compared to the 2015 and combined dataset. Except *Reputation* (β=0.090, s.d.=0.042) which is significant ($p<0.05$) and thus aligns with the findings from 2015 and combined, only *Subsidies* (β=-0.085, s.d.=0.047) appear to be moderately significant ($p<0.1$) which stands in contrast to insignificant results in 2015 and the combined dataset. All other variables have a not significant effect on *Product Ecoinnovation*.

Appendix 8 – Discussion of control variables in the further analysis

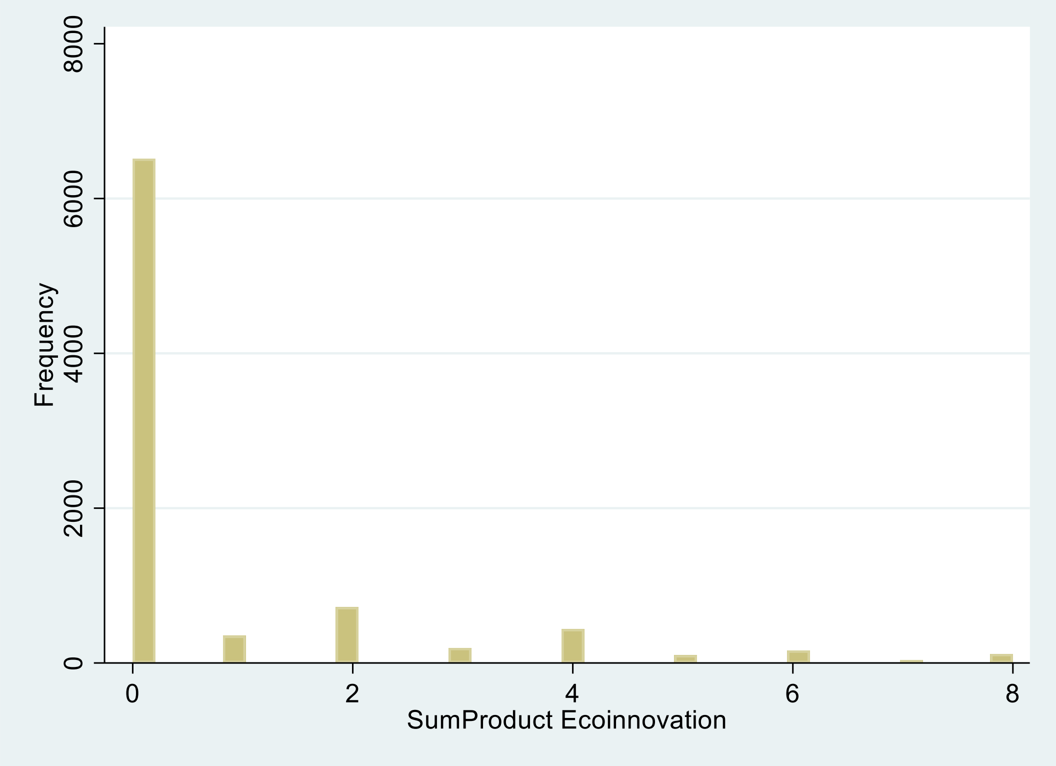
Over all three models, we see three predictors namely *Regulation*, *Reputation* and *Cost* that are consistently highly significant at $p<0.01$. Except for subsidies with no significance for any of the models all other variables have some kind of significance for some of the models. The model for Hypothesis 1 encompasses values of β=0.088 (s.d.=0.025) for *Regulation*, β=0.142 (s.d.=0.025) for *Reputation* and β=0.181 (s.d.=0.024) for *Cost*. Furthermore the regression shows a high significance ($p<0.01$) of *Competition* (β=-0.029, s.d.=0.010) and *Year* (β=-0.367, s.d.=0.075), a significance ($p<0.05$) of *Export* (β=0.138, s.d.=0.058) and a moderate significance ($p<0.1$) for *Size* (β=0.071, s.d.=0.042), *Academics* (β=-0.017, s.d.=0.010) and *R&D* (β=0.120, s.d.=0.067). These observed relationships except subsidies are consistent with the findings of previous papers (Demirel & Kesidou, 2011; Doran & Ryan, 2012; Horbach et al., 2012; Tsai, 2002). The *Year* variable exhibits high significance and a moderately high negative coefficient, which further supports the findings of the main analysis. This suggests the proportional differences between the 2015 and 2021 datasets regarding EI and NEI. For Hypothesis 2 the regression indicates highly significant values of β=0.082 (s.d.=0.030) for *Regulation*, β=0.177 (s.d.=0.031) for *Reputation* and β=0.164 (s.d.=0.029) for *Cost* which demonstrates consistency with the main analysis. We observe more similarities to the main analysis for *Size* (β=0.071, s.d.=0.042), *Competition* (β=-0.029, s.d.=0.010) and *Academics* (β=-0.017, s.d.=0.010). There are some deviations in the significance levels for certain variables. Specifically, for the *Export* variable (β=0.138, s.d.=0.058), the significance level is $p<0.05$, which differs from the main analysis where it was $p<0.1$. Similarly, for the *R&D* variable (β=0.120, s.d.=0.067) and the *Year* variable (β=-0.367, s.d.=0.075), the significance level is $p<0.1$ instead of $p<0.01$ as observed in the main analysis. However, the pattern of all significant variables and insignificant variables did not change, confirming the previous findings.

The regression analysis conducted for Hypothesis 3 demonstrates a reasonably consistent pattern in line with the main analysis. Notably, the variables *Size* (β=0.115, s.d.=0.041), *Reputation* (β=0.118, s.d.=0.026), *Cost* (β=0.182, s.d.=0.024), *Academics* (β=-0.028, s.d.=0.010), and *Year* exhibit high levels of significance ($p<0.01$). While the variables *Export* (β=0.144, s.d.=0.058) and *R&D* (β=0.137 s.d.=0.067) maintain significance at $p<0.05$ compared to the high level of significance observed in the main analysis ($p<0.01$), the difference remains minor. However, in the case of *Competition* (β=-0.033, s.d.=0.010), the negative binomial regression yields a higher level of significance ($p<0.01$) compared to the probit regression ($p<0.05$). Despite these minor deviations, the regression analysis held one major difference for the variables *Regulation* (β=0.084, s.d.=0.024) and *Subsidies* (β=-0.049, s.d.=0.030). For *Regulation,* the negative binomial regression shows a high significance $p<0.01$ contrary to the main analysis with *Regulation* being insignificant for *Product Ecoinnovation*. Vice versa the variable *Subsidies* that was highly significant in the main analysis is in the negative binomial regression not significant.

Appendix 9 – Histogram SumEcoinnovation for further analysis



Appendix 10 – Histogram SumProduct Ecoinnovation for further analysis



Appendix 11 – Histogram SumProcess Ecoinnovation for further analysis