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Four Essays on Firms' Eco-innovation: The Role of Appropriability

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Acknowledgments

This thesis emphasizes two ideas: eco-innovation as a collective process, and the appropriability of value as the innovator's ability to capture the value of their innovation. In addition to eco-innovation, this thesis was a process in which many people were involved professionally and personally, who contributed in some way to this document, and to whom I am grateful:

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Abstract

Eco-innovation has gained significant attention in the past two decades due to growing global environmental concerns. Eco-innovation has positioned itself as a field that integrates technological development with the natural environment, to create value for both firms and society. In this context, a central aspect that explains why firms engage in eco-innovation is the possibility of capturing value from such endeavors. However, firms face obstacles in appropriating the benefits of eco-innovation owing to challenges such as imitation, ineffective environmental policies, and greater uncertainty regarding returns on investment compared to conventional innovations. As a result, appropriability has emerged as a crucial issue in eco-innovation research and environmental and innovation policy.

This thesis explores the role of appropriability on a firm's eco-innovation and how firms appropriate the value of their eco-innovation. To achieve this, we integrate the eco-innovation literature with the profiting from innovation framework in four empirical chapters. The empirical strategy in this thesis uses both quantitative and qualitative methods. The literature review applies bibliometric techniques (co-citation analysis and factor analysis) and text analysis (structured topic modeling). The quantitative chapters use multiple regressions, and the qualitative chapter uses case studies.

This thesis demonstrates that informal mechanisms are more effective in promoting eco-innovation than formal ones. Firms are more likely to adopt eco-innovations when they protect their knowledge through internal resources (complementary assets) and informal mechanisms, rather than relying on formal institutions that enforce intellectual property rights. When considering complementary assets, this thesis reveals that a firm's marketing capabilities work as a complementary asset that amplifies the influence of formal and informal appropriability mechanisms on eco-innovation. The moderating effect of marketing investment on eco-innovation depends on the cumulative effect of appropriability mechanisms.

The effectiveness of informal mechanisms and complementary assets in securing value expectations suggests that the patent system does not need to be enforced strongly. This is because strict enforcement has led to reduced social value creation and wealth distribution from innovation. Our findings indicate that firms can still appropriate rents informally without legally excluding competitors or hindering society's access to eco-innovation benefits.

Keywords: eco-innovation, green innovation, environmental innovation, appropriability, appropriation, appropriability mechanisms, value appropriation, designation of origin.

Chapter 1

1. Introduction

1.1. Problem Statement and Research Objectives

Eco, green, and environmental innovation is a growing research field that has attracted significant attention from scholars in innovation studies. The eco-innovation field integrates disciplines such as economics, business, management, and engineering, and their studies are grounded in frameworks such as resource-based theory (Barney, 1991), natural-resource-based view of the firm (Hart, 1995), dynamic capabilities (Dangelico et al., 2017), institutional theory (North, 1990), open innovation (Cainelli et al., 2015; Ghisetti et al., 2015), and, recently, the appropriability framework (Malen & Marcus, 2019). Studies on eco-innovation have endeavored to contribute to a concept that is sufficiently broad and satisfies multiple disciplines and heterogeneous interests. Eco-innovation defined in a broad sense refers to "... the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp & Pearson, 2007, p. 7). Thus, a common denominator is that eco-innovation has environmental benefits as its defining feature.

A unique feature of eco-innovation is that it creates value for the innovating firm and society by producing knowledge and environmental spillovers (e.g., reducing or mitigating environmental impacts) (Rennings, 2000). Eco-innovation thus produces positive knowledge and environmental externalities. This double externality arises because the benefits of eco-innovation are often not fully captured by the innovator firm, leading to underinvestment in eco-innovation. Because firms find it difficult to appropriate the benefits of eco-innovation because of problems of imitation, ineffective environmental policies, and the greater uncertainty in the return of investments compared to innovations, appropriability is a relevant problem for eco-innovation research and for environmental and innovation policy.

How and why eco-innovating firms use appropriability mechanisms and how to effectively appropriate the benefits of eco-innovation is a research problem that has been little studied in the innovation literature (Malen & Marcus, 2019). This research aims to improve our understanding of the processes and motivations behind eco-innovation in firms through the use of appropriability mechanisms, as well as the appropriation of the benefits derived from such eco-innovations. The general objective of this research is developed through four specific objectives:

- To uncover the internal structure of the eco-innovation field by looking into its underlying knowledge and conceptual base.
- To analyze the influence of formal and informal appropriability mechanisms and the moderating role of marketing capability on firm's eco-innovation.
- To analyze how firms eco-innovate by combining open innovation strategies with appropriability.
- To analyze how rice farmers' organizations appropriate the benefits of their production process by combining designation of origin and marketing strategies.

1.2. Contribution of the Thesis

There is an agreement in eco-innovation studies that market failures associated with eco-innovation prevent firms from capturing value and maximizing profits (e.g., knowledge and environmental externalities, asymmetric information, and market power) (Ambec et al., 2013). For firms to fully realize their profit potential, eco-innovation scholars have emphasized the pivotal role of environmental regulation. This distinction makes regulation play an important role in triggering eco-innovation (Horbach et al., 2012, 2013). Thus, literature has provided evidence on how and to which extent well-designed environmental regulations can promote eco-innovation in firms (Porter, 1991; Porter & van der Linde, 1995).

In this sense, environmental regulations can increase R&D investments associated with environmental technologies by forcing compliance with standards that generate lower environmental impacts and make cleaner production or end-of-pipe technologies relatively more viable options. In this context, appropriability mechanisms play a complementary role in environmental regulations. The eco-innovation literature has placed emphasis on resolving technological knowledge externalities and asserts that well-established property rights reduce imitation in R&D, thereby motivating investments in environmental technologies.

The appropriability problem of eco-innovation has been partially addressed in the literature by using a regulatory perspective and emphasizing technological investments and knowledge externalities. This thesis contributes to understanding how firms can fully capture the value of their eco-innovation by examining from the profiting from innovation framework how appropriability stimulates firm eco-innovation and how firms appropriate the value of their eco-innovation.

One contribution of this thesis is to point out that appropriability is a topic that has been little studied in eco-innovation literature. How firms that develop and adopt green technologies capture the value of their eco-innovations is an important aspect of understanding why and how firms eco-innovate. As mentioned earlier, eco-innovation has characteristics that distinguish it from other innovations, such as knowledge and environmental externalities. This makes the drivers of eco-innovation different from those of other innovations (Díaz-García et al., 2015a). Thus, this thesis integrates the profiting from innovation framework into the eco-innovation literature and develops the arguments under which appropriability mechanisms influence eco-innovation.

Firms rely on appropriability mechanisms and complementary assets to capture the benefits of their innovations. Combining appropriability strategies with complementary assets (such as manufacturing capacities, distribution channels, marketing and advertising capabilities, and specialized knowledge or skills) allows the firm to have greater control once its innovation is launched in the market (Teece, 1986, 2006). With eco-innovation, we show that both formal and informal mechanisms promote eco-innovation, highlighting the greater influence of informal (non-statutory) mechanisms. In an emerging economy, such as Colombia, informal mechanisms are more suitable for protecting eco-innovation. The complexity in the design and the industrial secret allows the firm to protect the core knowledge of environmental technologies in sectors where environmental regulations incentivize the wide use of these technologies.

Recent studies have shown the importance of external knowledge sources for eco-innovation (Ghisetti et al., 2015; Horbach et al., 2013). However, an open innovation strategy can create tensions when combined with an appropriability strategy. This thesis contributes to understanding how firms seek and protect their knowledge to create and capture value from eco-innovation, i.e., how firms combine openness and appropriability strategies to eco-innovate. We reveal that appropriability mechanisms can play a dual role by stimulating external collaboration and discouraging knowledge sharing. Appropriability mechanisms allow a firm to keep knowledge separated into pieces and thus decide what knowledge to share and what to keep secret.

Recently, the profiting from innovation literature has distinguished appropriability from appropriation. Appropriability refers to the potential to benefit from an innovation, which accrues through appropriability mechanisms. Appropriation refers to the realization of that potential, which manifests in private and social benefits when the instruments are employed in processes for exclusion, leverage, or disclosure (Hurmelinna-Laukkanen & Yang, 2022). Having shown evidence of the use of appropriability mechanisms in eco-innovation, this thesis then focuses on how value appropriation occurs when combined with complementary assets.

When firms use the designation of origin as a market differentiation and appropriability mechanism, they can share knowledge among competitors in the same geographical area and, in turn, protect against imitation by external competitors. The appropriation of benefits occurs by combining the designation of origin with the use of marketing strategies. The designation of origin gives a brand to companies, which is commercially exploited through the use of marketing strategies that allow them to sell the product at a higher price.

1.3. Theoretical Background

A firm's ability to capture value from its eco-innovation is a crucial determinant of innovation. The theoretical framework of appropriability of innovation explains how some companies succeed in appropriating the value of their innovation while others fail (Pisano, 2006; Pisano & Teece, 2007; Teece, 1986, 2006). This framework highlights the importance of the innovative firm possessing and effectively using some form of protection to prevent competitors from imitating and capturing the value of its innovations.

The innovating company can protect the value of its innovations by using appropriability mechanisms and combining them with complementary assets. One way to classify the mechanisms widely used in literature is to classify them as formal and informal. Formal mechanisms confer exclusivity rights to the innovative firm. These mechanisms include intellectual property rights (IPRs) -such as patents, trademarks, industrial designs, utility models, and copyright- contracts and labor legislation (Hurmelinna-Laukkanen et al., 2008; Teece, 1986). Informal mechanisms are non-statutory means of intellectual property protection, such as secrecy and complexity in design (Gallié & Legros, 2012). Formal mechanisms provide institutional protection by relying on legal protection efficacy, while informal mechanisms depend on the firm's knowledge management systems and the tacit knowledge to be protected.

Besides appropriability mechanisms, a firm needs complementary assets to capture the value of an innovation. Complementary assets are resources and capabilities that are needed to capture the value of an innovation (Hurmelinna-Laukkanen & Yang, 2022; Teece, 2018). While appropriability mechanisms can prevent imitation of an innovation by competitors, complementary assets are only loosely coupled to innovation and may exist independently of the innovation. In other words, they are assets that complement the core innovation and enable it to be more valuable to customers. Examples of complementary assets include distribution channels, marketing expertise, customer relationships, and other technologies that are needed to make innovation work effectively. The Profiting from Innovation framework emphasizes the importance of complementary assets in value capture and suggests that innovators should focus on developing and controlling complementary assets in order to capture a larger share of the value they create.

Although the private returns to innovation have been more extensively studied, innovations also produce social returns (Hurmelinna-Laukkanen & Yang, 2022; Teece, 2018). Social returns are the benefits that an innovation brings to society. It goes beyond the private benefits obtained by the innovator. These benefits encompass technological advances, a broader knowledge base, an expanded market, or other externalities. Social returns are a natural result of introducing an innovation and the subsequent diffusion of knowledge (Hurmelinna-Laukkanen & Yang, 2022). While social returns primarily focus on the advantages for parties other than the innovator, innovators themselves can benefit from these social returns. In other words, the positive impact on society can also create favorable conditions for the innovator, leading to further benefits for them.

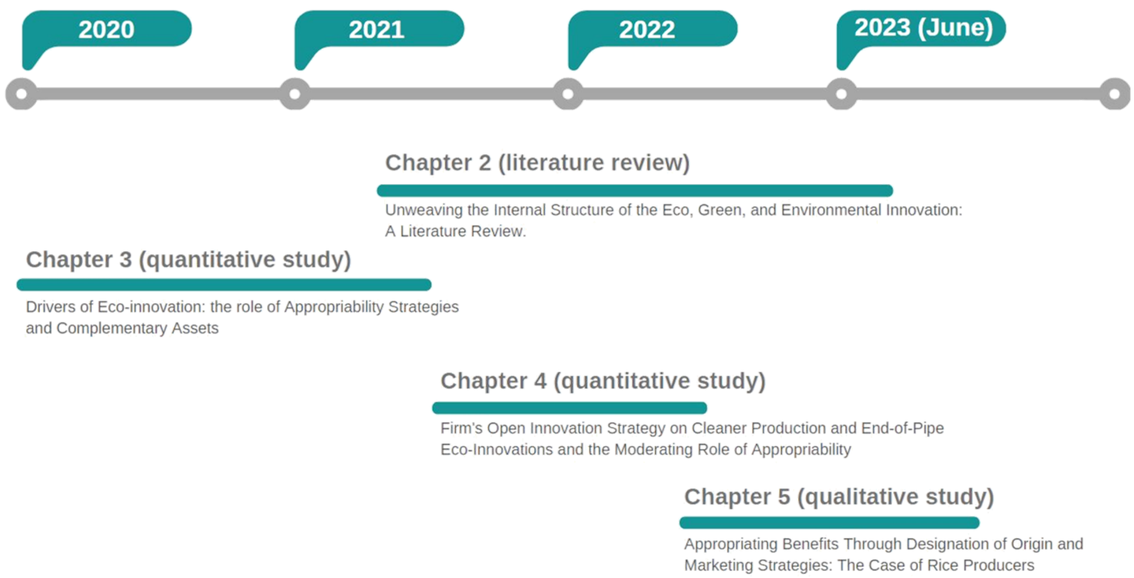
The environmental externalities derived from eco-innovations can be framed as social returns according to the profiting from innovation framework. The environmental benefits derived from an eco-innovation is the value that the innovating company develops and translates in the form of reduced environmental impacts. One way in which the firm can leverage these benefits is through reputational improvements that increase market share or through marketing strategies that allow access to specific consumer niches that value these attributes more highly.

1.4. Structure of the Thesis

This thesis comprises this introduction, four empirical chapters (2 to 5), the conclusions (chapter 6) and the references. The introduction states the problem, contributions, theoretical background, structure, and overview of the empirical chapters.

Different research methods were used to develop the four empirical chapters. Chapter 2 is a systematic literature review of the eco-innovation field and combines bibliometric techniques with text analysis. Chapters 3 and 4 are quantitative studies, and Chapter 5 is a qualitative chapter. The four empirical chapters were written over a period of three and a half years (2020-2023). The order of the chapters does not reflect the order in which they were written. Chapters 3, 4, and 5 follow a chronological order in which they were developed, while the literature review was a cross-sectional chapter throughout the thesis. The literature review was developed in parallel to Chapters 3 to 5 as the author was introduced to the debates in the eco-innovation literature, learning about the main approaches and questions in the field, as well as learning the techniques needed to answer the research question of the literature review. This chronology can be visualized in Figure 1.

Figure 1. Chronology of the chapters.



Chapter 2 introduces the reader to the eco-innovation field of eco-innovation. This review identifies the building blocks and topics addressed by the eco-innovation literature. It aims to give a full picture of the development of the field. Chapter 3 focuses on the relationship between appropriability and eco-innovation and applies the framework of appropriability of innovation to examine the influence of appropriability mechanisms in the adoption of eco-innovations in manufacturing firms in Colombia. Chapter 4 broads the concept of eco-innovation to the most discussed eco-innovation typologies in the literature: cleaner production and end-of-pipe innovations. Here, the relationship between appropriability mechanisms and types of eco-innovation is explored by considering that firms use open innovation strategies to eco-innovate. Chapter 5 goes beyond the use of appropriability mechanisms and focuses on the process of benefit appropriation. This chapter explains how producer organizations use appropriability mechanisms to obtain benefits from their production processes.

1.5. Overview of the Four Empirical Chapters

The first chapter (2) is a literature review that traces the internal structure and conceptual building blocks of eco-green and environmental innovation literature. Despite over two fast-growing decades of research, the eco-innovation field remains characterized by overlapping, ambiguous concepts and causal links, needing a comprehensive theoretical framework. Our review aims to systematize past debates and developments, reveal the major topics driving the field, and propose venues for future theoretical advancement. To accomplish this, first, we will conduct a quantitative literature review of articles published between 1992 and 2022 using co-citation and factor analysis to uncover the major scientific subfields forming the conceptual bases of eco-innovation literature and their relationships. Then we will apply a probabilistic and structured Topic Model analysis (Latent Dirichlet Allocation LDA) of the papers' titles, abstracts, and keywords to identify the emergent themes and conceptualizations that closely represent and predict the field's evolution. Next, we will review the most cited and groundbreaking papers to review state-the-art and future research lines comprehensively.

Chapter 3, titled Drivers of Eco-innovation: the role of Appropriability Strategies and Complementary Assets, examines the implications of combining appropriability mechanisms and complementary assets to influence eco-innovation in companies. A crucial driver of innovation is a firm capacity to capture value from their knowledge efforts. In this sense, appropriability is a key concept in innovation studies. How can innovators protect and benefit from their innovations so that they are motivated to innovate? Literature has stressed how environmental externalities broaden and worsen this appropriability problem, as competitors and society might also benefit from the value created by eco-innovation.

To increase the capacity to capture value from econ-innovation, firms might implement intellectual property rights -IPR- and knowledge management strategies such as industrial secrecy and complex design to exclude others from profiting from their innovative efforts. As IPR and informal mechanisms can only partially protect firms' knowledge, firms complement this knowledge protection and value-capturing strategies by developing complementary assets such as marketing capabilities that maximize firms' capacity to profit from eco-innovation.

This chapter tests this idea by analyzing how knowledge protection mechanisms and complementary assets influence eco-innovation. We contribute to the literature by integrating the eco-innovation literature and the profiting from innovation framework to provide a better understanding of the contingent effect of formal and informal mechanisms for firms' eco-innovation when combined with complementary assets. We developed a panel data regression model to test the influence of formal and informal appropriability mechanisms and the moderating effect of complementary assets. Our results reveal that marketing capability strengthens formal and informal mechanisms; nevertheless, this complementarity differs as a firm increases the use of appropriability mechanisms. Surprisingly, informal mechanisms (e.g., complexity design and industrial secrecy) are more relevant than statutory mechanisms for eco-innovation. Marketing capability enhances the effect of appropriability mechanisms by differentiating eco-innovation from other technologies in the market. Still, higher investments in marketing divert economic resources away from knowledge protection, especially in small firms.

Chapter 4 is titled Firm's Open Innovation Strategy on Cleaner Production and End-of-Pipe Eco-Innovations and the Moderating Role of Appropriability. This chapter starts from the tension between open innovation and appropriability to analyze how both strategies can coexist to influence different eco-innovation. Eco-innovation drives firms to seek knowledge and information that goes beyond their boundaries. At the same time, firms eco-innovating produce knowledge and environmental externalities that hinder them from benefiting from eco-innovation. The search for and protection of knowledge to create and appropriate the value of eco-innovation implies that firms simultaneously must manage openness and appropriability strategies. By extending the open innovation and appropriability frameworks in the eco-innovation literature, we explain how appropriability reinforces the positive influence of a firm's openness on its adoption of cleaner production and end-of-pipe eco-innovations. Based on panel data regression fixed effects, we show that the breadth of knowledge sources positively influences the adoption of cleaner production and end-of-pipe eco-innovation. The results show appropriability strengthens the breadth of a firm's knowledge sources for its adoption of eco-innovation in both cleaner production and end-of-pipe.

Chapter 5 is titled Appropriating Benefits Through Designation of Origin and Marketing Strategies: The Case of Rice Producers. This chapter examines how organizations have implemented a designation of origin combined with marketing strategies to differentiate their products and appropriate their value. These strategies simultaneously protect and promote imitation. The appropriability of the innovation framework emphasizes protection and profit as central aspects of appropriability but has paid little attention to the coexistence of processes that exclude and at the same time allow imitation. We use the case of Colombian rice producers' organizations to examine the process of appropriating the value of their eco-innovations and local practices by implementing the designation of origin and marketing strategies. We argue that the designation of origin encourages working collectively to have minimum quality standards for a product in a territory, which fosters collaboration between farmers' organizations. Simultaneously, it protects the production process so that its recognition is associated with a specific geographical area. Designation of origin serves as a mechanism for differentiation and protection by transforming the reputation of rice into a higher price. We have also argued that the designation of origin alone does not benefit appropriation and that it needs to be complemented by marketing strategies that promote and sell the product to different segments of consumers.

Chapter 2

2. Unweaving the Internal Structure of the Eco, Green, and Environmental Innovation: A Literature Review

2.1. Introduction

Eco, green and environmental innovation (hereafter eco-innovation) are used to designate how managers integrate environmental concerns into the firms' strategy through innovation. In its over twenty-year history, the eco-innovation field has expanded in scope to encompass a variety of themes studied with a range of theoretical lenses. These multidisciplinary efforts triggered a proliferation of overlapping and ambiguous concepts which have characterized the eco-innovation field and stimulated its growth but also attracted criticism. For example, scholars have not yet intentionally considered and agreed upon a comprehensive theoretical framework to provide guidelines, common ground, or even shared language in this research domain (De Marchi, 2012; del Río et al., 2016). The richness of exploration that integrates disciplines such as economics, business, management, and engineering can be seen as natural, but it is also characterized by evident conceptual ambiguity, unwarranted argumentations and generally, a lack of theoretical integration (Franceschini et al., 2016; He et al., 2018).

Although some progress in integrating ideas that adequately address how and why firms develop and adopt eco-innovations was made (Dangelico et al., 2017), the concept of eco-innovation is fragmented. Eco-innovation relies on diverse knowledge streams and as such at a systemic level it must account for specific ecosystem aspects including as environmental externalities and the interaction between ecological, social, and institutional systems (Horbach, 2008; Jaffe et al., 2005; Rennings, 2000). Therefore, we study the internal structure of the eco-innovation field by looking into its underlying knowledge and conceptual base. This should be recognized as an important step towards disentangling the internal structure and the conceptual building blocks of the field despite some reservations regarding the feasibility of the task (Cainelli et al., 2012).

The main risks for any growing empirical body of research characterized by theoretical underdevelopment and conceptual ambiguity are that of proliferating false implications and poor causal relations that generate misuse of resources and misguided societal priorities. The approach proposed in this paper helps researchers understand the intellectual structure of the eco-innovation field, the extent of the scientific subfields that integrate and their interdependencies, and the possible paths that can lead to a coherent and integrated framework of thought. Only by addressing these tasks is it possible to uncover the common elements that have agglutinated a rapidly growing field, analyze, and uncover the most promising venues that eco-innovation research can take within a coherent framework of analysis. Therefore, this chapter aims to systematize past developments, reveal the main topics that represent the eco-innovation field, and propose venues for future theoretical advancement.

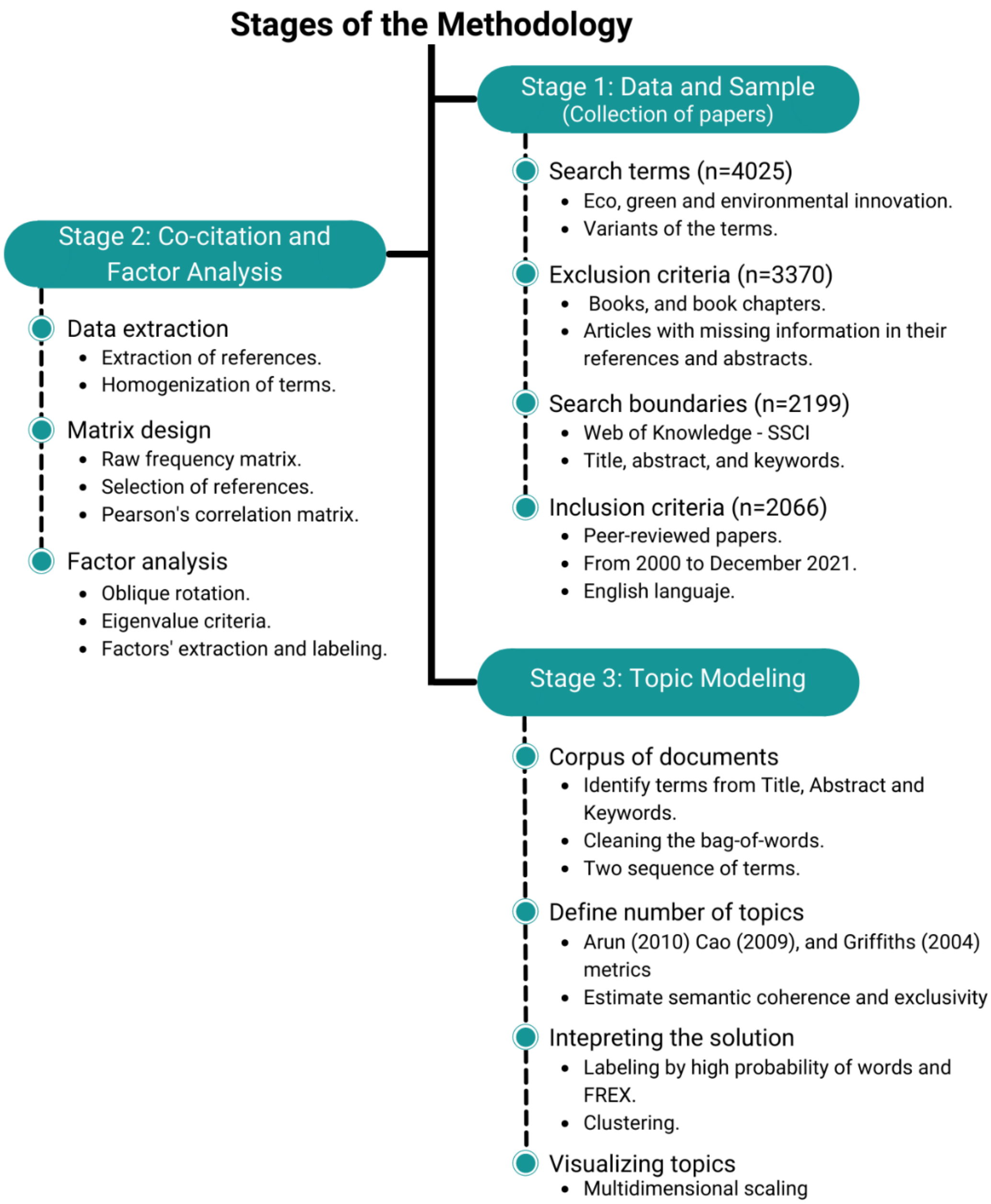
We conduct a literature review to uncover the intellectual structure of the eco-innovation field. For this purpose, 2061 articles published between 1992 and 2021, representing 51% of the academic writings on eco, green and environmental innovation, are retrieved from the Web of Science database. By using co-citation and factor analysis the major scientific subfields inform the knowledge base of eco-innovation, and their relationships are uncovered. Then, by applying latent Dirichlet allocation, a topic modeling technique, we identify the topics that closely represent the field and the inferred interconnections.

The description of the methodology is presented in the next section. Then the list of the main scientific subfields of eco-innovation is described as well as the associated topics. Finally, we offer a discussion of the findings, present the conclusions, possible limitations and propose venues for future research.

2.2. Methodology

To trace the intellectual structure of the eco-innovation field we identify its scientific subfields and major topics by first conducting a systematic literature review that relies on a well-established and replicable process (Snyder, 2019). The intellectual structure of a research field refers to the set of ideas used in creating new knowledge (Cole, 1983; Shafique, 2013). When ideas are identified as closely related, they are grouped in scientific specialties which represent subfields in the scientific literature that internally exhibit high levels of citation activity (Small, 1973).

Figure 2. Three-stage Methodology.



A systematic literature review allows tracking the steps and decisions and minimizes the potential bias related to the search and selection of research studies (Tranfield et al., 2003). A replicable three-stage methodology was designed for this empirical chapter aiming at uncovering the intellectual structure of the eco-innovation field (Figure 2). The first stage follows a systematic process for searching and selecting relevant research studies (Snyder, 2019). The second and third stages of the methodology apply bibliometric and statistical techniques for data processing and analysis. At stage two, co-citation and factor analysis allow us to identify the major scientific subfields in eco-innovation and the relationships among them, while at stage three the application of a topic modeling technique allows to discover the topics that represent the corpus of scientific papers in eco-innovation.

2.2.1. Data and sample

The unit of analysis chosen for this chapter is academic research papers published in scientific journals. Such research products allow identifying the knowledge base of a scientific field through the structure of their references (Zupic & Čater, 2015). Scientific research papers in the eco-innovation literature are identified by using the search strings "eco-innovation", "green innovation" and "environmental innovation", and their variants. These terms are validated in previous research (Díaz-García et al., 2015a; Türkeli & Kemp, 2018) as the terms "eco", "green", and "environmental" innovation are used interchangeably. Articles addressing sustainability-oriented innovation are excluded because this broader concept confers equal importance to ecological, social, and economic aspects and itself constitutes another research field (Klewitz & Hansen, 2014), while the narrow focus of the present chapter is on the environmental aspect specifically.

Table 1. Search query and criteria for selection of documents.

Criteria	Search query	Results
WoS	(TS=("eco-innov*" OR "ecoinnov*" OR "green innovat*" OR "green product innovat*" OR "environment* innovat*"))	4025
Including articles, reviews, books and editorial material	((TS=("eco-innov*" OR "ecoinnov*" OR "green innovat*" OR "green product innovat*" OR "environment* innovat*"))) AND (DT==("ARTICLE" OR "EARLY ACCESS" OR "REVIEW" OR "BOOK CHAPTER" OR "BOOK" OR "EDITORIAL MATERIAL"))	3370
Social Science Citation Index		2199
Only articles		2069

The database comprises peer-reviewed papers published in English between January 1992 and December 2021. Peer-reviewed papers are expected to provide novel contributions with a focus on theoretical or conceptual insights related to the phenomenon and apply scientific rigor while expanding the knowledge domain. Although the role of firms in the natural environment was manifested in 1987 with the Brundtland report, it was not until 1992 when researchers published the first scientific papers, the year which is considered the birth year of the field.

Database representativeness is an important aspect of the chapter of scientific activity (Mongeon & Paul-Hus, 2016). Web of Science and Scopus databases are the two major sources of bibliometric data, making them suitable for bibliometric analysis for international and multidisciplinary research domains. Since previous studies found that the information contained in both databases is rather similar (Archambault et al., 2009), choosing one over the other database depends on additional consideration such as the coverage of the specific subject area and the scope of the chapter. The bibliometric information for this chapter is retrieved from the Social Science Citation Index of the Web of Science database, as it is the most frequently used bibliometric source in the domain of innovation (Shafique, 2013) and it provides cross-disciplinary data from 58 social sciences disciplines.

The search query was performed in December 2021. Initially, 4025 documents were retrieved. After delimiting the query to only scientific papers, 2069 documents remained. Then, the information in the database was checked for missing information in relation to the references lists, and eight papers were dropped. As a result, the final database consists of 2061 papers. The database represents 51.2% of all documents on eco, green and environmental innovation contained in the WoS database.

2.2.2. Empirical strategy: co-citation, factor analysis, and topic modeling

Co-citation and factor analysis

Co-citation occurs when two distinct documents are cited together by a third one, and as such a co-citation emerges as a relationship that authors establish by citing two documents together (Small, 1973). Arguably the phenomenon expressed by co-citation implies that the more frequently two articles are cited simultaneously, the stronger is the relationship attributed by the citing authors (White & Griffith, 1981). Therefore, the frequency with which two documents are cited together can be used as a measure of similarity that is recognized and manifested by researchers in a scientific field (McCain, 1990; Small, 1973). Subsequently, co-citation allows to trace relationships between ideas and track their interconnectedness within a scientific field.

Since documents embody knowledge, two co-cited documents represent knowledge combinations in a scientific field (Small, 1973). In this way, high co-citation frequency also reveals the relevance of prior works that influence a field, specifying the key primary ideas on which new insights are built. A set of highly co-cited documents makes up the seminal works of a field (Small, 1973). When these core documents in a field are identified, they can be used as a proxy for the intellectual structure of a scientific field.

Identifying the core documents of any research field through a co-citation analysis has to be a rigorous process, since selecting too large of a number of documents will introduce unnecessary noise to the results as documents with little explanatory value are taken into account (Nerur et al., 2008). On the other hand, including only a few documents will exclude some of the most relevant ideas in a field (Acedo et al., 2006). There is no consensus in literature about the procedure of how to select the core documents or authors affiliated with a field of study. Previous studies have used a wide range of strategies depending on the specific research objective. Some of the most common strategies include selection of highly cited documents or authors (Nerur et al., 2008; Ramos-Rodríguez & Ruíz-Navarro, 2004; Tsai & Wu, 2010) and the snowball sampling, which starts from selected core documents and the sampling extends to other related works (Acedo et al., 2006; Shafique, 2013).

In the present chapter, 78,724 cited documents were extracted from the 2,061 research articles that represent the scientific field of eco, green and environmental innovation. Subsequently, all cited documents were used to select the core documents, and an initial co-citation matrix was obtained to quantify the frequencies with which the 78,724 documents were co-cited in the 2,061 research articles.

Previous studies have used a single cut-off threshold of the top 100 documents (Shafique, 2013) to identify core documents. This research uses an alternative approach to avoid spurious selection and eliminate subjective bias. Four co-citation matrices were retrieved using the top 60, 70, 80, and 100 most cited documents, and then results were compared. These iterations with different numbers of documents provide guidance to exclude documents that do not contribute to the interpretability of the results and prevent omitting relevant documents. (The detailed appendix for each iteration is available as an online supplement.

Previous research has used factor analysis, cluster analysis, multidimensional scaling, and network analysis to reduce the dimensionality of large co-citation matrices (McCain, 1990; Zupic & Čater, 2015). In this chapter, factor analysis is performed. Factor analysis treats the main diagonal in each co-citation matrix and converts the frequency co-citation matrix into a correlation matrix. Values in the main diagonal are assumed to be missing because it is impossible for a document to be cited by itself. Since a matrix with the frequency of co-citations suffers from scale effects, it is preferred to use a standardized measure, such as Pearson's correlation (McCain, 1990). Therefore, each matrix with co-citation frequency is converted to a Pearson's correlation matrix using pairwise deletion for managing missing values (McCain, 1990).

Eigenvalue criteria are used to assess the proper number of factors extracted from each correlation matrix. For the correlation matrices generated by 60, 70, 80, and 100 documents, the eigenvalue criteria ≥ 1 suggests retaining six factors in each matrix, and seven factors for the matrix of 100 documents. As the number of most cited documents increases, the number of potential factors also increases. Then, factor axes were rotated using oblique rotation with the oblimin method. For this chapter, oblique rotation is the most appropriate as it allows documents to contribute to multiple factors, producing accurate and comparable factor loadings (Schmitt, 2011). Therefore, documents contributing to several factors indicate their bridging function, suggesting intercorrelations between the orthogonal dimensions represented by the underlying factors.

The selection of the most appropriate factor solution is based on the criteria of comprehensibility and parsimony. First, the factor analysis with different numbers of co-cited documents produced similar factors and corresponding factor loadings. Such data structure robustness ensures that the factors' interpretability does not change as the number of co-cited documents varies.

Although the matrix with 60 co-cited documents produces the factor solution that has the highest explained variance, some documents have factor loadings greater than 1, indicating a possible overfit. The six-factor solution with 70 documents produces adequate factor loadings under the standard assumptions of factor analysis. Therefore, the six-factor solution from the 70 co-cited documents is the factorial solution with the best interpretability and parsimony. (See online supplement for details of the factor analysis).

The six-factor solution from the 70 co-cited documents is reported using a loadings threshold of ±0.3 to ensure statistical and practical significance. The six factors are proxies for the major scientific ideas and are defined by the seminal papers in the field (Small, 1973). To interpret the six factors, documents with loadings higher than ±0.7 were selected since they measure the contribution of a document to a factor (McCain, 1990; Vogel & Güttel, 2012). A higher positive factor loadings suggest a greater influence of a document in interpreting a factor, and documents with loadings in more than one factor indicate possible connections between factors (Acedo et al., 2006). Then, the selected documents are reviewed and grouped into the corresponding factor to assign a meaningful label to each scientific subfield.

In order to uncover the interconnection between subfields, a correlation matrix between factors is also estimated. A higher correlation between two subfields shows a stronger relationship and a lower score indicates possible independence of the subfields.

Topic modeling

Topic modeling is an unsupervised machine learning technique that helps to discover the topic structure in a corpus of documents. In topic modeling, the documents are the observable structure, while topics and topic-document and topic-word relationships constitute the hidden structure to be uncovered. We used latent Dirichlet allocation (LDA), a generative probabilistic model that allows uncovering the topics in a collection of documents. The LDA algorithm defines a joint likelihood distribution on both observed and hidden random variables and identifies the conditional distribution of hidden variables. In this way, LDA creates a bag-of-words from which topics emerge. An assumption of the LDA model is that the order of the papers does not matter (Blei, 2012; Blei et al., 2003). This assumption is unrealistic in this case, as recent scientific papers have developed from information from preceding papers and the volume of scientific papers in eco-innovation has substantially increased over time. Relaxing this assumption is important and allows topics to vary over time. To capture the relationship between topics and time of publication, a structural topic model is employed to incorporate information of documents into the LDA model (Roberts et al., 2019) and the year of publication of each document is included to estimate the final topic modeling.

Topic modeling requires two specific parameters: document corpus and number of topics to be specified. In this chapter, the document corpus is 2061 scientific articles representing the eco-innovation field. Each article is characterized by its title, abstract, and keywords, because these three strings of text synthesize and signal an article's core contribution. The bag-of-words is optimized by lowercasing all characters, removing punctuation signs, symbols, numbers, URLs and excluding stop-words without semantic meaning (e.g., literature, however). The bag-of-words is generated using unigrams and includes 134,068 terms.

Topic modeling assumes that the number of topics that best represent the corpus is known beforehand (Arun et al., 2010). This demands that the adequate number of topics for a corpus be identified. However, there is not one best method to determine the optimal number of topics.

Two methods are used to identify the number of topics for the corpus of documents in this chapter. The first method estimates a topic range using three metrics: the range of topics should be the one minimizing the proposed metrics by Arun (2010) and Cao (2009) and maximizing the metric proposed by Griffiths (2004). Based on this method, the optimal range of topics for this chapter is between 16 and 25 (Figure A-1 in Appendix A).

The second method estimates semantic coherence (Mimno et al., 2011) and exclusivity (Airoldi & Bischof, 2016; Bischof & Airoldi, 2012). Semantic coherence measures the relationship between words in a topic. Higher semantic coherence occurs when more likely words in a topic co-occur more frequently (Mimno et al., 2011). Thus, higher semantic coherence is desirable when selecting the number of topics. Higher exclusivity of words reflects a higher likelihood that words provide specific content in a topic (Bischof & Airoldi, 2012). 21 topics optimize both semantic coherence and exclusivity (Figure A-2 in Appendix A).

To interpret the 21-topic solution of the eco-innovation corpus, a label for each topic was assigned based on the ten words with the highest probability specific to each topic and the ten words with the highest frequency-exclusivity (Airoldi & Bischof, 2016; Bischof & Airoldi, 2012). The subsequent sections contain the results of the analyses.

2.3. Scientific Subfields and Topics in Eco-innovation

2.3.1. Interpreting the scientific subfields and their relatedness

The co-citation and factor analysis reveals six underlying factors that emerged from the 70 core documents and represent a parsimonious model of the knowledge base of the eco-innovation field. Table 1 contains the most frequently co-cited documents in the eco-innovation field. Eigenvalues indicate that, together, the six factors accumulate 90% of the explained variance.

The 70 core documents were published from 1977 to 2018 (41 years) in 32 journals; 73.4% of documents are published in journals classified in the social sciences according to the WoS journal classification (economics, business, management, psychology, and ethics); 20% of documents are published in journals combining social and environmental sciences, and 6.6% are published in journals encompassing social, environmental sciences and engineering.

The first scientific subfield (factor 1) refers to corporate environmental management. Studies grouped in this subfield focus on the antecedents and influence of eco-innovation on the firm competitive advantage (Y. Chen et al., 2006). In addition, seminal papers in this subfield chapter green management practices (Chiou et al., 2011; R.-J. Lin et al., 2013). Researchers highlight organizational practices that integrate internal and external aspects for eco-innovating (Li et al., 2018). The theoretical background of this scientific subfield has been based on the resource-based perspective and institutional theory and more recent works have adopted the construct of dynamic capabilities, which identifies external and internal resource integration, resource creation and reconfiguration as pillars of the sustainability-oriented ordinary capabilities framework (Dangelico et al., 2017).

The second scientific subfield (factor 2) analyzes eco-innovation from the perspective of managerial activities. The managerial activities are non-binding instruments such as environmental management systems (EMS), environmental management and auditing systems (EMAS), product life cycle assessments, waste disposal or recovery systems, informing consumer, and environmental labeling, which are part of an overarching environmental policy. Studies in this field have highlighted the limited stimulus for firms considering the adoption of eco-innovation and measuring its impacts (Rehfeld et al., 2007).

The body of research in the subfield of environmental regulation (factor 3) highlights how properly designed environmental regulations improve firms' competitiveness and environmental performance by fostering the design and implementation of eco-innovations (Porter, 1991; Porter & van der Linde, 1995). This proposition has triggered extensive academic debate, and it is widely known as the Porter Hypothesis(Ambec et al., 2013). In the field of eco-innovations, this subfield has the longest period of development (1991-2013). Environmental regulations here are understood as mainly market-based instruments, such as technology standards, environmental taxes, and tradable emissions.

The fourth subfield (factor 4) focuses on the determinants of eco-innovation. This subfield has put much effort into identifying and testing the different drivers of firm-level eco-innovation. Literature reviews stand out as the most important to making sense of the numerous firm-level empirical studies. The drivers of firm-level eco-innovation are classified into external and internal according to their relationship to firms (Bossle et al., 2016); by the phases of development and diffusion, and according to the type of eco-innovation (Hojnik & Ruzzier, 2016); by the country's development stage (Cai & Zhou, 2014); and according to their effect on firm performance (Cai & Li, 2018), among other criteria.

The fifth subfield (factor 5) constitutes the Natural-Resource-Based View of the Firm (NRBV). This subfield is grounded in the strategic management field and represents a balanced approach between an organization and its environment (Aragón-Correa & Sharma, 2003). A premise in this subfield is that strategy and competitive advantage depend on capabilities that are in harmony with the natural environment and society (Hart, 1995). This subfield broadly considers which firms' strategies lead to environmentally sustainable activities and is not limited to eco-innovation alone.

The sixth subfield (factor 6) stands for an open eco-innovation approach. This is one of the most recent subfields, and most of the core papers were published during the period 2012-2015. The studies emphasize the need to understand the drivers of eco-innovation beyond those of corporate nature (Cainelli et al., 2012). These studies highlight cooperation for innovation, knowledge transfer and sharing within companies and network activities, as well as the resources needed to leverage the adoption and development of innovations.

Table 2. Document loadings by factor.

Author	Year	Journal	F1	F2	F3	F4	F5	F6
Chiou Ty	2011	Transport Res E-Log	0.98					
Lin Rj	2013	J Clean Prod	0.97					
Chang Ch	2011	J Bus Ethics	0.96					
Chen Ys	2008	J Bus Ethics	0.92					
Chen Ys	2006	J Bus Ethics	0.88					
Li Dy	2017	J Clean Prod	0.85			0.32		
Dangelico Rm	2017	Bus Strateg Environ	0.79					
Eiadat Y	2008	J World Bus	0.79					
Dangelico Rm	2016	Bus Strateg Environ	0.78					
Dangelico R	2010	J Bus Ethics	0.76					
Baron Rm	1986	J Pers Soc Psychol	0.68				0.35	
Fornell C	1981	J Marketing Res	0.63				0.42	
Podsakoff Pm	2003	J Appl Psychol	0.61				0.39	
Schiederig T	2012	R&D Manage	0.54			0.51		
Pujari D	2006	Technovation	0.49	0.34				
Berrone P	2013	Strategic Manage J	0.47					
Wagner M	2008	Ecol Econ		0.98				
Rehfeld Km	2007	Ecol Econ		0.86				
Rennings K	2006	Ecol Econ		0.83				
Frondel M	2007	Bus Strateg Environ		0.82				
Wagner M	2007	Res Policy		0.77				
Demirel P	2011	Ecol Econ		0.69				
Kammerer D	2009	Ecol Econ		0.66				

Gonzalez Pd	2009	Ecol Econ		0.61				
Frondel M	2008	Ecol Econ		0.58	0.35			
Horbach J	2008	Res Policy		0.53				
Veugelers R	2012	Res Policy		0.47				0.36
Horbach J	2012	Ecol Econ		0.45				0.31
Beise M	2005	Ecol Econ		0.42	0.34			
Kesidou E	2012	Res Policy		0.41		0.33		0.32
Rennings K	2000	Ecol Econ		0.39				
Porter Me	1995	J Econ Perspect		0.38	0.35			
Porter Me	1991	Sci Am			1.00			
Lanoie P	2011	J Econ Manage Strat			0.97			
Ambec S	2013	Rev Env Econ Policy			0.94			
Lanjouw Jo	1996	Res Policy			0.93			
Jaffe Ab	1997	Rev Econ Stat			0.90			
Johnstone N	2010	Environ Resour Econ			0.87			
Brunnermeier Sb	2003	J Environ Econ Manag		0.33	0.70			
Jaffe Ab	2005	Ecol Econ			0.65			
Ghisetti C	2014	J Clean Prod			0.31			
Bossle Mb	2016	J Clean Prod				0.85		
Hojnik J	2016	Environ Innov Soc Tr				0.81		
Cai Wg	2018	J Clean Prod				0.81		
Boons F	2013	J Clean Prod				0.79		
Cai Wg	2014	J Clean Prod				0.75		
Diaz-Garcia	2015	Innov-Organ Manag				0.74		
Cheng Ccj	2014	J Clean Prod				0.68	0.44	
Klewitz J	2014	J Clean Prod				0.64		
Lee Kh	2015	J Clean Prod				0.58		
Triguero A	2013	Ecol Econ		0.34		0.46		0.31
Carrillo-Hermosilla	2010	J Clean Prod				0.45		
Kemp R	2007	Final Report Mei Pro		0.31		0.40		
Oltra V	2009	Technol Forecast Soc				0.30		
Aragon-Correa Ja	2003	Acad Manage Rev					0.91	
Hart Sl	2011	J Manage					0.91	
Russo Mv	1997	Acad Manage J					0.89	
Teece Dj	1997	Strategic Manage J					0.74	
Hart Sl	1995	Acad Manage Rev					0.71	
Barney J	1991	J Manage	0.31				0.64	
Armstrong Js	1977	J Marketing Res	0.35				0.60	
Ambec S	2008	Acad Manage Perspect			0.38		0.48	
Dimaggio Pj	1983	Am Sociol Rev					0.35	
Ghisetti C	2015	Res Policy						0.76
Cainelli G	2015	J Clean Prod						0.73

Horbach J	2013	Ind Innov						0.66
Cainelli G	2012	Ind Innov		0.38				0.58
De Marchi V	2012	Res Policy		0.31				0.49
Cohen Wm	1990	Admin Sci Quart					0.30	0.43
Cuerva Mc	2014	J Clean Prod		0.30		0.39		0.41
Sum of squares (eigenv.)			12.87	12.66	10.75	10.08	8.68	7.67
Variance explained (%)			0.18	0.18	0.15	0.14	0.12	0.11
Cumulative variance (%)			0.18	0.36	0.51	0.66	0.79	0.90

Our results also suggest that scientific subfields are interconnected, as evidenced by the presence of core documents with a positive factor loading that bridge subfields and contributes to the interpretation of multiple areas (see Table 1). However, we also found that core documents with low factor loadings primarily mediate the connection between subfields. This indicates that while there is some evidence of shared knowledge among subfields, its impact on each other development is limited.

Table 2 shows the inter-factor correlations, indicating the degree of relationship between scientific subfields. The correlations between the subfields are all below 0.8, suggesting that over-factoring is not an issue and that the subfields are distinct from one another without any problems of discriminant validity. One relationship is between the subfield of the natural-resource-based view of the firm and corporate environmental management, where the former has influenced the latter. Specifically, the Natural-Resource-Based View of the Firm subfield has employed the resource-based theory (Barney, 1991) to elucidate how organizations interact with the environment.

Table 3. Inter-factor Correlation.

		F1	F2	F3	F4	F5	F6
Corporate environmental management	**F1**	1					
Organizational capabilities	**F2**	0.16	1				
Environmental regulation	**F3**	0.12	**0.64**	1			
Eco-innovation drivers	**F4**	0.32	**0.58**	0.29	1		
Natural-Resource-Based View of the Firm	**F5**	**0.72**	0.31	0.24	0.37	1	
Open eco-innovation	**F6**	0.09	**0.66**	0.36	**0.64**	0.25	1

Scores higher than 0.5 in bold.

The subfield of environmental organizational capabilities has a strong link with environmental regulation and open eco-innovation. The first relationship groups together different environmental policy measures that are distinguished by their degree of coercion. The intersection between these two specialties has been the analysis of the complementarity of environmental policy measures, such as EMS and regulatory measures. On the one hand, researchers have pointed out that environmental organizational measures and stricter environmental policy instruments, such as regulations, can function as complements to incentivize eco-innovation (Rennings et al., 2006). However, other studies show that managers may implement EMS to avoid major revisions to their production processes, so they will not make additional efforts, such as adopting eco-innovations, which would improve the environmental performance of their firms (Frondel et al., 2008).

Studies linking environmental organizational measures with open eco-innovation address how firms' network activities influence the adoption of environmental standards. Multinational firms benefit from cooperation with research institutes, as they allow acquiring knowledge on implementing environmental standards (Cainelli et al., 2012). There is a strong relationship between the determinants of eco-innovation and open eco-innovation. Studies bridging the two specialties have analyzed the relationship between internal and external factors of the firm associated with different types of eco-innovation. In particular, these studies have pointed out that managerial and technological capabilities within a firm and access to external knowledge do not explain product eco-innovation adoption.

Interconnectedness among the six scientific subfields of eco-innovation is at the thematic level. To determine the topics through which the subfields are linked, the following section discovers the topics that best represent the field of eco-innovation and seven groups the themes.

2.3.2. Facets of eco-innovation

We find evidence that the scientific subfields have developed different facets of the concept of eco-innovation, thus giving it a more tangible definition but without resolving completely the conceptual ambiguity that has characterized it since its beginnings. While studies in eco-innovation have endeavored to contribute to a concept sufficiently broad and satisfying to multiple disciplines and heterogeneous interests, a common denominator might be extracted. Eco-innovation has environmental benefits as its defining feature, and they cover the entire value chain of the firm, its organizational resources and competences and competitive advantage and highlight a wide range of benefits associated with the use of fewer resources (energy or materials), the substitution of scarce resources, the generation of less waste and increased recycling.

Individually, however, it is clear that subfields emphasize distinct eco-innovation aspects that sometimes contradict each other. For example, the corporate environmental management approach associates eco-innovation with a rational competitive reaction to meet external pressures. Studies recognize the role of eco-innovation in overcoming pressures from suppliers, customers, and regulators, and eco-innovation allows firms to avoid sanctions for environmental damage and legitimacy problems in the eyes of stakeholders(Y. Chen et al., 2006; Chiou et al., 2011).

Studies on organizational capabilities emphasize the so-called double externality as they perceive eco-innovation as simultaneously producing knowledge spillovers and environmental benefits. Here, management activities for eco-innovation comprise technological and environmental learning processes and activities such as marketing, recycling, eco-labeling, and informing customers that lead the firm to improve its understanding of innovations with environmental benefits (Wagner, 2008). A specific stream of the literature on resources and capabilities has approached pollution prevention as the deployment of measures to anticipate contaminant generation and stimulate greater involvement, coordination, and integration among employees (Aragón-Correa & Sharma, 2003; Russo & Fouts, 1997). Environmental regulatory pressures have drawn attention to the fact that the eco-innovation process can lead to win-win situations as eco-innovation allows a firm to simultaneously pollute less and can reduce costs or improve the quality of products (Porter & van der Linde, 1995). Uncovering the win-win opportunities, however, takes resources and requires a specific organizational setup, as firms choose to innovate in the eco domain not only with the mere objective of reducing pollution. There are much stronger drivers and motivations for innovation beyond the reduction of environmental burdens (Bossle et al., 2016) that link to the firm profit-maximizing objectives. Such an approach resonates with the concept of open eco-innovation. In this case, eco-innovations are defined in terms of their relative environmental impact regarding other technologies since these cannot have an absolute impact on the environment. This implies that any product or process that uses fewer resources or pollutes less is considered an eco-innovation (Horbach et al., 2013).

Although the NRBV does not explicitly refer to the term eco-innovation, it makes explicit that the relationship between a firm's environmental strategy and competitive advantage depends on the level of environmental improvements considered, e.g., pollution prevention, product stewardship, and sustainable development.

2.3.3. Topics in eco-innovation field

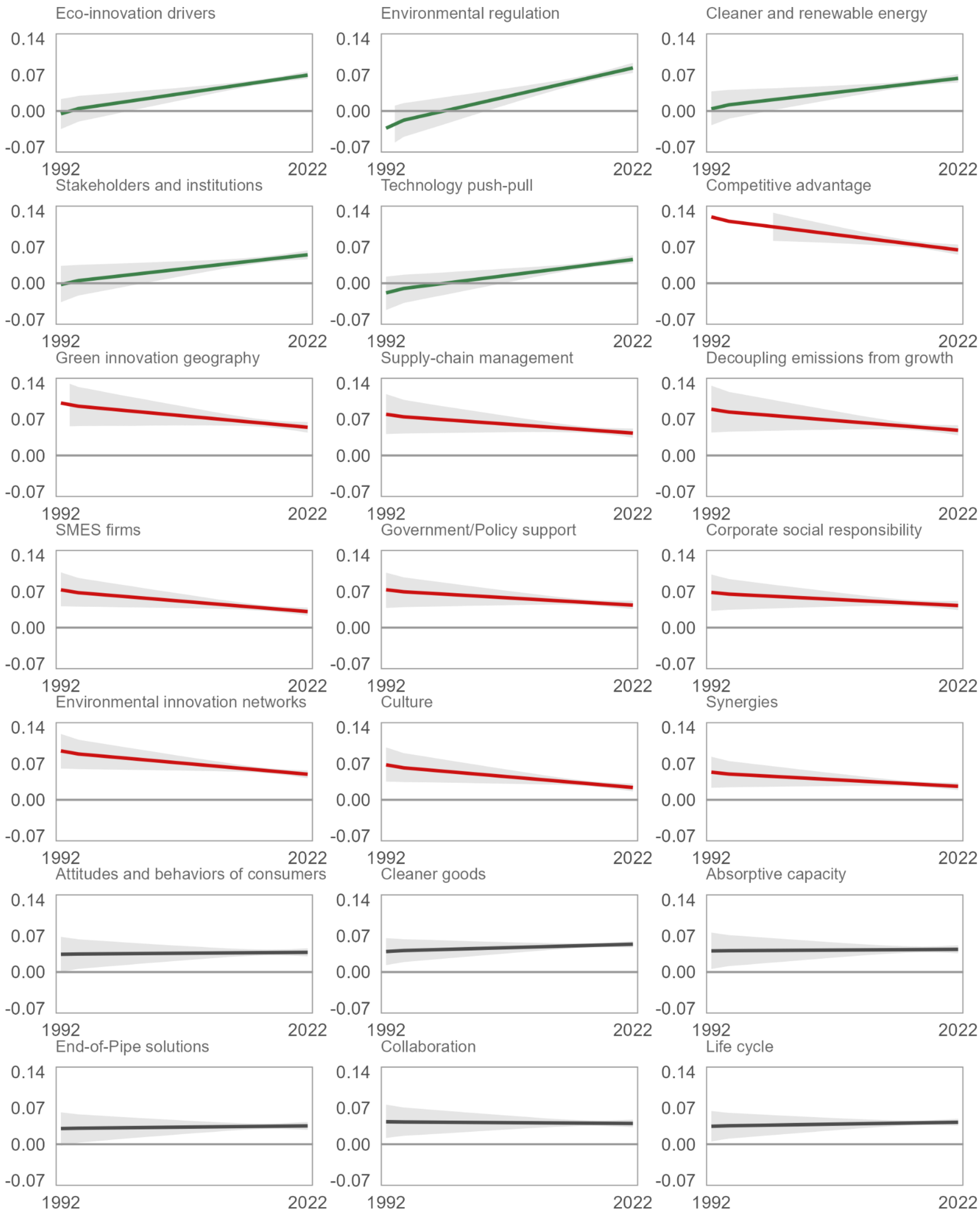
Topic modeling reveals that twenty-one topics represent the field of eco, green and environmental innovation. Appendix B shows the labels assigned to the twenty-one topics, the ten most frequent and exclusive term-words in each topic, and the top ten terms with the highest probability in each topic. Both types of term-words were used to assign the labels to the topics.

The topics that represent the eco-innovation literature pertain to areas of management and strategy (topics of competitive advantage and corporate social responsibility), determinants of eco-innovation (drivers, absorptive capacity, and attitudes and behaviors of consumers), policy measures (environmental regulation and government/policy support), scaling eco-innovation (green innovation geography), eco-innovation typology (cleaner and renewable energy, cleaner goods, end-of-pipe solutions, and life cycle), and topics related to the eco-innovation system (supply-chain management, environmental, stakeholders and institutions, innovation networks, collaboration, and synergies).

The results indicate a shift in research interests as evidenced by a change in the proportion of topics over time. Topics of determinants of eco-innovation, environmental regulation, clean and renewable energy, and technology push-pull are gaining more attention. In contrast, ten topics have reduced their prevalence in the eco-innovation literature (Figure 3). Interestingly, the topic of competitive advantages has lost importance, although it was one of the main topics that drove the beginning of the field. Six of the topics have remained stable over time and with low participation in the literature (less than 4%) (Figure 3).

This shift in research interests may be due to a broadening in the discussion of new themes related to the eco-innovation phenomenon. The study of eco-innovation was initially focused on the competitiveness of firms; however, it is detached from its relationship with competitiveness and has been extended to other spheres.

Figure 3. Topic proportions from 1992 to 2022 on the eco-innovation field.



Note: Topic proportions represent the prevalence of a topic over time.

Our topic modeling analysis of the 2061 papers has uncovered the thematic structure of eco-innovation literature as a mix of 21 topics. This means that a study can address more than one topic. Figure 4 shows relationships between the topics in the eco-innovation literature. It reflects the structure of relationships between topics. The network shows the most addressed topics in the field and indicates the largest and smallest relationships between topics, i.e., topics that have been most and least studied together. The size of the nodes indicates the number of papers published on a topic, while the width of the links is the degree of correlation between two topics.

Figure 4. Topic network.

Topic 1, named competitive advantage, comprises terms associated with the firm, such as performance, resources and capabilities, management, and manufacturing. These terms refer to the use of resources and capabilities of firms to improve their competitive advantage. Overall, this topic represents the study of how organizations can improve their performance and achieve competitive advantage from green innovation, which is one of the most explored topics in this literature.

The topic labeled environmental regulation focuses on stringent environmental policies as incentives for environmental innovation. The terms regulation, Porter's hypothesis, stringent, reduction and induced reinforce the idea associated with a set of market-based measures for environmental innovation. In addition, terms related to the topic of cleaner and renewable energy include diverse types and sources of energy such as wind, fossil, solar, coal and the term renewables.

2.4. Topics on Eco-Innovation Through the Lens of the Scientific Subfields

2.4.1. Eco-innovation drivers and typology of eco-innovation

The topic of eco-innovation drivers aims to understand what factors motive and drive firms to adopt eco-innovation. Studies have addressed this question by considering external and internal factors according to various types of eco-innovations and by linking actors in the firm's value chain. The growing interest in studying eco-innovation drivers has been reflected in a large number of studies, and recently, literature reviews have emerged that compile and attempt to create explanatory frameworks that link the relationship between drivers, motivations, and eco-innovation outcomes (Bossle et al., 2016; He et al., 2018). Different scientific subfields address the topic of eco-innovation drivers and typology.

The scientific subfield of corporate environmental management emphasizes the importance of resources and capabilities in the eco-innovation process. Capabilities enable the integration, construction, and reconfiguration of internal and external competencies of an organization to manage the changing environment (Teece et al., 1997). Thus, studies of corporate environmental management link eco-innovation drivers with obtaining competitive advantages. Dynamic capabilities drive eco-innovation, specifically by configuring the company's operational capabilities, such as relationships with customers and suppliers (Albort-Morant et al., 2016). On the other hand, knowledge management, for example, knowledge exchange facilitates collaboration by allowing a company to access external knowledge necessary for intensive R&D activities (Abbas & Sağsan, 2019).

The drivers of eco-innovation associated with the subfield Management activities, such as the use of environmental management systems, relationships with stakeholders, product marketing, recycling, and eco-labeling, have been studied in the subfield of organizational capabilities (Wagner, 2008). Studies in this subfield have shown the positive pressure that customers exert on companies to adopt eco-innovations. For example, the use of environmental management systems or product certification is a way to inform customers about a company's environmental management and allows access to new markets (Le Van et al., 2019).

Studies in the subfield of Environmental regulation have demonstrated that regulation is an important driver for eco-innovation. The increased environmental regulation introduced by governments and the many available environmental policy instruments have made this subfield one of the most important in explaining eco-innovation. Research in this subfield has advanced understanding of the relationship between regulation and eco-innovation in different contexts.

The Eco-innovation driver's subfield has a broader vision than other subfields when studying the determinants of eco-innovation in companies. Studies in this subfield have advanced in classifying different drivers into external factors (regulations, cooperation, technological) and internal factors (capabilities, management, resources, and strategy) (Bossle et al., 2016).

In the subfield of the Natural resource-based view of the firm, three key strategies for competitive advantage have been analyzed: pollution prevention, product stewardship, and sustainable development (Hart, 1995). These strategies have different drivers, which are studied within this topic. Studies have focused predominantly on studying the relationship between organizational capabilities oriented toward pollution prevention and profit generation.

2.4.2. Environmental regulation

The field of corporate environmental management highlights that the resources firms invest in developing green competencies contribute to meeting environmental regulatory requirements and consumer demands. The interaction between managerial activities and environmental regulation lies in studying the combination of environmental policy instruments, such as eco-labeling and taxes. The debate over the combination of these mechanisms or the preference for one over the other lies in compliance by firms. Another angle that has been studied is whether non-binding mechanisms can increase compliance with environmental regulations.

The topic of Environmental regulation is the primary field for developing ideas on how market-based instruments influence innovation in firms from a policy perspective. Environmental regulations guide firms towards more efficient use of their resources. The study of environmental regulation as a driver has advanced understanding of the conditions under which regulations influence eco-innovation, as well as what types of eco-innovation.

Regulators are stakeholders who transmit external demands to firms to achieve or maintain improvements in the environment, according to the subfield of Natural-Resource Based View (NRBV). As such, firms can coordinate their exploration and exploitation strategies with regulatory pressures to enhance corporate sustainable development (F. Zhang & Zhu, 2019).

2.5. Conclusions

Most of the research in eco, green and environmental innovation has the potential to contribute to solving the major environmental problems of our society. The field has integrated insights from diverse disciplines, creating analytical frameworks to integrate economic and environmental domains. Uncovering the internal structure and topics that best represent the field reveals knowledge bases, boundaries, and challenges for innovation's role in the future of the environment.

Despite efforts to reach a common concept that integrates innovation and the environment, there remains conceptual ambiguity about how innovations can produce environmental benefits. The most widely accepted concept of eco-innovation has subordinated environmental impacts to profits, hindering organizations' ability to develop and adopt eco-innovations that benefit the environment. Understanding the environmental impacts of eco-innovation as a random element rather than as an intentional, normative, and goal-oriented component of an organization has implications for system transformation (Béné, 2022).

In the eco-innovation literature, environmental benefits have been assumed to be implicit. Making explicit how innovation impacts the environment could provide more precise information on the determinants of eco-innovation. However, there is scant research analyzing the development and adoption of eco-innovations with demonstrated environmental impacts, and evidence is lacking on whether the environmental impacts of firms are sufficient for planetary well-being. Organizations need to demonstrate their reduction of environmental impacts to provide a favorable scenario for future studies.

The transition to cleaner technologies and their wide diffusion is one of the most significant global challenges, and there is considerable evidence of eco-innovation's development and adoption at the firm level. However, little progress has been made in understanding the diffusion of eco-innovations at the level of multiple industries and technologies. It remains to be explored how the diffusion of technologies that address one environmental problem may contribute to the persistence of other environmental problems, such as the high input extraction required for constructing renewable energy equipment (Fichter & Clausen, 2021). For example, the transition to renewable energies such as solar or wind power requires a high extraction of inputs for the construction of equipment.

Chapter 3

3. Drivers of Eco-innovation: the Role of Appropriability Strategies and Complementary Assets

3.1. Introduction

Eco-innovation research has drawn policy and scholarly interest because of its potential contribution to global environmental challenges through developing less polluting and resource-consuming technologies and practices (Díaz-García et al., 2015b; Horbach, 2016; Karakaya et al., 2014; Karimi Takalo et al., 2021; Kemp & Oltra, 2011; Pacheco et al., 2017). The literature on eco-innovation has extensively explored the role of environmental regulations (Jaffe, 1997; Rennings, 2000) and then incorporated other institutional factors (Berrone et al., 2013). It has also explored the role of firms' resources and capabilities regarding eco-innovation (Aragón-Correa & Sharma, 2003; Cainelli et al., 2015; Y. Chen, 2008). Innovation studies have particularly highlighted the importance of economic returns and the firms' capabilities to capture value for innovation (Cohen et al., 2000; Teece, 1986). Notably, the eco-innovation literature has found mixed results regarding whether eco-innovation produces economic benefits for an eco-innovative firm (Aguilera-Caracuel & Ortiz-de-Mandojana, 2013; J. Chen & Liu, 2019; Ghisetti & Rennings, 2014; Palmer & Truong, 2017).

Despite the importance of value appropriation from innovation, there has been little discussion about how firms' capabilities and mechanisms to appropriate value incentives or not eco-innovation. Value-capturing strategies are essential because eco-innovation simultaneously produces positive knowledge and environmental externalities (Jaffe et al., 2005; Rennings, 2000), which create suboptimal investments and hinder value appropriation, reducing incentives for managers to eco-innovate. Knowledge externalities benefit imitators/competitors once an eco-innovation enters the market. In addition, eco-innovation benefits society by reducing environmental externalities.

To overcome the appropriability problem, firms rely on appropriability mechanisms and complementary assets (Christmann, 2000; Pisano, 2006; Teece, 1986). Formal (intellectual property rights) and informal (non-statutory) appropriability mechanisms grant innovative firms exclusive (but incomplete) rights to profit from their innovations. However, as environmental externalities arise – as in the case of eco-innovation-, appropriability mechanisms are insufficient for successful value appropriation and commercialization. In this case, complementary assets, such as marketing capabilities, allow a firm to capture greater value from their eco-innovations, for instance, by accessing new market segments and impeding the imitation of eco-innovation by competing firms. We thus argue that appropriability mechanisms and complementary assets encourage eco-innovation in firms.

This study integrates the eco-innovation literature (Cuerva et al., 2014; Horbach, 2008; Rennings, 2000) and the profiting from innovation framework (Teece, 1986) to analyze the influence of formal and informal appropriability mechanisms and the moderating role of marketing capability on firm's eco-innovation. We argue that formal and informal appropriability mechanisms positively influence a firm's eco-innovation and that informal mechanisms have a greater positive influence than formal ones. When firms complement appropriability mechanisms with complementary assets, we argue that marketing capabilities strengthen the influence of formal and informal appropriability mechanisms on eco-innovation.

To test the hypotheses, this study used a panel data logistic regression model with random effects in a sample of 4,630 manufacturing firms from a ten-year panel (2009-2018). The evidence shows the positive influence of formal and informal appropriability mechanisms and supports the greater effect of informal mechanisms on a firm's eco-innovation. We also uncover evidence that firms use their marketing capabilities to amplify the effect of formal and informal appropriability mechanisms on eco-innovation. However, interestingly, firms combining formal mechanisms with a high investment level in marketing do not increase their likelihood of eco-innovating, compared to when marketing investment is low. Conversely, a firm's likelihood of eco-innovating increases as the use of informal mechanisms increases when it uses high levels of marketing investment. These results demonstrate complementary and substitution effects between appropriability mechanisms and marketing capabilities on eco-innovation.

Our chapter contributes to the literature on eco-innovation drivers by providing evidence that appropriability mechanisms and complementary assets are necessary for firms to eco-innovate by protecting against imitation and decreasing the risk of eco-innovating. Our chapter draws attention to the role of marketing capability by combining it with formal and informal appropriability mechanisms. Communicating environmentally friendly actions to stakeholders improves a firm's reputation, allows access to specialized markets, and provides value by differentiating its products and services.

The rest of the chapter is structured as follows. In the theoretical framework in Section 2, we synthesize the main ideas regarding eco-innovation, appropriability and marketing capabilities of managers. In Section 3, we argue why eco-innovative firms need formal and informal appropriability and the role of marketing capabilities in firms. We describe the methodology in Section 4 and show our findings in Section 5. We discuss our results in Section 6 and the conclusions, limitations, and future directions in Section 7.

3.2. Theoretical Framework of Eco-innovation, Appropriability, and Complementary Assets

The eco-innovation literature has provided an understanding of the complex relationship between innovation and the environment. Eco-innovation refers to new ideas, behaviors, products, or processes that, intentionally or not, reduce environmental impacts or resource use (Kemp & Pearson, 2007; Rennings, 2000). Once an eco-innovation is on the market, it creates knowledge and environmental externalities (Jaffe et al., 2005; Rennings, 2000).

Both knowledge and environmental externalities can affect a firm's ability to appropriate the benefits from eco-innovation, reducing its incentives to pursue it, but they do so in distinct ways. Innovations produce knowledge externalities, while eco-innovations produce both knowledge and environmental externalities. Knowledge externalities benefit imitators/competitors, and environmental externalities benefit a society by reducing pollution and lowering natural resource use per unit produced (Rennings, 2000). Compared to conventional innovations, eco-innovations generate externalities that benefit a wider range of actors. Eco-innovations have benefits for society as a whole, whereas the benefits of conventional innovations are typically limited to the innovative firm, its competitors, suppliers, and customers (Teece, 1986).

To encourage innovation, a firm must be able to benefit from it (Neuhäusler, 2012). An innovative firm can use various means of protection, grouped into formal and informal mechanisms, to capture the private returns of an innovation (Cohen et al., 2000; Levin et al., 1987; Teece, 1986). The means of protection are part of a firm's appropriability regime and integrate the incentive system influencing the managerial decision to innovate (Harabi, 1995), affecting the capture of economic returns from an innovation (Teece, 1986).

Formal mechanisms confer exclusivity rights to the profit from innovation to the innovative firm. These mechanisms include intellectual property rights (IPRs) -such as patents, trademarks, industrial designs, utility models, and copyright- contracts and labor legislation (Hurmelinna-Laukkanen et al., 2008; Teece, 1986). Informal mechanisms are non-statutory means of intellectual property protection, such as secrecy and design complexity (Gallié & Legros, 2012). Formal mechanisms provide institutional protection by relying on legal protection efficacy, while informal mechanisms depend on the firm's knowledge management systems and the tacit knowledge to be protected.

Although an innovative firm relies on appropriability mechanisms, it can only partially capture the returns of the knowledge it creates. The profiting from innovation framework (Teece, 1986) explains that in a weak appropriability regime, firms need complementary assets for value appropriation in addition to appropriability mechanisms. Complementarity is understood as the combination of a firm's resources and capabilities in unique ways, affecting the distribution of rents from innovation(Christmann, 2000; Teece, 1986, 2006). Since the scope of intellectual protection mechanisms is narrow to protect innovative firms against imitators/competitors, complementary assets compensate for the limitations of appropriability mechanisms to bring innovations successfully to the market and link economic returns with the use of resources and capabilities (Gambardella et al., 2021). Therefore, the set of assets that a firm can develop, or buy is its basis for supporting appropriability.

3.3. Hypotheses Development

3.3.1. Why do Eco-Innovative Firms Need Formal and Informal Appropriability mechanisms?

We argue that appropriability mechanisms serve different purposes for eco-innovation in firms. First, an appropriability regime protects innovative firms from imitation. Second, firms develop eco-innovation in coopetition in response to the technological mandates imposed on the industry, and appropriability mechanisms safeguard part of the knowledge shared between firms.

The attributes characterizing eco-innovation make it attractive for imitation. Firms investing in environmental activities perceive eco-innovation as necessary to comply with environmental regulations, to improve corporate image, to achieve social legitimacy, or as an opportunity for cost reductions (Berrone et al., 2013; Porter & van der Linde, 1995). Research has identified the different attitudes of managers towards socio-environmental concerns (Azzone & Noci, 1998; Klewitz & Hansen, 2014; Noci & Verganti, 1999). For example, managers can assume a proactive or reactive mentality regarding eco-innovation (Y. Chen et al., 2012). Managers characterized by a proactive attitude "… take initiatives, new practices or products ahead of competitors, to decrease cost, to seize opportunities, to lead in the market, or to obtain competitive advantages" (Y. Chen et al., 2012, p.

375). This means that managers anticipate environmental regulations and the environmental demands of consumers. In this way, proactive firms are pioneering in their industry, using environmental innovations to gain market advantages (Noci & Verganti, 1999). Proactive firms are characterized as early adopters of new technologies, and they benefit from eco-innovation in, for example, cost reductions or increasing their market share. Since eco-innovation benefits can encourage competitors to imitate, an eco-innovative firm characterized by environmental leadership, an environmental culture, and environmental capability (Y. Chen et al., 2012) requires mechanisms to protect and capture the economic returns from their eco-innovation.

Governmental incentives to reduce harmful environmental impacts may encourage the massive dissemination of green technologies. Governments impose technological mandates or performance standards to this end. Technological mandates require firms to comply with adopting specific technologies or practices in the production process (Goulder & Parry, 2008). On the other hand, performance standards require that a firm's products meet specific standards (Goulder & Parry, 2008). If the environmental policy instrument is effective, industries will respond by adopting fewer polluting technologies while replacing conventional technologies. To respond to previous environmental policies, firms can eco-innovate in coopetition or implement open innovation strategies by developing standard technologies in an industry (Ritala & Hurmelinna-Laukkanen, 2013; Roh et al., 2021). However, these innovation processes expose a firm's core knowledge, which is the basis for its competitive strategy. Firms, therefore, use formal and informal appropriability mechanisms to protect their core knowledge (Ritala & Hurmelinna-Laukkanen, 2013).

We argue that informal mechanisms have a greater effect on eco-innovation than formal ones. The regulatory framework and demand-side factors characterizing eco-innovation make informal mechanisms more suitable for protecting eco-innovation. First, eco-innovation is strongly dependent on the environmental regulatory framework. As noted above, governments sometimes incentivize a particular technology to be used by the most significant number of firms to fulfill national environmental goals. This means that a technology commonly used by all firms is unlikely to be protected through legal schemes. Firms thus choose to protect their improvements in implementation or design. These informal mechanisms, such as complexity in design and industrial secrecy, have a greater influence on encouraging eco-innovation. Second, commercial uncertainty makes it less attractive for a firm to invest in formal appropriation mechanisms due to higher costs for the legal proceedings to protect a technology that may not be successful. Consequently, we expect that:

H1. Formal and informal appropriability mechanisms have a positive influence on eco-innovation in firms. Moreover, informal appropriability mechanisms have a greater influence than formal ones.

3.3.2. Marketing Capability Moderating the Relationship Between Appropriability and Eco-Innovation

A firm's marketing capability and its appropriability strategy complement each other since they can ensure greater appropriation of the economic value of eco-innovation when applied together. In other words, marketing capability strengthens a firm's appropriability strategy by bringing superior value to eco-innovation through market differentiation between eco-innovations and other innovations.

Marketing capabilities mean that eco-innovations differ from other marketed goods, allowing the eco-innovative firm to access new or specialized markets. Successful eco-innovation aligns stakeholder needs with product/process features. Similarly, a firm needs to communicate its favorable actions regarding the environment to consumers, which improves its reputation in society. Communicating eco-innovation benefits and the positive externalities generated by its production and consumption improves consumer preferences, giving a firm a distinctive advantage regarding other products in the market (Wong et al., 1996).

The lower environmental impact of eco-innovation alone is insufficient to maintain consumer demand (Wong et al., 1996). Investing in product attributes, such as product design, packaging, or its positioning in the market, means that a firm improves the value of an eco-innovation, as related to its use by the innovative firm and consumers, and the benefits provided to society by reducing environmental damage.

In this way, rents from eco-innovation depend on appropriability mechanisms that partially inhibit imitation and ease value appropriation and on complementary assets that communicate eco-innovation benefits to stakeholders, improving the firm's image and attracting new consumers. Therefore, a firm's marketing capabilities are another channel to influence consumer purchasing decisions regarding green products, increasing value appropriation.

On the other hand, coopetition and open innovation processes imply that firms share knowledge with other firms in the industry. Since an appropriability regime is less helpful in gaining exclusivity in this context (Ritala & Hurmelinna-Laukkanen, 2013), firms can develop marketing capabilities as a distinctive factor. Appropriability mechanisms, in combination with marketing capabilities, protect a firm's core knowledge better, and allow firms to capture more value by differentiating their products, incentivizing a firm to eco-innovate. We, therefore, suggest that:

H2. A firm's marketing capabilities strengthen the influence of formal and informal appropriability mechanisms on eco-innovation in firms.

3.4. Methodology

3.4.1. Data and Sample

The empirical analysis is based on panel data whose information comes from the Colombian Innovation Survey (Encuesta de Desarrollo e Innovación Tecnológica–EDIT). The EDIT characterizes the innovation activities of firms over time. The EDIT has been conducted biennially since 2003 by the National Department of Statistics (DANE). The EDIT follows guidelines from the Oslo Manual, allowing the harmonization of information by including standard terms and structures in the survey (OECD/Eurostat, 2005). The EDIT also follows the Bogotá Manual guidelines, allowing it to adapt to the specific characteristics of innovation systems and firms in Latin America and the Caribbean (RICYT, 2000). This ensures reliability and comparability between the EDIT and other national innovation surveys in Latin America and Europe (Crespi et al., 2021).

The EDIT comprises information about innovation outcomes, obstacles and effects, intellectual property rights and other protection mechanisms, the firm's investments and financing of scientific and technological activities, internal and external collaboration partners, and innovation sources.

Five EDIT surveys were used to design a balanced panel covering a ten-year period from 2009 to 2018. The initial dataset contained information from 49,774 observations and 8,295 firms per survey on average. After including only firms that reported information in all five surveys, the final database comprised 23,140 observations and 4,630 firms. The panel database contains information about firms' eco-innovation and appropriability mechanisms from 2009 to 2018.

3.4.2. Variables

Dependent variable

The dependent variable represents a firm's likelihood of introducing an eco-innovation in the market. As noted above, eco-innovations are new or significantly improved goods and services characterized by mitigated environmental burdens that can be environmentally motivated or unintentional. Eco-innovation is measured based on previous studies (e.g., Frondel et al. (2007); De Marchi (2012); Garrone, Grilli, and Mrkajic (2018); Horbach (2012)) that operationalize eco-innovation as an innovation with a positive environmental impact.

We used four items from the EDIT questionnaire to identify the environmental impact of innovation: (i) raw materials and input reduction, (ii) energy consumption reduction, (iii) water consumption reduction, and (iv) the use of waste in a firm's processes. Managers were asked to rate each variable about the importance of the environmental impact of an innovation on a scale of 1-3: whether the environmental impact of an innovation was zero, medium, or high, respectively. To measure eco-innovation, each variable was encoded as 1 if the manager reported a medium or high impact during the reference period and 0 otherwise. The four dummy variables were summed, and the resulting variable was transformed, with 1 indicating a positive environmental impact and 0 otherwise. Following De Marchi (2012), this variable was used as a filter to identify firms reporting innovations with a positive environmental impact. There is a decrease in the proportion of eco-innovative firms reporting eco-innovations from 2008 to 2018.

Independent variables

Studies on the appropriability of innovation categorize mechanisms as formal and informal (Cohen et al., 2000; Levin et al., 1987; Teece, 1986; Yacoub et al., 2020; Zobel et al., 2017). Formal mechanisms rely on intellectual property rights for compliance, and informal mechanisms depend on a firm's business strategy.

Information from the EDIT questionnaire was used to identify the appropriability mechanisms and group them into formal and informal mechanisms. First, the EDIT asks managers regarding formal mechanisms, whether a firm owns, has obtained, or has used intellectual property rights such as 1) patents, 2) trademarks, 3) industrial designs or 4) utility models in the past two years. Each variable takes 1 if the firm has owned, obtained, or used an appropriability mechanism and 0 otherwise.

Second, the EDIT asks managers whether their firm used appropriability mechanisms during the last two years, such as 1) complexity in design or 2) industrial secrecy. Each variable takes the value of 1 if the firm has used the mechanisms and 0 otherwise. The variables were then summed and then transformed to binary forms for each formal and informal mechanism.

An alternative measure of formal and informal mechanisms was designed as a robustness test. The variable *formal_sum* summed the four binary variables of formal mechanisms. The variable *informal_sum* summed the two binary variables of informal mechanisms. These variables represent the number of appropriability mechanisms a firm uses for formal and informal mechanisms.

A firm's marketing capability, conceptualized as a complementary asset, involves the set of activities they use for advertising and commercializing eco-innovation. Marketing capability (*Marketlg)* measures a firm's one-period-lagged investments in marketing. The marketing capability variable measures the value of a firm's investment to make changes in the design or packaging of a product; in its positioning, promotion, or pricing; and new market research techniques and launch advertising. This variable is expressed on a logarithmic scale and was mean-centered.

Control variables

Eight control variables were included to minimize the model's potential omitted variable bias and control other important drivers of eco-innovation. Research and development investment (*R&D (log)*) was included to control a firm's knowledge absorption and internal capacity to eco-innovate. *R&D (log) was* measured on a logarithmic scale as the firm's R&D expenditure in the last two years. We argue that small-medium sized firms face more obstacles and have fewer resources to eco-innovate. A firm's size (*Size (log)*) is thus positively associated with eco-innovation and was measured as the firm's number of employees expressed in log terms.

We control collaboration with scientific partners, such as universities and research centers. *Sci. Coop* measures whether a firm collaborates with or uses universities or research centers as a source of ideas for eco-innovation. It is a binary variable taking the value of 1 if a firm collaborates with or uses universities or research centers as a source of ideas, and 0 otherwise. We also control whether a firm is open to international competition (Export), measured as whether it sells its product in national or international markets. It takes the value of 1 if a firm sells its product on the international market, and 0 otherwise.

We also control firms belonging to a business group (*Corp*). The variable *Corp* has a value of 1 if the firm collaborates with other firms in the same business group to innovate, and 0 otherwise. External knowledge acquisition, such as patents and licenses, enables firms to adopt innovations based on a stock of knowledge validated by other firms. The variable *Tech. transfer (log)* measures a firm's expenditure on technology transfer activities and external knowledge acquisition, expressed in log terms, such as patent and license acquisition in the last two years.

Five dummy variables measure whether a firm belongs to a manufacturing sector. Each dummy variable takes the value of 1 if a firm belongs to the food sector (*Sector 1*); the textile and clothing sector (*Sector 2*); the wood, paper, cardboard, and chemicals sector (*Sector 3*); the minerals, and metallurgy sector (*Sector 4*); or other manufacturing sectors (*Sector 5*), and 0 otherwise (Schmutzler & Lorenz, 2018). We also control time effects by including four dummy time variables for each survey wave. The control variables *R&D (log)*, *Size (log)*, *Sci. Coop*, *Export, Corp*, and *Tech. transfer* were included as lagged variables in the panel model to mitigate endogeneity.

3.4.3. Estimation Technique

The dependent variable represents a firm's probability of introducing eco-innovation and takes binary values. A logistic regression model was used, as it is the most appropriate model within the category of generalized linear models. This model uses the maximum likelihood method to provide consistent estimators and is commonly used in innovation studies.

A panel data random-effects model was estimated to test Hypotheses 1 and 2. It is a suitable technique for solving the incidental parameter problem that characterizes binary panel data models. Using a fixed-effects model is impossible since the explanatory variable is constant over time. The model was thus specified as follows:

$$ecoinnov_{it} = \beta_0 + \beta_1 Formal_{it} + \beta_2 Informal_{it} + \beta_3 Marketlg_{it} + \beta_4 Formal * Marketlg_{it} + \beta_5 Informal * Marketlg_{it} + \beta_6 C_{1it-1} + \beta_7 C_{2it}$$

Where $ecoinnov_{it}$ is the probability that the firm i will introduce an eco-innovation in the period t. $Formal_{it}$ and $Informal_{it}$ represent the use of formal and informal mechanisms for the firm i in the period t, respectively. $Marketlg_{it}$ represents marketing investments for the firm i in the period t expressed on a logarithmic scale and mean centered. The vector C_{1it-1} compresses the five control variables *R&D (log)*, *Size (log)*, *Sci. Coop*, *Export, Corp*, and *Tech. transfer (log)* lagged one period, and C_{2it} represents the two control variables *Sector* and *Year*.

The model reports odds ratios to facilitate their interpretation. Marginal effects were estimated to compare the influence between formal and informal mechanisms with respect to eco-innovation. Given the complexity of interpreting the interaction between a binary and a continuous variable, moderating effects and their differences in probabilities were plotted.

3.5. Results

Table 3 reports the dependent, independent, and control variables' means, standard deviations, and Pearson correlation coefficients. On average, 23% of manufacturing firms reported the introduction of at least one eco-innovation into the market. The proportion of eco-innovative firms in Latin American countries is lower than those found by studies in European countries such as Spain (47%) (Cainelli et al., 2015; De Marchi, 2012) and Germany (43.8%) (Horbach et al., 2012).

Table 3 reports moderate and statistically significant correlations (r < 0.50). We observe that eco-innovation is positively related to formal and informal appropriability mechanisms. The low correlation between the formal and informal mechanisms (1%) suggests low complementarity, which differs from previous studies which have found high complementarities between formal and informal appropriability mechanisms (Amara, Landry, & Traoré, 2008; Amara, Landry, Becheikh, et al., 2008; Gallié & Legros, 2012; Thomä & Bizer, 2013). The higher share of firms using formal mechanisms (34%) rather than informal ones (19%) differs from the findings of previous studies (Neuhäusler, 2012). Finally, we tested for multicollinearity between the independent variables by calculating the variance inflation factor (VIF) and its tolerance values (1/VIF), resulting in a tolerance value of 5.78, indicating a low conditional association between the explanatory variables.

Table 4. Means, Standard Deviations, and Pearson Correlations.

Variables	Mean	s.d.	Min	Max	1	2	3	4	5	6	7	8	9	10
Eco-innovation	0.23	0.42	0	1	1									
Formal appropriability	0.34	0.47	0	1	0.19*	1								
Informal appropriability	0.19	0.40	0	1	0.12*	0.01	1							
Marketing	0.44	1.35	0	7.22	0.40*	0.22*	0.10*	1						
R&D (log)	0.56	1.48	0	7.76	0.29*	0.20*	0.08*	0.31*	1					
Size (log)	1.68	0.56	0	3.71	0.28*	0.29*	0.02*	0.31*	0.39*	1				
Sci. Coop.	0.25	0.44	0	1	0.30*	0.18*	0.11*	0.23*	0.46*	0.28*	1			
Export	0.25	0.43	0	1	0.12*	0.17*	-0.15*	0.12*	0.23*	0.38*	0.15*	1		
Corp	0.05	0.22	0	1	0.18*	0.11*	0.07*	0.19*	0.35*	0.24*	0.34*	0.12*	1	
Tech. transfer.	0.13	0.73	0	7.82	0.14*	0.10*	0.06*	0.18*	0.35*	0.22*	0.21*	0.10*	0.19*	1

Note: statistical significance * p < 0.05.

We report the results of the logistic regression model in Table 4. Model 1 shows the results of the control variables. Model 2 includes the results of the control and independent variables, and Model 3 shows the control, independent, and moderation effects between the formal and informal appropriability mechanisms and the firm's marketing investment. We provide interaction plots to identify the moderation effects of the appropriability mechanisms and the firm's marketing investment.

The results of the control variables from Model 3 show that the R&D investment of firms is positively and significantly associated with eco-innovation (1.07; $p < 0.01$). Firms with a knowledge absorption capacity can obtain or develop technologies. Low R&D investment is characteristic of firms in emerging economies and, particularly for eco-innovation, previous studies also indicate that firms might be reluctant to invest in R&D because of uncertainty regarding stricter regulations once firms comply with environmental requirements (Brunnermeier & Cohen, 2003).

The results also suggest that firm size has a positive and statistically significant relationship with eco-innovation (2.07; $p < 0.01$). Large firms rely more heavily on their image and reputation, and they can achieve social legitimacy by developing products with less environmental impact. The results also indicate that firms collaborating with scientific partners (2.06; $p < 0.01$) and firms open to international competition (1.10; $p < 0.05$) are more likely to eco-innovate. One possible reason is that collaboration with scientific actors such as universities and research centers provides the complementary knowledge required for eco-innovation (De Marchi, 2012).

A firm belonging to a business group (1.18; $p < 0.15$) shows statistically significant results, while investment in technology transfer (0.96; $p < 0.13$) does not seem to influence eco-innovation. It is possible that knowledge transmitted through business groups does not add value to a firm's knowledge because eco-innovation requires multidisciplinary knowledge. The acquisition of knowledge on its own is not enough for eco-innovation.

Regarding sectors, only the textile and clothing sector (*Sector 2)* shows a negative relationship with a firm's likelihood of eco-innovating. Time variables show that firm performance in eco-innovation has decreased from 2008 to 2018. Colombian manufacturing firms are thus less likely to eco-innovate over time.

The results in Model 2 reveal that formal (1.88; $p < 0.01$) and informal mechanisms (3.32; $p < 0.01$) positively and significantly influence eco-innovation in firms. Moreover, the marginal effects of the appropriability mechanisms on eco-innovation indicate that formal mechanisms have a greater effect on eco-innovation than informal mechanisms (Appendix A). Hypothesis 1 is thus supported.

Although few studies are providing empirical evidence of the effect of appropriability mechanisms on eco-innovation(Roh et al., 2021), the positive effect of formal and informal mechanisms is similar in the context of innovation, regardless of the environmental impact (Thomä & Bizer, 2013; Yacoub et al., 2020). We also found that a firm's marketing investment has a positive and statistically significant effect on eco-innovation, as expected in hypothesis two.

Table 5. Drivers of firms' eco-innovation.

	Model 1	Model 2	Model 3	Model 3 dy/dx
Independent				
Formal appropriability		1.70 (0.07) ***	1.88 (0.09) ***	0.06
Informal appropriability		3.03 (0.37) ***	3.32 (0.40) ***	0.15
Marketlg		3.62 (0.25) ***	3.99 (0.27) ***	0.14
Marketlg x Marketlg		0.84 (0.01) ***	0.86 (0.01) ***	-0.02
Moderation				
Formal appropriability x Marketlg			0.82 (0.02) ***	
Informal appropriability x Marketlg			0.87 (0.02) ***	
Controls				
$R\&D\ (log)_{t-1}$	1.11 (0.01) ***	1.06 (0.01) ***	1.07 (0.01) ***	0.01
$Size\ (log)_{t-1}$	2.83 (0.13) ***	2.09 (0.10) ***	2.07 (0.10) ***	0.08
$Sci.Coop_{t-1}$	2.18 (0.10) ***	2.08 (0.10) ***	2.06 (0.10) ***	0.09
$Export_{t-1}$	1.20 (0.06) ***	1.10 (0.06) *	1.10 (0.06) *	0.01
$Corp_{t-1}$	1.18 (0.09) *	1.18 (0.10) *	1.18 (0.10) *	0.02
$Tech\ transfer\ (log)_{t-1}$	1.00 (0.02)	0.965 (0.02)	0.96 (0.02)	-0.00
Sector 2	0.62 (0.04) ***	0.75 (0.06) ***	0.76 (0.06) ***	-0.03
Sector 3	1.18 (0.08) **	1.29 (0.09) ***	1.29 (0.09) ***	0.03
Sector 4	0.88 (0.07)	1.13 (0.09)	1.14 (0.09)	0.01
Sector 5	1.04 (0.06)	1.24 (0.08) ***	1.25 (0.08) ***	0.03
Year 2012	0.58 (0.03) ***	1.76 (0.23) ***	1.78 (0.22) ***	0.07
Year 2014	0.45 (0.02) ***	1.45 (0.19) ***	1.49 (0.19) ***	0.04
Year 2016	0.44 (0.02) ***	1.28 (0.17) *	1.30 (0.17) **	0.03
Year 2018	0.42 (0.02) ***	1.26 (0.26) ***	1.28 (0.17) *	0.03
Intercept	0.04 (0.00) ***	0.01 (0.00) ***	0.01 (0.00) ***	
Num. obs.	23,140	23,140	23,140	

Num. firm-period obs.	4,628	4,628	4,628
Log-Likelihood.	-10,047.25	-9,121.45	-9,091.57
Wald Chi2	2,140.25***	2,778.57***	2,941.37***

Robust standard errors in parentheses. Statistical significance: * p < 0.1; ** p < 0.05; *** p < 0.01.

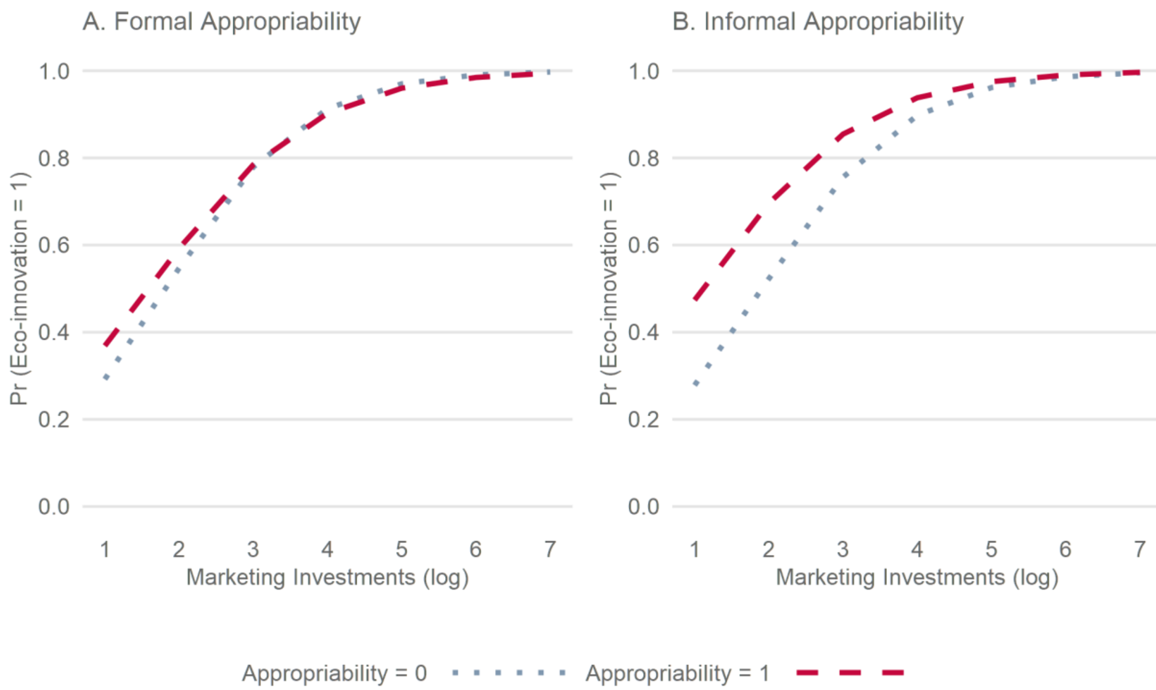
Hypothesis 3 suggests that a firm's marketing investment strengthens the influence of formal and informal appropriability mechanisms for eco-innovation. The results indicate a significant interaction between marketing investment and formal and informal appropriability mechanisms, suggesting the presence of differences in marketing investment patterns between firms utilizing appropriability mechanisms and those that do not.

To identify the form of interaction, we estimated predicted probabilities for eco-innovative firms at different marketing investments and we compute the marginal changes of the appropriability variable for different marketing investment values[1]. Figure 5 shows a firm's likelihood of eco-innovating using formal (Figure 5-A) and informal (Figure 5-B) appropriability mechanisms at different levels of marketing investment. Figure 5 confirms that formal and informal appropriability's effect on eco-innovation increases as marketing investment increases. That is, the effect of appropriability mechanisms on eco-innovation is contingent on a firm's marketing investment level. Our results, therefore, support Hypothesis 2, confirming that firms combining marketing capabilities and appropriability mechanisms increase their effect on eco-innovation.

The complementarity between appropriability mechanisms and marketing differs according to the level of investment in marketing. With low investments in marketing, there are significant differences between using and not using formal mechanisms, i.e., the effects are different from 0 (Appendix B). As marketing investments increase, the differences cease to be significant. In the case of informal mechanisms, the effects of using and not using them are different from zero for almost all levels of marketing investment. This indicates that the use of informal mechanisms can complement different levels of investment in marketing and will have a positive effect on the probability of eco-innovation (Appendix B).

[1] Statistical measures such as the mean along with one standard deviation below and above the mean are usually employed. However, given the left-skewed distribution of the moderator variable, such measures may fall outside the range of the scale or extend beyond the minimum and maximum values observed in the dataset (Hayes, 2018).

Figure 5. Predicted probabilities of formal and informal appropriability.



3.5.1. Robustness Checks

We specified three alternative regression models to test the robustness of the results. Table 5 reports the coefficients for the complete sample (Model 4), and for small (Model 5) and medium/large (hereafter large) firms (Model 6) using the sum of formal and informal mechanisms. We also illustrate the moderation effect by providing interaction plots for small (Figure 6-A, 6-B) and large firms (Figure 6-C, 6-D).

The results in Table 5 support Hypothesis 1. The results for small and large firms reveal that informal mechanisms have a greater positive and significant effect on eco-innovation than formal ones. Appropriability mechanisms, in particular, have a greater influence on eco-innovation in small firms than in large firms.

Table 6. Odd ratio of appropriability mechanisms of firms' eco-innovation in small and large firms.

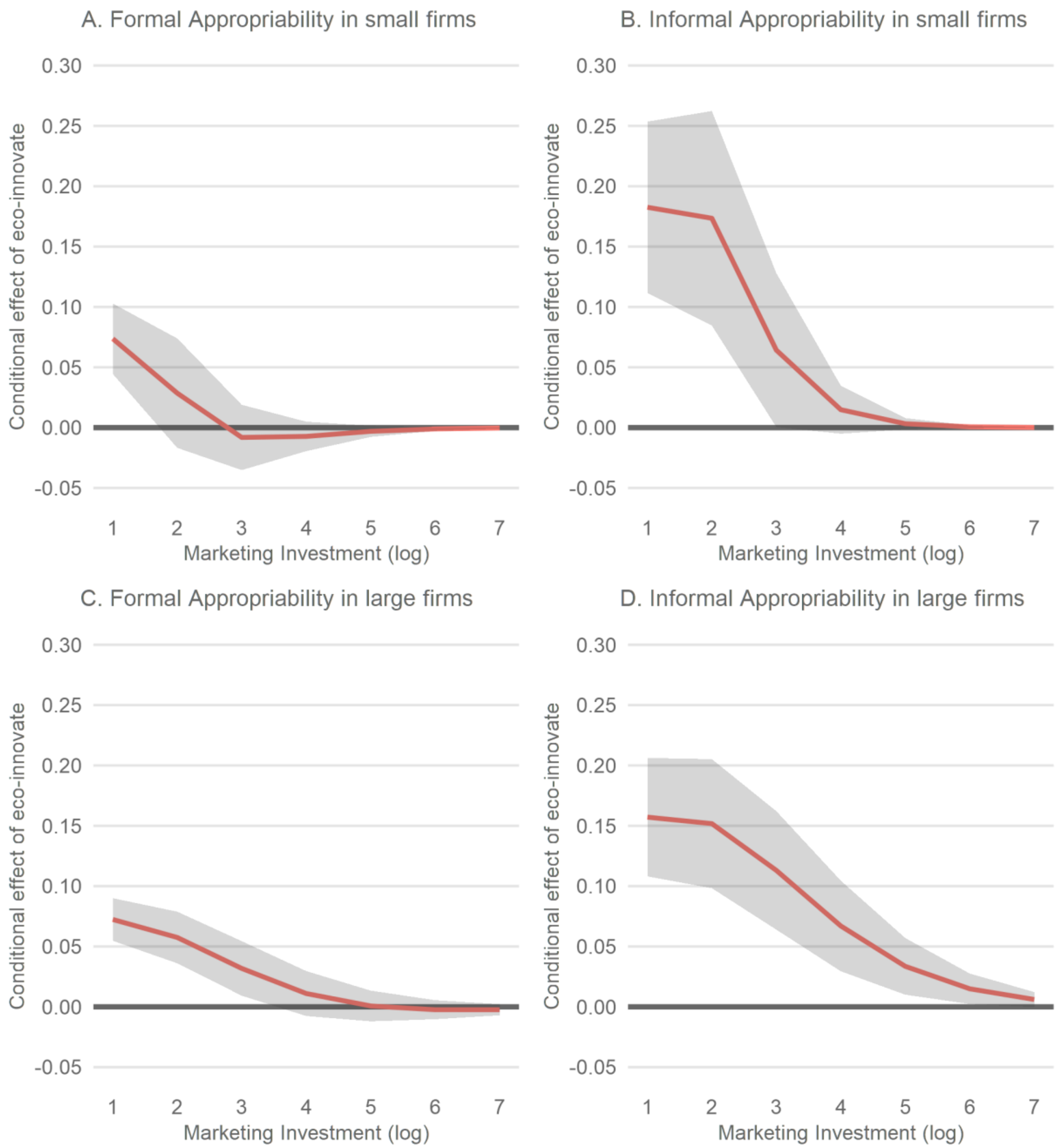
	Model 4 (All sample)	Model 5 (Small firms)	Model 6 (Medium/Large firms)
Independent			

Formal appropriability (sum)	1.74 (0.07) ***	1.96 (0.17) ***	1.61 (0.08) ***
Informal appropriability (sum)	2.65 (0.28) ***	3.05 (0.61) ***	2.47 (0.33) ***
Marketlg	3.88 (0.26) ***	6.60 (1.32) ***	2.76 (0.23) ***
Marketlg x Marketlg	0.86 (0.01) ***	0.79 (0.04) ***	0.91 (0.01) ***
Moderation			
Formal appropriability x Marketlg	0.87 (0.01) ***	0.77 (0.04) ***	0.91 (0.02) ***
Informal appropriability x Marketlg	0.94 (0.01) ***	0.91 (0.03) ***	0.94 (0.01) ***
Controls			
$R\&D\ (log)_{t-1}$	1.06 (0.01) ***	1.12 (0.04) ***	1.07 (0.01) ***
$Size\ (log)_{t-1}$	2.06 (0.10) ***	2.39 (0.34) ***	1.46 (0.13) ***
$Sci.Coop_{t-1}$	2.07 (0.10) ***	1.23 (0.20) ***	1.97 (0.13) ***
$Export_{t-1}$	1.10 (0.06) *	0.91 (0.10)	1.15 (0.08) *
$Corp_{t-1}$	1.17 (0.10) *	1.59 (0.30) **	1.08 (0.98)
$Tech\ transfer\ (log)_{t-1}$	0.96 (0.02)	0.93 (0.08)	0.98 (0.02)
Sector 2	0.76 (0.06) ***	0.81 (0.10)	0.73 (0.07) ***
Sector 3	1.28 (0.09) ***	1.44 (0.16) ***	1.17 (0.11)
Sector 4	1.10 (0.09)	1.06 (0.14)	1.19 (0.13)
Sector 5	1.22 (0.07) ***	1.14 (0.12)	1.26 (0.11) ***
Year 2012	3.78 (0.83) ***	4.86 (1.96) ***	3.27 (0.89) ***
Year 2014	3.19 (0.70) ***	3.97 (1.62) ***	2.84 (0.78) ***
Year 2016	2.77 (0.61) ***	3.43 (1.40) ***	2.50 (0.69) ***
Year 2018	2.73 (0.60) ***	2.84 (1.16) **	2.67 (0.74) ***
Intercept	0.00 (0.00) ***	0.00 (0.00) ***	0.01 (0.00) ***
Num. obs.	23,140	11,960	9,469
Num. firm-period obs.	4,628	2,975	2,272
Log-Likelihood	-9,091.85	-3,497.88	-4774.09
Wald Chi2	2,903.76 ***	1025.91 ***	1305.84 ***

Note. Statistical significance: * p < 0.1; ** p < 0.05; *** p < 0.01.

Results indicate that complementarities between appropriability and marketing differ according to the size of the firm. Figure 6 shows that large firms can combine more appropriability mechanisms with higher investments in marketing than small firms to increase their probability of eco-innovation. In the case of small firms, the conditional effect of formal appropriability mechanisms on eco-innovation is statistically significant at a confidence level of 95% when marketing investment is ≤ 1 (Figure 6-A), whereas for large firms, it occurs when marketing investment is ≤ 3 (Figure 6-C). The same occurs with the conditional effect of informal appropriability mechanisms. For small firms, the effect of informal appropriability on eco-innovation is statistically significant when marketing investment is ≤ 3 (Figure 6-B), while for large firms, it occurs at levels of 6 (Figure 6-D).

Figure 6. Conditional effect of appropriability on eco-innovation at different levels of marketing for small and large firms.



Note: The red line shows the average marginal effects when the firm uses different marketing investments. The shaded gray area corresponds to the range of values of appropriability.

3.6. Discussion

3.6.1. Discussion and Contributions

Our chapter makes theoretical contributions to the eco-innovation literature and has implications for policy and green corporate strategies. We contribute to the eco-innovation literature by integrating it with the profiting from innovation framework to better understand how a firm's appropriability mechanisms and complementary assets affect eco-innovation. Recent studies point out that committing to lowering environmental externalities can bring additional challenges to appropriability of an eco-innovating firm (Malen & Marcus, 2019). Current evidence suggests that intellectual property rights reduce the risk of firms embedded in an open innovation process for eco-innovation (Roh et al., 2021). Our findings advance in this direction, indicating that both formal and informal mechanisms promote eco-innovation and, particularly, that informal mechanisms stimulate it to a greater extent than formal ones. Statutory mechanisms relying on legal schemes can hardly protect widely disseminated environmental technologies in an industry developed by firms that engage in coopetition and open innovation processes. Commercial uncertainty is also more likely to make formal mechanisms to protect eco-innovation less attractive because of higher costs in legal actions that may fail to protect technology. Thus, knowledge protection through a firm's internal resources and informal mechanisms is more likely to drive eco-innovation than institutions that enforce intellectual property rights.

Previous studies have highlighted the role of complementary assets in eco-innovation (De Marchi, 2012; Mazzanti & Zoboli, 2005). We have developed this line of research by demonstrating that a firm's marketing capabilities work as a complementary asset that amplifies the influence of formal and informal appropriability mechanisms on eco-innovation. First, since a technology's lower environmental impact differentiates it from other innovations in the market, marketing investments can complement appropriability mechanisms, as a firm can profit from the lower environmental externalities of eco-innovation. Communicating environmental attributes and positive social impacts to stakeholders can differentiate eco-innovation from other innovations, improving a firm's reputation, attracting new customers, and gaining consumers who prefer green products.

Second, we found that the moderating effect of marketing investment on eco-innovation depends on the cumulative effect of appropriability mechanisms. Studies have highlighted that firms combine distinct appropriability mechanisms to complement their appropriability strategy (Cohen et al., 2000;

Thomä & Bizer, 2013). Our results show that, as a firm employs diverse formal mechanisms, it reduces the difference in the likelihood of eco-innovation between high and low marketing investments. In this case, complementing distinct legal mechanisms with marketing investments may not increase the likelihood of eco-innovation as the cumulative effect of patents, trademarks, and industrial designs may replace capabilities developed through high marketing investment.

The result described above is the opposite when analyzing informal appropriability mechanisms. Our findings indicate that distinct informal mechanisms combined with high marketing investments increase eco-innovation likelihood. One probable explanation is that industrial secrecy and complexity in design protect aspects mainly related to the specific features of an eco-innovation. On the other hand, marketing investments differentiate the external attributes of eco-innovation. The cumulative effect of informal mechanisms does not supersede high investment in marketing.

High marketing investments reduce the likelihood of eco-innovation compared to low marketing investments, particularly for small firms using distinct formal mechanisms. One probable explanation is that complementarity increases coordination problems (Teece, 2018). Small firms may have a low capacity to manage and align the use of distinct appropriability mechanisms with marketing investments.

3.6.2. Policy and Managerial Implications

Our results have several policy implications for eco-innovation strategy and policy. First, given that appropriability mechanisms may drive eco-innovation in firms, implementing statutory and, especially, non-statutory appropriability strategies in firms can encourage the development of non-polluting and resource-consuming technologies. Firms´ appropriability strategies should go beyond statutory mechanisms, with a particular emphasis on mechanisms such as industrial secrecy and complexity in design. Our chapter suggests that marketing investments are a suitable complementary asset to strengthen appropriability mechanisms. Managers could develop tactics and actions that enable firms to use marketing to transform their environmental externalities into a competitive advantage.

The decision to eco-innovate must be aligned with deciding which mix of appropriability strategy and complementary assets is the most effective to obtain the greatest economic value. Our results indicate that formal and informal mechanisms can provide confidence to managers about reducing the risk of eco-innovation. Informal mechanisms such as trade secrecy and complexity in design may be more suitable, as they appear to have a stronger influence on eco-innovation, and their cumulative effect does not decrease the likelihood of eco-innovation when combined with marketing investments.

3.7. Conclusion

This chapter has addressed eco-innovation in firms as related to appropriability and complementary assets. We have shown that formal and informal mechanisms encourage eco-innovation. In particular, informal mechanisms seem more suitable since they better protect a firm's internal knowledge and involve fewer costs associated with the commercial uncertainty of eco-innovation. We found empirical support that combining formal and informal mechanisms with marketing capability fosters eco-innovation because it allows a firm to profit from reducing environmental externalities by differentiating its eco-innovation in the market, improving its reputation, and attracting new customers. Still, marketing capability complements informal mechanisms better than formal ones. Using different formal mechanisms has a cumulative effect that can replace the influence of marketing capability. In contrast, informal mechanisms protect aspects related to the production process of eco-innovation, and marketing capability complements it by protecting attributes of the eco-innovation once it enters the market.

This chapter has several limitations. First, the causal relationship between eco-innovation and appropriability is challenging to identify. Previous studies have shown two-way causality (Laursen & Salter, 2014). We thought have alleviated this problem by implementing a panel data regression model. Second, as noted in the methodology, we use a measure of eco-innovation from the managers' perspective, and eco-innovation implies the positive environmental impact of innovation. Since innovation surveys were not designed to evaluate eco-innovation (De Marchi, 2012), an alternative measure of eco-innovation and the use of specialized surveys or other types of studies would help confirm the results of this research. Third, intellectual property rights rely on compliance with the rules of the game, so whether mechanisms such as patents and trademarks effectively protect eco-innovation is an open question. Including contextual measures to assess the institutional environment could help to understand the increased use of formal compared to informal mechanisms but their lesser effect on eco-innovation.

Chapter 4

4. Firm's Open Innovation Strategy on Cleaner Production and End-of-Pipe Eco-Innovations and the Moderating Role of Appropriability

4.1. Introduction

There has been growing interest among eco-innovation scholars to understand how firms use external knowledge sources to drive eco-innovation (Ghisetti et al., 2015; Horbach et al., 2013). While open innovation strategies can help firms access external knowledge, there is concern that too many sources of knowledge may discourage eco-innovation adoption (Ghisetti et al., 2015). Moreover, recent studies highlight that firms require greater interdependence of knowledge, skills, and resources to complement their internal knowledge for eco-innovation (Cainelli et al., 2012, 2015).

Despite the increasing attention given to the firms' open innovation strategy, there is still a need to understand how firms search for and protect their knowledge to create and capture value from eco-innovation, that is, how firms combine openness and appropriability strategies to eco-innovate. Specifically, more knowledge is needed about how firms' breadth of knowledge influences eco-innovation (i.e., cleaner production and end-of-pipe) and how appropriability moderates these relations. Eco-innovation drives firms to search for knowledge beyond their boundaries while simultaneously producing knowledge and environmental spillovers that may hinder its potential benefits. In such collaborative contexts, firms are encouraged to collaborate with external knowledge sources, but the double externality characterizing eco-innovations highlights the importance of appropriability mechanisms. The relationship between openness and the appropriability of innovation has been approached from the perspective of both tensions and synergies in innovation literature (Chesbrough et al., 2018; Hurmelinna-Laukkanen & Yang, 2022; Lauritzen & Karafyllia, 2019; Laursen & Salter, 2014).

In this chapter, we aim to address these gaps in the literature by integrating the frameworks of open innovation and appropriability in the context of eco-innovation. We focus on the breadth of the firm's external knowledge search, and how this affects their decisions to adopt cleaner production and end-of-pipe eco-innovations. We argue that a broad range of external knowledge sources positively influences cleaner production and end-of-pipe eco-innovation. When firms combine openness with appropriability, we argue that appropriability mechanisms strengthen the positive influence between the breadth of the firm's knowledge sourcing and cleaner production and end-of-pipe technologies.

The chapter uses balanced panel data of 5,720 firms from the Colombian Innovation Survey. Results indicate that breadth of knowledge sources positively influences the adoption of cleaner production and end-of-pipe eco-innovations, and that appropriability strengthens the relationship between a firm's knowledge sourcing and eco-innovation adoption for both cleaner production and end-of-pipe.

The rest of the chapter is organized as follows: Section 2 provides a conceptual background on eco-innovation, openness, and appropriability. Section 3 presents the hypotheses on the role of openness and appropriability in the firms' adoption of cleaner production and end-of-pipe eco-innovations. Section 4 describes the methodology used in the chapter. Section 5 reports the results, while sections 6 and 7 discuss the implications and provide concluding remarks, respectively.

4.2. Conceptual Background on Eco-innovation, Openness, and Appropriability

4.2.1. Cleaner Production and End-of-Pipe Eco-innovations.

Scholars and practitioners define eco-innovation as "... the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives" (Kemp & Pearson, 2007, p. 7). This definition distinguishes eco-innovation from innovation by its positive environmental impact, including changes in product portfolio or production process (De Marchi, 2012).

According to the Oslo manual (OECD/Eurostat, 2005), technological innovations can be divided into product and process, with the latter distinguished according to the stage of the production process between cleaner and end-of-pipe production technologies (OECD/Eurostat, 2005). Firms use cleaner production technologies at an earlier stage in the production process compared to end-of-pipe technologies, which are used for waste treatment. Therefore, cleaner production technologies anticipate waste production at the source, while end-of-pipe technologies treat waste to reduce emissions and discharges into the environment.

New or modified cleaner production processes result in positive environmental impacts (Demirel & Kesidou, 2011). Firms adopting cleaner production technologies optimize processes by reducing raw energy or material use or replacing the latter with less polluting materials. Achieving process efficiency requires developing or acquiring new knowledge through innovation modes based on science and technology, ways based on learning by doing, or by combining both (Demirel & Kesidou, 2011). Thus, efficient resource use and waste generation reduction involve changes in production and management processes.

Compared to end-of-pipe technologies, adopting cleaner production technologies has superior economic and environmental potential for firms. Firms introducing cleaner production eco-innovation can reduce production costs by reducing material and energy use, replacing raw materials with less expensive materials, or reusing materials. These practices produce environmental benefits as firms use fewer natural resources and generate fewer emissions and spills. By contrast, firms perceive end-of-pipe technologies as costly investments, as the costs of these technologies increase depending on the amount of waste the firm needs to treat (Porter & van der Linde, 1995). For example, regulations based on standards and technological mandates encourage firms to introduce end-of-pipe technologies. Cleaner production eco-innovations are a source of competitive advantage, with the potential for cost reduction and improvement in firms' production processes. Their development requires the use of knowledge, which appropriability mechanisms must protect.

Previous studies on determinants of eco-innovation have demonstrated that firms' eco-innovation is positively associated with pollution abatement costs, while governmental monitoring activities do not serve as a motivation for eco-innovation (Brunnermeier & Cohen, 2003). Horbach et al. (2012) note that eco-innovation determinants affect different types of environmental technologies. For example, regulations are critical for reducing air, water, and noise emissions, while determinants such as cost savings are significant for decreasing energy and material use. Additionally, customer requirements encourage improvements in product environmental performance and material efficiency.

The unique features of eco-innovation have led scholars to broaden our understanding of its determinants, barriers, and performance. High levels of uncertainty characterize eco-innovation, and firms invest substantial resources without certainty of the outcomes and returns on investment. Institutions are critical in providing a favorable environment to reduce uncertainty. The role of regulatory pressures and market pull has been extensively studied and are essential determinants in eco-innovation literature (Bossle et al., 2016; Hojnik & Ruzzier, 2016). Although much research has focused on regulatory pressures, the role of appropriability mechanisms and complementary assets in eco-innovation literature has received less attention.

4.2.2. Openness.

Previous literature identifies firm openness as an important element for innovation and, recently, for eco-innovation (Ghisetti et al., 2015; Muscio et al., 2017a). The open innovation approach comprises different forms of openness, such as revealing internal resources to the environment, marketing, sourcing and procurement (Dahlander & Gann, 2010). Regarding firms' openness to the environment, literature highlights that innovation requires different types of information and knowledge obtained from internally and externally. Under this form of openness, firms that successfully combine their internal knowledge with diverse sources broaden the range of knowledge needed to innovate.

Breadth is a form of openness defined in the open innovation literature as the number of sources of information and knowledge external to the firm that it uses in its innovation activities (Laursen & Salter, 2004a). Firms seeking information and collaborating with diverse organizations need to develop organizational practices to adapt to the search environment (Laursen & Salter, 2014). Firms that also engage in cooperative agreements with other organizations can access complementary resources that enable them to develop new products and processes (Laursen & Salter, 2014).

4.2.3. Appropriability.

There is a tight relationship between open innovation and appropriability of innovation in that the value of an innovation is determined by the innovator's creation of value and his ability to capture it (Chesbrough et al., 2018). In this sense, appropriability of innovation is "… an innovator's potential to benefit from an innovation. This potential builds on the instruments of appropriability -isolating appropriability mechanisms and complementary assets- that afford the innovator control over the innovation" (Hurmelinna-Laukkanen & Yang, 2022, p. 9). Appropriability mechanisms such as intellectual property rights (patents, utility models, design registration and trademark) and non-statutory mechanisms (secrecy and complexity) influence the value capture from firms' innovation (Cohen et al., 2000; Levin et al., 1987; Teece, 1986). Intellectual property rights are rights granted by an authority, and their effectiveness depends on institutional enforcement. Conversely, strategic mechanisms such as secrecy and complexity depend on firms' efforts to keep within the boundaries of the organization the features of a technology or practice (James et al., 2013). The literature on appropriability of innovation distinguishes between those mechanisms depending on institutional enforcement, which are categorized as formal appropriability mechanisms, and those mechanisms depending on the firm's strategy, which are categorized as informal (Hall et al., 2014; Zobel et al., 2017).

Because intellectual property rights depend on a legal institution for compliance, these mechanisms are costly to use and enforce. Thus, expected litigation costs influence a firm's propensity to use formal mechanisms. At higher expected costs that a firm must incur to enforce, for example, its patents, less likelihood of using such mechanisms (James et al., 2013). In addition, since intellectual property rights protect novelty, which is obtained mainly through R&D investments, the fact that a firm must make constant R&D investments to meet the government's technological requirements may discourage the use of formal mechanisms.

A firm's appropriability regime can be “weak” or “strong” according to the knowledge and the law's enforcement. A weak appropriability regime is characterized by innovation that is difficult to protect because of its largely codified knowledge, which makes it easy to transfer and imitate, and by ineffective enforcement of property rights (Teece, 2018). In a strong appropriability regime, innovation is easy to protect, since knowledge is mostly tacit and the legal system guarantees property rights protection (Teece, 2018). Therefore, an appropriability regime is part endogenous and part exogenous to a firm (Pisano, 2006) which is why a firm's innovation depends on its appropriability strategy (Cohen et al., 2000).

4.3. Hypotheses

4.3.1. Breadth of the Firm's Knowledge Sourcing Influencing Cleaner Production and End-of-Pipe Eco-Innovations.

We propose that the breadth of knowledge sources positively affects eco-innovation, and the firm's approach towards adopting a breadth-of-knowledge strategy varies between cleaner production and end-of-pipe technologies. This implies that a firm's decisions regarding openness differ depending on the nature of eco-innovation. Cleaner production and end-of-pipe technologies are adopted at different stages of the production process, so the firm needs knowledge specific to the adoption stage (Frondel et al., 2007). Furthermore, both types of eco-innovation differ in their benefits, impacts, and lifespan (Hammar & Löfgren, 2010).

We argue that the breadth of external sources of knowledge positively influences the adoption of cleaner production technologies. Adopting cleaner production eco-innovation requires a firm to make changes to its production process, which necessitates information from diverse actors. For instance, a firm needs close communication with its suppliers to learn about the characteristics and ways of handling inputs and materials that are less polluting or easier to treat. Reducing emissions and discharges during the production process also requires changes in the way the firm produces and manages its products. To implement these changes successfully, it is crucial for a firm to be aware of the machinery used by competitors, as well as to communicate with suppliers for the acquisition of new equipment that complies with environmental standards. In addition, involving all staff in the company is another crucial aspect for understanding waste as a potential resource. The staff should be receptive to new ideas on how to implement alternative uses for waste. In this case, competitors can be a source of information on how other firms integrate their waste into the production process. Since cleaner production adoption has a close connection with consumers, a firm involves consumers to guarantee social legitimacy.

Cleaner production technology is a continuous improvement process for a firm, and its adoption has a long-term time frame. Cleaner production involves increasing production and efficiency using inputs without increasing emissions per unit of output. In other words, the firm continuously searches for ways to produce more using fewer inputs and generating less waste. The constant search for efficiency requires permanent collaboration with actors (e.g., universities and research centers) providing information on new technologies. In summary, a firm eco-innovating towards cleaner production integrates eco-innovation into its organizational and production processes. Therefore, we state that:

H1a. The breadth of a firm's knowledge sourcing positively influences its adoption of cleaner production eco-innovation.

We argue that the breadth of external sources of knowledge positively influences the adoption of end-of-pipe technologies. End-of-pipe technologies refer to solutions that treat waste generated after the production process. That is, once waste is created. Since firms often adopt end-of-pipe technologies for regulatory compliance (Frondel et al., 2007), competitors or other firms in the sector can be sources of information to learn about technologies useful for regulatory compliance.

End-of-pipe technologies become less useful for regulatory compliance in the short term as environmental standards become stricter over time, reducing emissions and waste allowed for the firm. This leads the firm to constantly communicate with technology suppliers, competitors, and other firms in the industry to adopt technologies that enable them to comply with current regulations.

End-of-pipe technologies control and treat specific wastes, and managing each type of waste requires specific information. For example, filters and scrubbers are air pollution control devices that remove some particulates from company exhausts. Wastewater treatment systems remove pollutants from wastewater so that firms can discharge them into effluent. Each type of solution requires specific expertise for which a firm relies on certain actors. Therefore, we state that:

H1b. The breadth of a firm's knowledge sourcing positively influences its adoption of end-of-pipe eco-innovation.

4.3.2. Appropriability Moderating the Relationship Between Breadth of Knowledge and Eco-innovation.

Firms' openness strategy for eco-innovation also depends on their potential for value appropriation. The paradox of openness emphasizes the importance of firms being open to new knowledge while protecting their innovation-related knowledge. Previous research has shown tensions and synergies between openness and appropriability (Chesbrough et al., 2018; Hurmelinna-Laukkanen & Yang, 2022; Lauritzen & Karafyllia, 2019; Laursen & Salter, 2014). Appropriability mechanisms can encourage external collaboration by signaling that a firm owns valuable knowledge and is a potential collaborator for other actors (Laursen & Salter, 2014). However, if a firm places a greater emphasis on protecting its knowledge can discourage external actors from sharing their knowledge (Laursen & Salter, 2014; Wang et al., 2017).

Firms can successfully eco-innovate by differentiating and integrating appropriability and openness strategies (Hurmelinna-Laukkanen & Yang, 2022; Lauritzen & Karafyllia, 2019). Differentiation of appropriability and openness allows firms to operate concurrently in different temporal, spatial, or structural areas of a firm, while the integration of appropriability and openness allows a firm to benefit from their complementarities (Lauritzen & Karafyllia, 2019). As a result, a firm can manage its appropriability and openness strategies by differentiation and integration to increase its success in eco-innovation.

We argue that firms that simultaneously use the breadth of knowledge sources and appropriability mechanisms at different stages of the production process strengthen their adoption of cleaner production eco-innovation. Linking suppliers to the production process enables a firm to share its knowledge and skills about the environmental standards of inputs and materials needed to reduce waste generation, while safeguarding its input and material transformation stage by using design complexity or trade secret strategies (Chiou et al., 2011). Accessing external knowledge through collaboration with suppliers and protecting the transformation process through appropriability mechanisms can increase a firm's potential for eco-innovation.

An integrated approach to cleaner production technologies implies that the breadth of knowledge sources and appropriability help a firm efficiently use its resources while reducing waste generation. An eco-innovative firm can meet both principles of cleaner production technologies by selectively revealing (Henkel, 2006). A firm can broaden its sources of knowledge to reduce waste generation while protecting the methods in which it efficiently uses its resources. Appropriability mechanisms allow a firm to benefit from information obtained from the adoption of cleaner production, which the firm can use to improve its production process. Given that firms use appropriability and openness simultaneously and complementarily according to the adoption of cleaner production technologies, we suggest that:

H2a. Appropriability positively moderates the relationship between breadth of knowledge with cleaner production eco-innovation.

A firm can increase its adoption of end-of-pipe technologies by differentiating between its breadth of knowledge and appropriability. This differentiation allows the firm to reveal knowledge of non-essential parts of the production process while protecting the stages that give it a competitive advantage. End-of-pipe technologies are not involved in the production process but are instead implemented to mitigate waste once it is generated. Because the primary objective is waste mitigation, these technologies are often homogeneous within an industry, as they are specific to the type of waste that is produced (Hammar & Löfgren, 2010). This means that a firm has an incentive to share knowledge with other firms and technology suppliers to benefit from their knowledge. As a result, the adoption of end-of-pipe technologies increases a firm's information about production process problems and makes it possible to correct these problems (Dutt & King, 2014a). Appropriability mechanisms provide a firm with the opportunity to benefit from this information, which can be used to improve the production process.

We argue that appropriability mechanisms can both stimulate external collaboration and discourage knowledge sharing. Firms strengthen their adoption of cleaner production eco-innovation by using both the breadth of knowledge sources and appropriability mechanisms at different stages of the production process (Dutt & King, 2014b; Frondel et al., 2007). Accessing external knowledge through collaboration with suppliers and protecting the transformation process via appropriability mechanisms enables a firm to improve its inputs while also keeping its knowledge separate and protected, serving as a source of competitive advantage. This, in turn, facilitates the firm's adoption of eco-innovation in cleaner production processes. In addition, an integrated approach to cleaner production technologies involves using the breadth of knowledge sources and appropriability to efficiently use resources while reducing waste generation.

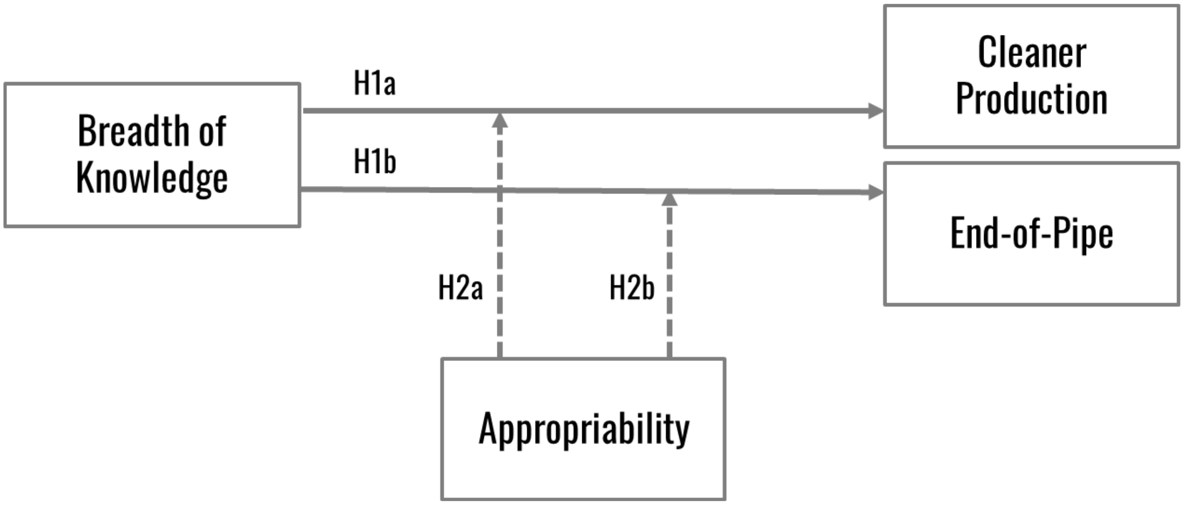
In the production process, end-of-pipe technologies are responsible for mitigating waste generated during production. As these technologies are not an essential part of the production process, firms can differentiate between breadth of knowledge and appropriability to reveal non-essential knowledge while protecting their competitive advantage. By accessing external knowledge through collaboration with competitors and other firms, a firm can learn about new technologies for mitigating waste generated. This knowledge can be incorporated into the firm without exposing core knowledge, thus protecting the firm's competitive advantage.

We, therefore, propose that:

H2b. Appropriability positively moderates the relationship between breadth of knowledge with end-of-pipe eco-innovation.

In summary, we suggest that appropriability positively moderates the relationship between the breadth of knowledge with cleaner production eco-innovation and end-of-pipe eco-innovation. By differentiating and integrating their appropriability and openness strategies, firms can improve their potential for eco-innovation. The four hypotheses in this chapter are shown in the conceptual model in Figure 7 and relate a firm's breadth of knowledge to the types of eco-innovation (H1a and H1b) and the relationship between appropriability and breadth to eco-innovate (H2a and H2b).

Figure 7. Conceptual Model.



4.4. Methodology.

4.4.1. Data and Sample.

Innovation surveys are an important data source used in innovation studies worldwide, capturing diverse aspects of innovation processes (Cirera & Muzi, 2020). In eco-innovation studies, surveys have been the primary source of information to advance our understanding of firms' eco-innovation phenomenon (Cainelli et al., 2015; De Marchi, 2012). Previous studies have relied on innovation surveys (Cainelli et al., 2015; Cleff & Rennings, 1999; De Marchi, 2012; Marzucchi & Montresor, 2017), specialized surveys on firms' environmental aspects (Cainelli et al., 2015; De Marchi, 2012), or self-administered questionnaires to overcome information restrictions (Cuerva et al., 2014).

This chapter is based on balanced panel data with information from the Colombian Innovation Survey (Encuesta de Desarrollo e Innovación Tecnológica–EDIT). The survey is conducted biennially by the National Administrative Department of Statistics (DANE) and provides information on the innovation activities of small, medium, and large manufacturing firms. The EDIT adheres to the Oslo manual guidelines (OECD/Eurostat, 2005) and has adapted its methodology for use in emerging economies (RICYT, 2000), allowing for harmonization with other innovation surveys in Latin America. The EDIT covers an average of 8,000 firms per survey and has records from 2007 to 2018. This makes the EDIT one of the continent's most comprehensive longitudinal innovation surveys (Crespi et al., 2021).

The unit of analysis for the EDIT is the firm, with information reported by both firm managers and staff experts. Five waves were used to construct a balanced panel (2009-2010, 2011-2012, 2013-

2014, 2015-2016, 2017-2018). Surveys prior to 2009 were not considered as they did not ask firms about the environmental impacts of innovation in the same way as later surveys. The sample compress 5,720 firms appearing in the five surveys with 28,600 observations. The panel database contains information on firms' adoption of innovations, their environmental impacts, the breadth of knowledge, and the appropriability mechanisms firms use.

4.4.2. Measures and Variables.

Dependent Variable.

Information on firms' adoption of process innovation and their environmental impact was used to design two binary response variables on a firm's adoption of cleaner production and end-of-pipe eco-innovations. Cleaner production and end-of-pipe eco-innovations are waste reduction technologies implemented in a firm's production process. Cleaner production technologies anticipate waste production at the source, while end-of-pipe technologies treat waste to reduce emissions and discharges into the environment. In this sense, firms reported whether their firm adopted process innovation in the last two years and provided information on the level of importance (null, medium, or high) of the innovation's impact on i) energy consumption reduction, ii) raw materials and input reduction, iii) water consumption reduction, iv) and the use of waste in a firm's processes.

First, a binary variable was designed to indicate whether the firm had adopted or not, a process innovation in the last two years. Second, for cleaner production, a binary variable was designed if a firm reported a medium or high level of importance in at least one of the three environmental impacts: i) energy consumption reduction, ii) raw materials and input reduction, iii) water consumption reduction. The end-of-pipe variable was created indicating whether a firm reported a medium or high level of importance in the use of waste in a firm's processes. Therefore, cleaner production eco-innovation takes the value of 1 if a firm reported a process innovation with a medium or high level of environmental impact on reducing energy, materials, and input consumption, or water consumption, and 0 otherwise. End-of-pipe eco-innovation takes the value of 1 if a firm reported a process innovation with a medium or high level of environmental impact on waste use in a firm's processes and 0 otherwise.

Indirect measurement of eco-innovation through the environmental impacts of an innovation avoids overestimations, as managers tend to assign greater favorable attributes to their management (Marzucchi & Montresor, 2017). Previous studies have used this way of measure of eco-innovation and identifies an eco-innovation as an innovation with positive environmental impacts (Cainelli et al., 2015; Cleff & Rennings, 1999; De Marchi, 2012; Marzucchi & Montresor, 2017).

Independent Variables.

The independent variable, breadth, is a type of openness that refers to using sources of information or knowledge external to the firm. Breadth is defined as the number of external sources of information or knowledge that a firm uses in its innovative activities. (Laursen & Salter, 2004b). The level of openness of a firm measured as the number of sources has been used extensively in the open innovation literature. (Dahlander & Gann, 2010; Laursen & Salter, 2006) and recently in the eco-innovation literature (Ghisetti et al., 2015; Muscio et al., 2017b).

Following Laursen and Salter (2014), breadth was measured using organizational sources where interaction and risk of knowledge outflows may occur and excluding sources where interaction may not occur. Six types of organizational sources were used: suppliers, customers, competitors, universities, research centers, and technology development centers. Managers report information for each type of organization whether they have cooperated with or used as sources of ideas to innovate. Each variable is coded binary and takes the value of 1 if the firm cooperated or used an organization as a source of idea to innovate, and 0 otherwise. The six sources were then summed, so that breadth indicates the number of sources of information or knowledge, with a 0 score if no information or knowledge sources are used by a firm and a maximum score of 6 if all sources are used.

To gain insight into the relationship between breadth and appropriability, the EDIT information was used to design the measures of appropriability mechanisms used by firms. The measurement of appropriability mechanisms focuses on a firm level, so it considers that the use of appropriability mechanisms is contingent on a firm's strategy.

Information from the EDIT questionnaire was used to identify the mechanisms summed up. The EDIT asks managers whether the firm owns, obtained or used intellectual property rights such as patents, trademarks, industrial designs, utility models and copyrights in the last two years of each survey. The EDIT also asks managers whether the firm used appropriability mechanisms during the last two years, such as complexity in design and industrial secrecy. Each variable takes the value of 1 if the firm used each mechanism and 0 otherwise. Then, the six mechanisms were summed and transformed in their binary form.

Control Variables.

Seven control variables were included in the chapter. Research and Development investments (*R&D (log)*) controls a firm's absorptive capacity. R&D was measured on a logarithmic scale as a firm's internal and external research and development investments in the last two years at the time of each survey.

Firm's size (*Size (log)*) represents a firm's resources to eco-innovate. It was measured as the firm's number of employees expressed in log terms.

The variable *Public* represents the regulatory effect and indicates whether the firm has received public resources for R&D investment (Ghisetti et al., 2015). However, this variable does not capture specific information of investment of public resources for environmental R&D.

The variable multinational corporation (*MNC*) controls a firm's relationship with a multinational corporation. It takes the value of 1 if the firm uses its foreign firm as a source of ideas to innovate, and 0 otherwise.

The *Export* variable controls a firm's presence in international markets. It is a binary variable that takes the value of 1 if a firm reports revenues derived from its exports, and 0 otherwise. Models include effects over time to account for firms' performance to introduce eco-innovations.

4.4.3. Estimation technique.

Given the nature of the dependent variable and independent variables, a random effects logistic regression model was used. This type of model considers the heterogeneity not observed when allowing the existence of specific variables by a firm. The random effects model is an appropriate technique for solving the incidental parameter problem that characterizes binary data models panel (Croissant & Millo, 2018).

4.5. Results

The dataset's descriptive statistics are presented in Table 6. The strong correlation of 0.74 between cleaner production and end-of-pipe eco-innovations indicates that most firms tend to adopt both types of technologies. Prior research has suggested that firms typically adopt end-of-pipe technologies as a starting point, enabling them to build capabilities necessary to adopt more sophisticated technologies like cleaner production. Moreover, Table 6 displays comparable correlations between independent and control variables with cleaner production and end-of-pipe eco-innovations.

Table 7. Means, Standard Deviations and Pearson Correlations.

Variables	Mean	s.d.	Min	Max	1	2	3	4	5	6	7	8	9	10
Cleaner prod	0.11	0.31	0	1	1									
End-of-pipe	0.09	0.29	0	1	0.74*	1								
Appropriability	0.41	0.62	0	6	0.19*	0.19*	1							
Breadth	1.47	1.41	0	6	0.06*	0.07*	0.09*	1						
Size (log)	1.63	0.55	0	3.70	0.24*	0.22*	0.31*	0.07*	1					
R&D (log)	1.41	2.20	0	8.36	0.11*	0.11*	0.16*	0.1*	0.28*	1				
Sector	0.43	0.49	0	1	0.00	0.00	0.01*	0.00	0.00	0.04*	1			
Public	0.01	0.11	0	1	0.14*	0.13*	0.11*	0.07*	0.13*	0.14*	-0.01	1		
MNC	0.06	0.23	0	1	0.02*	0.02*	0.03*	0.15*	0.09*	0.06*	0.02*	0.01	1	
Export	0.27	0.44	0	1	0.11*	0.1*	0.19*	0.03*	0.42*	0.16*	0.08*	0.09*	0.06*	1

Note: statistical significance * $p < 0.05$.

Table 7 shows the results of logistic regression models for firms' adoption of cleaner production and end-of-pipe eco-innovations. Models 1 and 4 report the control variables, Models 2 and 5 report the control and independent variables and Models 3 and 6 report the full set of variables. Regarding the control variables, R&D investments show a positive and significant influence on firms' adoption of both types of eco-innovation. This result indicates that R&D enhances firms' technical capabilities to adopt new technologies, including cleaner production and end-of-pipe. Since end-of-pipe eco-innovations are technology oriented, R&D enables firms to absorb external knowledge.

Firm size is also positively associated with both types of eco-innovation, suggesting that larger firms have more resources to adopt complementary technologies. Although previous literature has indicated mix results (Demirel & Kesidou, 2011; Frondel et al., 2007). In the Colombian context, larger firms have more diversified resources to adopt technologies that complement their production process. Public support of firms' R&D activities (Public) also positively influences the adoption of cleaner production and end-of-pipe eco-innovation, as it compensates innovators and corrects spillovers from innovation (Guo et al., 2018).

The presence in international markets is another variable positively associated with both types of eco-innovation. This result suggests that firms trading in foreign markets need to comply with environmental requirements, and technology adoption enables them to meet such requirements and sell their products abroad. Multinational corporations (MNC) and Sector did not report statistically significant results.

Models 2 and 5 show that the breadth of a firm's knowledge sourcing positively and statistically significant influences the adoption of cleaner production and end-of-pipe eco-innovation, respectively. These results support Hypothesis 1a and 1b. The odds-ratio of a firm to adopt cleaner production and end-of-pipe eco-innovations increases as its breadth of knowledge sources increases. This suggests that firms that can leverage their knowledge sources are more likely to adopt cleaner production and end-of-pipe eco-innovations.

Table 8. Logistic regressions coefficients of cleaner production and end-of-pipe eco-innovations.

	Cleaner Production			End-of-Pipe		
Independent	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$Breadth_{t-1}$		1.05***	1.02		1.07***	1.04*
		(0.01)	(0.02)		(0.02)	(0.02)
$Appropriability_{t-1}$		1.20***	1.08		1.23***	1.10
		(0.04)	(0.06)		(0.05)	(0.07)
Moderation						
$Breadth_{t-1} * Approp_{t-1}$			1.05**			1.05**
			(0.02)			(0.02)
Controls						
$R\&D\ (log)_{t-1}$	1.03***	1.02**	1.02**	1.03***	1.02*	1.02*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
$Size\ (log)_{t-1}$	3.62***	3.38***	3.37***	3.40***	3.15***	3.14***
	(0.21)	(0.20)	(0.20)	(0.21)	(0.19)	(0.19)
$Public_{t-1}$	6.02***	5.67***	5.62***	5.56***	5.14***	5.09***
	(1.08)	(1.02)	(1.01)	(0.98)	(0.91)	(0.90)
MNC_{t-1}	0.99	0.94	0.94	1.04	0.97	0.97
	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)	(0.11)
$Export_{t-1}$	1.15**	1.12*	1.12*	1.18**	1.14*	1.14*
	(0.07)	(0.07)	(0.07)	(0.09)	(0.08)	(0.08)
Sector	1.02	1.02	1.02	1.02	1.02	1.02
	(0.05)	(0.05)	(0.05)	(0.06)	(0.06)	(0.06)
Year 2014	0.72***	0.75***	0.75***	0.68***	0.71***	0.72***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Year 2016	0.73***	0.77***	0.77***	0.71***	0.76***	0.76***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)	(0.06)
Year 2018	0.75***	0.77***	0.78***	0.68***	0.71***	0.71***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Intercept	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Num. obs.	22,880	22,880	22,880	22,880	22,880	22,880

Num. firm-period obs.	5,720	5,720	5,720	5,720	5,720	5,720
Log-Likelihood.	-6,538.20	-6,521.48	-6,519.03	-5,840.74	-5,819.09	-5,816.33
Wald Chi2	887.38***	919.05***	920.69***	785.03***	833.32***	837.52***

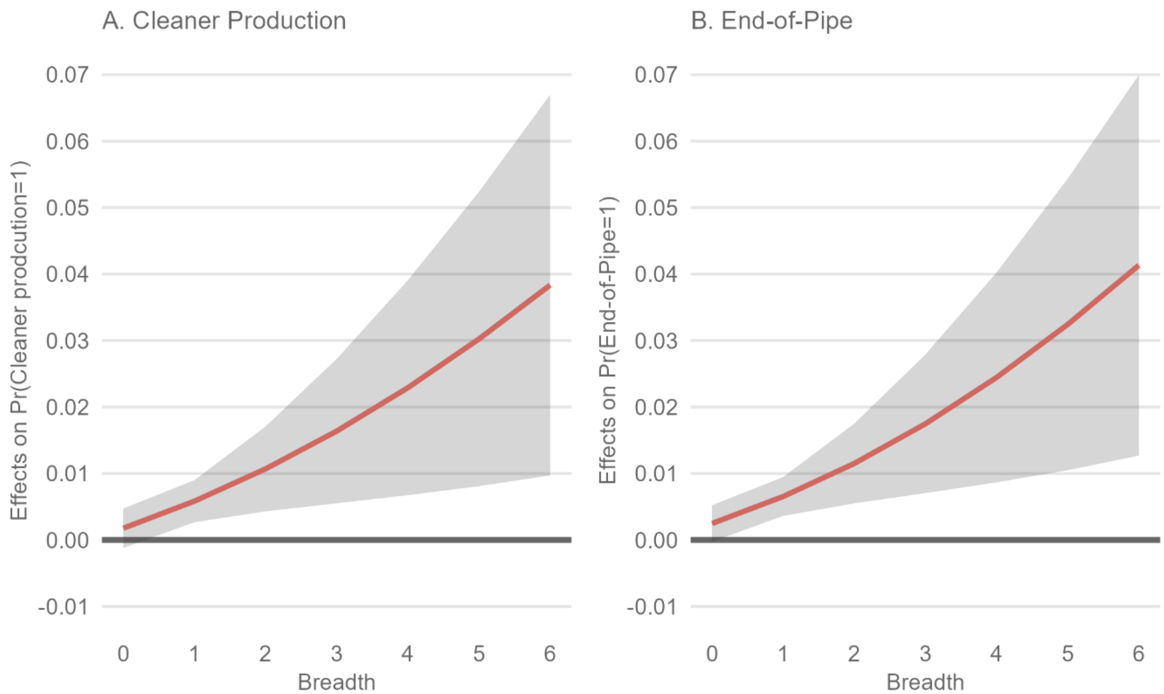
Robust standard errors in parentheses. Statistical significance: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

The results from Models 3 and 6 suggest that the relationship between the adoption of cleaner production and end-of-pipe eco-innovations and the breadth of a firm's knowledge sourcing is moderated by appropriability. These findings are in line with Hypotheses 2a and 2b. The results reveal a positive and statistically significant interaction between appropriability and the breadth of a firm's knowledge sourcing, which influences firms' adoption of cleaner production (1.05; $p < 0.05$) and end-of-pipe (1.05; $p < 0.05$) eco-innovations.

Figure 8 shows the probability of eco-innovation as the number of collaboration sources increases at different levels of appropriability mechanisms for cleaner production eco-innovation (Figure 8-A) and end-of-pipe eco-innovation (Figure 8-B). The probability of eco-innovation increases as the number of knowledge sources increases, and the effect strengthens when firms use more appropriability mechanisms. This indicates that the effect of using knowledge sources on eco-innovation depends on the use of appropriability mechanisms. In other words, collaboration with diverse actors has a positive influence on eco-innovation, and its influence is strengthened by using mechanisms that allow a firm to appropriate its value.

The results also show that the marginal effects of combining collaboration and appropriability are similar between cleaner production and end-of-pipe eco-innovations (Appendix A). This suggests that both collaboration and appropriability have a similar magnitude of influence on both types of eco-innovations and that the knowledge obtained by a firm from different sources can be used in complementarity with a different number of appropriability mechanisms to adopt both cleaner production and end-of-pipe eco-innovations.

Figure 8. Conditional effect of breadth on eco-innovation at different levels of appropriability.



Note: The figures show the interaction between predictor (breadth) and moderator (appropriability) variables. The red line shows the average marginal effects on cleaner production (2-A) and end-of-pipe (2-B) eco-innovations when the firm uses different sources of knowledge. The shaded gray area corresponds to the range of values of appropriability.

4.6. Discussion

This chapter advances in the area of green corporate strategies by better understanding how firms combine open innovation and appropriability strategies eco-innovate. We contribute to the eco-innovation literature by providing evidence on the role of knowledge sourcing in cleaner production and end-of-pipe eco-innovations and how firms' potential for value appropriation affects the relationship between the breadth of knowledge and eco-innovation. We argue that the paradox of openness highlights the need for firms to be open to new knowledge while protecting their innovation-related knowledge.

Recent findings in the literature suggest that collaboration positively affects eco-innovation (Cheng & Shiu, 2020; De Marchi, 2012; Ghisetti et al., 2015; Nuryakin et al., 2022; S. Zhang et al., 2022). Our chapter moves in this direction by indicating that the breadth of knowledge sources influences eco-innovation adoption. A greater and more diverse number of sources, such as customers, suppliers, universities, and research and technological development centers, makes it possible to obtain complementary information and knowledge. For example, end-of-pipe technologies are often adopted for regulatory compliance. Because technologies cease to meet the standards of the new regulations over time, firms need to be in constant communication with technology suppliers, competitors, and other firms in the industry to adopt technologies that enable them to comply with current regulations. Cleaner production is a continuous improvement process that requires permanent collaboration with diverse actors providing information on new technologies. Collaborating with multiple actors including suppliers, competitors, and universities provides information on the different components of technology, such as production efficiency and reducing waste. Although knowledge from diverse sources can be beneficial for eco-innovation, previous studies have shown that cooperation with too many sources can even deter companies from eco-innovating (Ghisetti et al., 2015).

Studies in open innovation have explored how firms use internal resources and capabilities to leverage knowledge from diverse sources for eco-innovation. Previous literature has found that in-house R&D strengthens the breadth of knowledge, but not the depth of knowledge (Ghisetti et al., 2015). Moreover, open innovation strategies are strengthened by alliance management capability (Cheng & Shiu, 2020). Our research delves deeper into the relationship between knowledge breadth, appropriability strategies, and eco-innovation potential of firms. We reveal that firms that successfully manage both breadth of knowledge and appropriability strategies can enhance their eco-innovation potential by acquiring external knowledge while maintaining their competitive advantage. Our findings emphasize the importance of effective knowledge management and appropriability strategies for firms aiming to foster eco-innovation.

Appropriability mechanisms can both stimulate external collaboration and discourage knowledge sharing. Firms strengthen their adoption of cleaner production eco-innovation by using both the breadth of knowledge sources and appropriability mechanisms at different stages of the production process. Accessing external knowledge through collaboration with suppliers and protecting the transformation process via appropriability mechanisms enables a firm to improve its inputs while also keeping its knowledge separate and protected, serving as a source of competitive advantage. This, in turn, facilitates the firm's adoption of eco-innovation in cleaner production processes. In addition, an integrated approach to cleaner production technologies involves using the breadth of knowledge sources and appropriability to efficiently use resources while reducing waste generation.

In the production process, end-of-pipe technologies are responsible for mitigating waste generated during production. As these technologies are not an essential part of the production process, firms can differentiate between breadth of knowledge and appropriability to reveal non-essential knowledge while protecting their competitive advantage. By accessing external knowledge through collaboration with competitors and other firms, a firm can learn about new technologies for mitigating waste generated. This knowledge can be incorporated into the firm without exposing core knowledge, thus protecting the firm's competitive advantage.

4.6.1. Recommendations for policy and practice

We found that there is no distinction in the effect of these two factors on the adoption of cleaner production or end-of-pipe eco-innovations. Our results suggest that increasing the number of sources and enhancing the use of appropriability mechanisms has an equal influence on both types of eco-innovations. Moreover, our chapter revealed that once a firm implements one type of eco-innovation, it does not need additional effort in terms of seeking new knowledge sources or applying appropriability mechanisms to adopt a different type of eco-innovation.

Cleaner production technologies are considered more socially desirable than end-of-pipe technologies due to their resource efficiency and ability to reduce emissions at the source. Thus, firms seeking to transition from end-of-pipe to cleaner production technologies can rely on the resources and capabilities gained through collaboration with external sources of knowledge and through the use of appropriability mechanisms. This accumulation of knowledge and resources can facilitate the transition to eco-innovations with greater environmental impact.

4.7. Conclusions

This chapter addresses how firms can eco-innovate by combining open innovation strategies with appropriability. We find empirical evidence that, for the case of firms in an emerging economy such as Colombia, broadening knowledge sources stimulates end-of-pipe eco-innovation. We find that combining the breadth of knowledge sources with appropriability mechanisms strengthens cleaner production and end-of-pipe eco-innovation. Thus, simultaneously managing knowledge openness and knowledge protection strategies leads the firm to successfully eco-innovate. To do so, the firm can differentiate and integrate its strategies by selectively disclosing knowledge while protecting core knowledge.

This chapter faces some limitations. At the methodological level, the survey does not allow for measuring the depth of knowledge, which is a dimension of open innovation. Future research should consider the depth of knowledge and its relationship with appropriability.

Chapter 5

5. Appropriating Benefits Through Designation of Origin and Marketing Strategies: The Case of Rice Producers.

5.1. Introduction

The Colombian rice sector has benefited from a tariff that maintained a high price for rice imports. Colombian farmers sustained a price advantage that ended in 2012 with a Free Trade Agreement (FTA) with the United States. The FTA will gradually reduce tariffs on imported rice until the tariff reaches zero in 2030. This has led to an increase in rice imports from the United States at a lower price. The FTA added to the impacts of climate change and variability on agriculture and the emergence of plant diseases, which prompted Colombian rice producers to seek new sources of competitive advantage.

In response to changing market and environmental conditions, rice producer organizations in a major rice-producing region in Colombia have implemented eco-innovations and other practices to reduce production costs. While these innovations have been effective in reducing production costs and increasing productivity, they have not been sufficient to improve the competitiveness of rice producers' organizations. The set of practices and eco-innovations implemented maintained price competition, rather than looking for differentiation. Thus, rice producers' organizations have implemented a designation of origin to differentiate their products and appropriate their value. The designation of origin makes it possible to highlight the intrinsic and extrinsic attributes of rice, which are linked to its origin and local production practices. This strategy simultaneously protected and promoted imitation and was complemented by marketing strategies.

In this case study, we examine how rice farmers' organizations appropriate the benefits of their production process by combining designation of origin and marketing strategies. Farmers' organizations use appropriability mechanisms that simultaneously foster knowledge sharing among organizations located in one place, while excluding competitors from outside the territory. This case study contributes to the profiting from Innovation framework, which addresses the different appropriation processes of the benefits of innovation. An innovative firm can follow diverse pathways to appropriate its benefits. Appropriation processes can prevent others from exploiting innovation and related knowledge (exclusion-oriented processes), give priority to profit over protection by facilitating knowledge exchange (leverage-oriented processes), or accept imitation and use appropriability mechanisms to disseminate innovation (disclosure-oriented processes) (Hurmelinna-Laukkanen & Yang, 2022).

While previous studies have improved our understanding of how appropriation processes occur, there is still a limited understanding of how a firm can use diverse appropriation processes simultaneously. One form of coexistence is to establish processes that enable appropriation among internal members and inhibit appropriation with members external to the network (Capaldo & Messeni Petruzzelli, 2011; Dhanaraj & Parkhe, 2006). The tension that exists when exchanging knowledge leads firms to become concerned about the appropriability of innovation. To this end, an environment of trust, openness, and commitment among firms reduces appropriability concerns within the network of collaborators (Dhanaraj & Parkhe, 2006).

This case study sheds light on how rice farmers in Colombia use appropriability mechanisms to benefit from eco-innovation, while also fostering knowledge sharing and excluding external competitors. This adds to our understanding of the complex and multifaceted processes involved in the appropriation of innovation and provides insights into how firms can use multiple appropriation processes simultaneously.

5.2. Theoretical Background

5.2.1. *Appropriability and Complementary Assets*

Appropriability is rooted in the fact that firms exert some form of protection or ownership over innovation (Harabi, 1995). For this purpose, firms use appropriability mechanisms as the means by which the innovating firm protects its innovation. Appropriability mechanisms increase the possibility of appropriating innovation benefits. Therefore, appropriability mechanisms facilitate the protection and acquisition of innovation benefits.

The Profiting from Innovation Framework asserts that both value creation and capture are crucial elements of successful innovation (D. Teece, 1986; D. J. Teece, 2006). There has been an emphasis in the literature on innovation studies on differentiating between appropriability and appropriation. Appropriability refers to an organization's capacity to profit from its innovation, whereas appropriation refers to the process of how that profit is realized (Hurmelinna-Laukkanen & Yang, 2022). In other words, appropriability is about building readiness to benefit from innovation, whereas appropriation is about realizing that potential.

Firms dispose of a broad portfolio of appropriability mechanisms to protect and benefit from their innovations (Hurmelinna-Laukkanen & Puumalainen, 2007). Researchers have developed several categories to classify appropriability mechanisms (Yang & Hurmelinna-Laukkanen, 2022). The distinction between formal and informal is one of the most commonly used categories in the appropriability of innovation literature. Formal mechanisms grant exclusive rights to innovative firms to profit from their innovation. These mechanisms encompass several intellectual property rights (IPRs) including patents, trademarks, industrial designs, utility models, and copyright, as well as contracts and labor legislation (Hurmelinna-Laukkanen et al., 2008; Teece, 1986). On the other hand, informal mechanisms involve non-statutory means of intellectual property protection, such as maintaining secrecy and creating design complexity (Gallié & Legros, 2012). While formal mechanisms offer institutional protection through the efficacy of legal safeguards, informal mechanisms rely on a firm's knowledge management systems and the safeguarding of tacit knowledge.

Previous studies have provided evidence on how appropriability mechanisms affect the protection of innovation and appropriation of its benefits. These studies have consistently demonstrated that the selection of appropriability mechanisms is contingent upon firm size, R&D investment, and the nature of collaboration with external stakeholders. In particular, small firms prioritize the use of appropriability mechanisms that align with their available resources (Leiponen & Byma, 2009). Formal appropriability mechanisms have been found to foster innovation and facilitate the adoption of open innovation strategies within small firms. However, it is crucial to note that the effectiveness of legal exclusion rights relies on a firm's capacity to enforce them through legal channels. Unfortunately, resource limitations often hinder small firms from fully leveraging legal avenues for protection (Freel & Robson, 2017).

The appropriability framework states that the effectiveness of appropriability mechanisms depends on their combination with complementary assets (Teece, 1986). Complementary assets refer to the resources and capabilities that firms possess and use to enhance the value and commercialization of their innovations. These assets include specialized knowledge, technologies, brand reputation, distribution networks, and customer relationships. They are considered essential for firms to fully exploit the potential of their innovations and capture their value (J.-H. Lin & Wang, 2015). The concept of complementary assets has been discussed in the literature on innovation and firm performance, particularly in relation to the commercialization and distribution of profits from innovation (Zhou, 2019). Scholars have emphasized the importance of firms' ability to combine and leverage their complementary assets to maximize the benefits of their innovations.

5.2.2. Labels of Origin as Protection Mechanism

A label (or designation) of the origin is an indication that associates a product with a geographical location. The particular form of production or transformation of a product by its inhabitants provides characteristics and/or reputation that differentiate the product from those produced in other places and prevents imitation (European Commision, 2007). Labels of origin have received increasing attention in psychology and market research literature because of the growing consumer demand for these products and their influence on consumer preferences (Menapace et al., 2011; Verlegh & Steenkamp, 1999). This topic of research has also been studied in terms of corporate strategy by differentiating products in the market and contributing to a firm's competitive advantage (Oberthür et al., 2011).

The literature distinguishes between two types of labels of origin: designation of origin and geographical indication. The main difference is the greater geographical link with the final product that the designation of origin has in comparison to the geographical indication. For a product to obtain a designation of origin, all stages of the production process must occur in the same geographical area (European Commision, 2007). On the other hand, geographical indication allows inputs to come from other places and requires at least one stage of the production process to have taken place in the geographical area (European Commision, 2007).

The designation of origin is an example of a protection mechanism that relies on the location where it is produced (Menapace et al., 2011). Unlike intellectual property rights and nonstatutory mechanisms, this protection mechanism is based on collective ownership. The designation of origin protects against imitation by competitors outside the geographical area and simultaneously facilitates collaboration between organizations within the geographical area covered by the mechanism. Because the designation of origin belongs to the government, it intervenes in the case of imitation, which makes it easier for small producers who cannot afford costly legal battles (Barham, 2003).

5.3. Methods

5.3.1. Empirical context: rice producers, eco-innovations and protected designation of origin

The organizations of rice producers located in the Meseta de Ibagué (Ibagué Plateau) provide an excellent empirical context for investigating how organizations develop and combine strategies that allow the appropriate benefits of their production processes. Specifically, this case study explores how a designation of origin differentiates and allows the appropriation of benefits. After reviewing archival sources such as reports from rice organizations, press articles, and sectorial studies in Colombia, it became clear that the Colombian rice sector has been facing numerous challenges that have forced it to implement measures to enhance its competitiveness.

At the industrial level, the Colombian Rice Federation responded by implementing the AMTEC program (En español, Adopción Masiva de Tecnología) to enhance rice farmers' productivity. Simultaneously, rice producers' organizations in the Meseta de Ibagué obtained a designation of origin for their rice as an appropriability strategy. This designation highlights the unique rice produced in the Meseta de Ibagué and distinguishes it from other varieties in the market. Notably, the Meseta de Ibagué rice producers possess an exclusive designation of origin in Colombia and are among the three such designations in Latin America and nine worldwide.

5.3.2. Research Design

We conducted a retrospective case study to investigate how rice producers in Ibagué use designation of origin as an appropriability mechanism to capture the benefits of eco-innovation. We chose a case study because of the nature of the research question, timing of the phenomenon, and blurred boundaries between the phenomenon and context, as explained by Yin (2014).

Our research question aims to explain the process of capturing value through the use of appropriability mechanisms and marketing strategies. The adoption of eco-innovations, use of designation of origin, and implementation of marketing strategies are contemporary events that can be directly observed, and the people involved can be interviewed (Yin, 2014). To comprehend the factors that led rice producers to utilize designation of origin as an appropriability mechanism and the process of capturing the benefits of eco-innovations, we must consider the contextual conditions relevant to the case under study (Yin, 2014).

5.3.3. Data Collection Process

The data for this chapter were collected between 2022 and 2023 through interviews and archival documents. The data collection process involved three stages, as presented in Table 8, which provides an overview of the number of interviews and archival documents, according to the information source. It is worth noting that the literature review was an integral part of the data collection and analysis process. This influenced the formulation of new interview questions and guided the search for documentary information.

In the initial stage of data collection, we acquired several documents including bulletins, journals, reports, and studies related to the AMTEC program. These documents were sourced from the National Rice Farmers ' Federation (FEDEARROZ) and other organizations through their websites and physical copies. By reviewing these documents, we gain insights into the operational aspects of the technology adoption program within the rice sector. Furthermore, we identified the key technologies and practices that were transferred to rice producers in the Meseta de Ibagué, as well as the program's major accomplishments and challenges.

The initial stage of data collection was primarily guided by eco-innovation literature (Kemp & Pearson, 2007; Rennings, 2000). This stage was in line with the definition of eco-innovation, which emphasizes technologies and practices that generate environmental benefits or reduce natural resource consumption. Thus, we identified that the AMTEC program provides technologies for reducing water usage in rice production.

Then, we conducted six informal interviews with experts in the rice sector, including researchers and consultants, to gain a deeper understanding of the functioning of the AMTEC program and identify high-achieving rice producers associated with the technology transfer program. These interviews highlighted the topic of designation of origin in Ibagué.

During these talks, the interviewees emphasized the designation of origin as a key factor in differentiating products in the market (Porter & van der Linde, 1995). This insight prompted the need for further investigation in the second stage to explore the specific attributes associated with the designation of origin within the context of rice producers in Meseta de Ibagué. We conducted a search for press articles, radio interviews, and technical documents related to the designation of origin in Ibagué. Archival data collection provided valuable insights into the characteristics that led to the designation of origin to Ibagué rice farmers. Additionally, the concept of protection has emerged, prompting a review of the literature on appropriability mechanisms (D. Teece, 1986).

During the third stage, we conducted interviews with representatives from three rice-producing organizations, including managers, owners, and staff from the commercial department. Additionally, we interviewed the manager responsible for overseeing the designation of origin and ensuring compliance with the established standards as well as two extensionists from FEDEARROZ. These interviews revealed the various strategies employed by rice producers to leverage the designation of origin, which led us to incorporate the concept of complementary assets into the innovation appropriability framework.

Table 9. Data Sources.

Interviews	Number
Consultants	2
Researchers (in the rice sector)	4
Extensionists	2
Manager farmers' organization	1
Farmers	4
Total Interviews	**13**
Archival data	**Number**
Press articles	7
Books	4
Reports	4
Scientific articles	3
Total Documents	**18**

5.3.4. Data Analysis

The collected data underwent an iterative analysis procedure involving continuous interaction and feedback between the processes of data systematization, interpretation, and literature review. This approach involved the collection of data to inform and enhance the theoretical framework, which guided the search for evidence in documentary sources and the interpretation of the collected data. The information obtained from archival documents regarding the FTA with the United States, the

AMTEC program, and the designation of origin revealed a chronological sequence of events. This chronology was confirmed through the interviews.

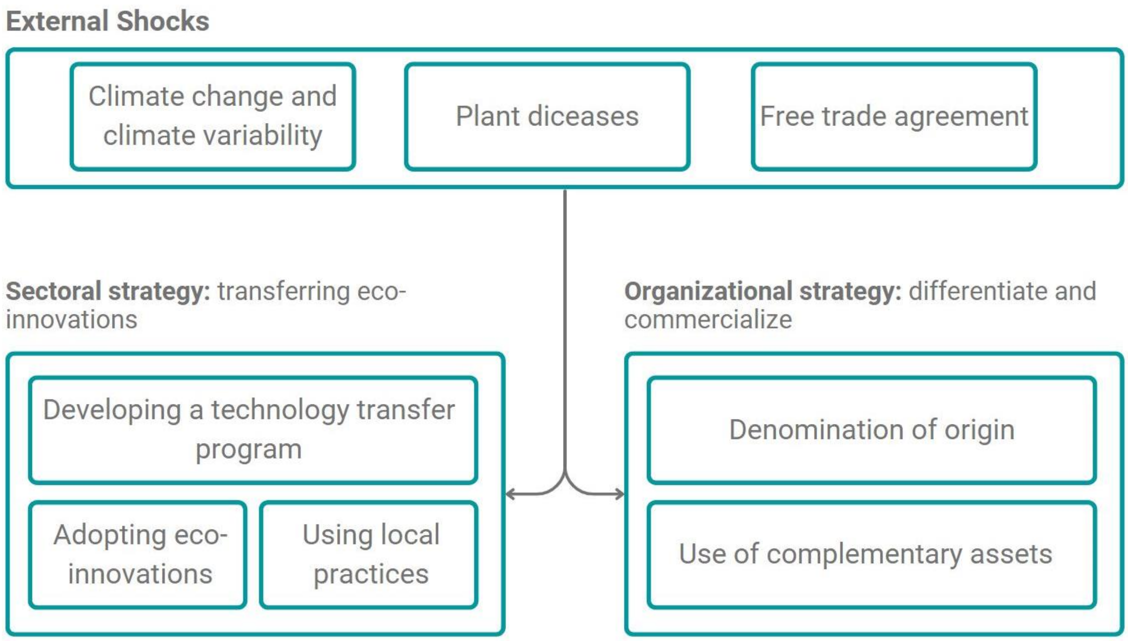
The interviews revealed the motivations behind the adoption of technologies and acquisition of the designation of origin. Plant diseases, climate change, and variability were identified as significant factors. Additionally, the interviews highlighted the use of designation of origin as a means to differentiate their products and their role in appropriability. Building on the initial chronology and information gathered from the interviews, a model was designed to illustrate the development of strategies for competitive advantage. This model consisted of three thematic blocks, as shown in Figure 9.

The first block focuses on external shocks that affect the rice sector. Through the interviews, two additional shocks related to the free trade agreement were identified: climate change and variability and plant diseases. These shocks, together with the resulting changes in competitive conditions, prompted the rice sector to adopt strategies aimed at seeking new avenues for competitive advantage.

The second thematic block unpacks the design and implementation of AMTEC, a technology-transfer program. It provides insights into the emergence of the programme and the adoption process undertaken by rice producers in Meseta de Ibagué.

Moving on to the third block, it delves into the strategies employed by rice producers, which aim to obtain and use the designation of origin as a means of differentiation and appropriability, along with the use of diverse complementary assets. This section outlines the process of acquiring the designation of origin and presents three exemplary rice producer organizations currently leveraging it. These rice producers have effectively combined designation of origin with different complementary assets.

Figure 9. Conceptual model of sectoral and organizational strategies.



5.4. The Case of the Colombian rice producers' Organizations

5.4.1 External Shocks that Triggered Sectoral and Organization Strategies

Over the last two decades, the Colombian rice sector has experienced changes in its market and production conditions that have affected its competitiveness. Three main aspects have influenced these changes, according to our analysis of documentary sources and our interviews with informants in the rice sector: the changing climate, the appearance of new plant diseases, and the free trade agreement with EE.UU. First, climate change and variability have negatively impacted food systems worldwide, including rice crops. Long-term agricultural production, nutrient quality, and yield are influenced by unstable weather conditions. Climate change has caused the Colombian rice sector to decrease, resulting in losses. Climatic factors explain a great part of the variation in yield between different areas in Colombia (Delerce et al., 2016).

Second, the productivity of Colombian rice harvest decreased from 2006 to 2009, mainly because of diseases that harmed the crops (Becerra et al., 2020). Notably, rice productivity in Colombia is relatively low, averaging 5.8 tons per hectare, compared to the 8.5 tons per hectare produced in the United States. However, productivity on the Meseta de Ibagué is reported to be between 8 and 9 tons per hectare. Local challenges have been compounded by the free trade agreement (FTA), which has brought about changes in the rules of competition between producer organizations of Colombia and the EE.UU.

These three aspects (climate, plant diseases, and the FTA) created a highly uncertain environment for Colombian producers' organizations. The loss of its competitive advantage to an international competitor with higher productivity and government support led the rice sector to consider new sources of advantage.

5.4.2. The Rise of AMTEC: a Technology Transfer Program

In 2012, the National Rice Producers ' Association, FEDEARROZ, decided to develop and implement a technology transfer program (AMTEC in Spanish). AMTEC is aimed at transferring knowledge and technologies to farmers that improve crop productivity, reduce production costs, have fewer negative impacts on the environment, and improve adaptation to climatic events (FEDEARROZ, 2023).

The AMTEC programme encompasses a range of rice practices and technologies. These practices and technologies were either developed or adapted by FEDEARROZ researchers in collaboration with partners such as the International Center for Tropical Agriculture and local universities. As a result, AMTEC provides a knowledge offer that addresses all stages of rice production and post-harvest processes, spanning from soil preparation to final sale. Technical assistance offered to farmers covers a wide array of topics, including agronomic crop management, precision agriculture, soil preparation and adaptation, irrigation, drainage, efficient water usage, optimal planting and plant density, certified seed supply, timely and balanced nutrition, phytosanitary management, alternatives for biological pest control, harvest and post-harvest management, crop rotation, and the use of green manure (FEDEARROZ, 2015).

The technology transfer process initially focused on agronomic practices and crop varieties. Once their benefits are established, they are incorporated into the technological offerings and transfer process to farmers' commencement. The AMTEC technology transfer model consists of three stages outlined in its guidelines (FEDEARROZ, 2015) (FEDEARROZ, 2015). It begins with a farm-level diagnosis to identify the available resources, capacities, and barriers to technology adoption. The planning stage coordinates investment and implementation activities and assesses their financial and technical feasibility. The agronomic management stage addresses the physiological aspects of the production process in order to implement enhancements.

Monitoring studies of the AMTEC program have revealed obstacles to the adoption and dissemination of practices and technologies, as identified by FEDEARROZ. These obstacles arise from both supply and demand. FEDEARROZ acknowledges a problem in delivering transfer services because the current number of extensionists is insufficient to serve all rice producers. Furthermore, they emphasized the need for extensionists to acquire knowledge beyond agronomic management, including expertise in advising on the administrative aspects of farming. Some farmers are reluctant to adopt new practices and technologies because of a lack of trust in expected outcomes. This resistance is particularly prominent among farmers with lower educational levels, advanced age, non-landowners, small-scale farmers, and those without close connections to FEDEARROZ (Ramírez & Bedoya, 2019).

The adoption of new technologies and practices varies depending on the specific technology and the characteristics of farmers. FEDEARROZ highlights the importance of adopting and implementing all practices comprehensively rather than selectively for program success. This emphasis is reflected in the AMTEC manuals and is also evident in the interviews with technical assistants. For instance, rice producers in the Meseta de Ibagué have adopted practices and technologies such as planting time and multiple-input irrigation technology (MIRI), although some have implemented only one of the two.

Enhancing Water Efficiency: Combining Local Practices with a Multiple Inlet Rice Irrigation Technology

Rice production under irrigation typically requires the use of large amounts of water. The process begins with field preparation, which includes flooding a field with water. Rice seeds are then planted, and it is crucial to maintain a sufficient water supply as rice plants grow. The volume of water used often increases because of the crop's evaporative demand, which increases with higher temperatures and water evaporation. Insufficient understanding of crop water requirements also contributes to water usage.

In the case of Meseta de Ibagué, the slight slope of the land affects the flow of water, resulting in varying water availability for different producers. The distribution of water is interconnected among farms, meaning that water drainage depends on the order in which farmers receive water. Consequently, if a farmer in a higher area consumes more water, it can reduce water availability for farmers in lower areas, as the farms are interconnected.

The limited water availability challenges faced by rice farmers in Meseta de Ibagué prompted the development of various irrigation practices. One distinctive irrigation method observed in this region involves the creation of furrows within the plots and the application of a local technique called "mojes" (Victor Degiovanni B et al., 2010). Interviews with technical assistants, farm managers, and rice cooperative managers consistently confirmed that irrigators in the Meseta de Ibagué employ a unique approach to water distribution, enhancing its efficiency and promoting optimal utilization. This practice has played a crucial role in differentiating rice production in Meseta de Ibagué from that in other rice-growing areas in Colombia.

The multiple-inlet irrigation system (MIRI) has gained significant adoption among rice producers in Meseta de Ibagué. This system involves the use of hoses equipped with flow-regulating gates, enabling the controlled conduction and distribution of irrigation water within the plot (FEDEARROZ, 2018). Compared to the conventional flooding system, the gradual distribution of irrigation water through MIRI proves to be more efficient in terms of water consumption by the production area (FEDEARROZ, 2018).

MIRI technology was started as a research project and was subsequently tested in Meseta de Ibagué. Trials conducted on local farms in this area have demonstrated impressive water savings of up to 45% (FEDEARROZ, 2018). By combining the MIRI technology with indigenous irrigation practices, farmers have successfully mitigated the issue of excessive water usage, which is a significant challenge in rice production systems. Traditionally, rice cultivation relies on flooded fields to create water mirrors, necessitating a substantial water supply to cover the cultivable area. Consequently, limited water availability results in a reduction in cultivable area and, consequently, lower production yields. However, by enhancing water efficiency, farmers have effectively improved their rice production levels, while simultaneously reducing production costs.

Although recent studies have shown an increase in rice production yields at the national level (Nguyen et al., 2022), these strategies have not been sufficient to achieve a competitive advantage. The adoption of technologies and practices does not necessarily result in higher incomes for farmers, primarily because of their limited control over selling prices. Numerous studies on the rice value chain in Colombia highlight that millers exert significant influence over prices, as they possess a drying and storage infrastructure (Becerra et al., 2020; Espinal et al., 2005). Farmers mainly sell their rice to the mill, which handles drying and storage, rather than to the end consumer directly. The reliance on millers for pricing was emphasized by multiple interviewees. Some farmers manage to attain a price differential by implementing agricultural practices or by using specific seed varieties for which certain mills are willing to pay more.

In summary, rice farmers' organizations in the Meseta de Ibagué harvest and sell green grain, known as paddy. To prevent spoilage, rice grains that contain moisture after harvesting need to be dried in the dryer infrastructure. Once dried, the samples were stored in silos. However, most rice producers in the area lack dryers and mills, forcing them to sell rice before fungi and bacteria develop, compromising their quality. As a result, rice producers have limited influence on selling prices.

5.4.3. Organizational strategies: Differentiating and appropriate.

Designation of Origin

For decades, rice from Meseta de Ibagué has been known for its high quality and production practices. This is reflected in the final product, which consists of large grains with distinctive flavors. These unique characteristics are a result of geographical conditions and production methods specific to the area. However, despite being informally recognized by producers, millers, and consumers, this reputation has not translated into a significantly higher selling price.

To formalize their recognition, rice producers and the SERVIARROZ producers' association made the decision to pursue the designation of origin for rice from the Meseta de Ibagué. The interviewed rice producers and the manager of SERVIARROZ expressed that their main motivation was to gain recognition of the superior quality of their products in the local market. Their objective was primarily monetary, aiming to establish a higher price point for their rice by being officially recognized in the market.

The idea of obtaining a designation of rice origin from the Meseta de Ibagué originated in 2012 through various organizations. Members of the SERVIARROZ were influenced by Spanish experience with designations of origin. Furthermore, representatives from the departmental government and a technological development center in Tolima visited Spain, where they learned about successful cases of designations of origin. This exposure provided them with insights into the functioning, distribution channels, and market differentiation of these designations. As a result, the idea of pursuing a designation of origin emerged initially with the aim of distinguishing their products.

In 2013, the process began to obtain the designation of origin for rice from the Meseta de Ibagué. Over the subsequent three years, the SERVIARROZ cooperative gathered relevant information and prepared the necessary documentation to substantiate the recognition bestowed upon the production of rice from Meseta de Ibagué by consumers and industry stakeholders, highlighting its distinct qualities (Superintendencia de Industria y Comercio, 2016).

The designation of origin for the Meseta de Ibagué was successfully obtained in 2016, with FEDEARROZ entrusted to oversee its administration. Operationally, FEDEARROZ is responsible for ensuring that rice producers wishing to use the designation adhere to a set of requirements. For instance, if a rice producer intends to market their product under the Meseta de Ibagué designation of origin, it must meet certain production criteria, including the use of a specific seed variety, irrigation practices, and adherence to local agricultural practices.

Deploying complementary strategies to take advantage of origin designation.

Of the 220 rice producers in the municipalities of Meseta de Ibagué, only three have used the designation of origin. Informants from rice producer organizations not using the designation and representatives from FEDEARROZ acknowledge that certain rice organizations are uninterested due to the lack of immediate benefits, such as a higher selling price.

On the other hand, organizations using the designation of origin have adopted a long-term perspective and recognize that enduring advantages can outweigh initial efforts. When questioned about the absence of immediate benefits, informants indicated that the Colombian consumer market is currently unfamiliar with the significance of a product bearing a designation of origin, implying that consumers fail to distinguish between products with and without this designation.

The three rice organizations employing the designation of origin integrated them with complementary assets in diverse forms. For example, the Federal organization incorporates the designation of origin as a brand in its rice packaging, effectively distinguishing its rice with this designation as a premium product. The federal operates as a distribution company and adopts a strategy of selling to retail and wholesale market chains, particularly supermarkets, both within and beyond the region.

La Reserva de la Hacienda markets rice with a designation of origin through packaged products. In addition to selling through wholesalers, they chose to target restaurants. They engage in direct negotiations with restaurants to raise their awareness of their products.

Risonella adopted a long-term, strategic approach. In the initial phase, they sell rice directly to consumers on their farms, bypassing the wholesale and retail distribution channels. To facilitate this, they established a restaurant offering a variety of rice-based products. Over the years, Risonella has dedicated efforts to developing and establishing its brand, as well as to creating rice-derived products. In the long term, they aimed to expand their distribution by establishing points of sale and opening stores in the next phase of their vision. Their goal was to transform rice and offer a range of rice-based products.

5.5. Discussion

In this chapter, our objective was to explore how rice farmers' organizations appropriate the benefits of their production process by combining designation of origin and marketing strategies. In this case, appropriability mechanisms alone may not be adequate for profits. Therefore, farmers' organizations combine appropriability mechanisms with marketing strategies. Through a case study, we examine how rice producers in Meseta de Ibagué employ diverse strategies to capitalize on the benefits associated with the designation of origin. By analyzing these strategies, we gain insights into how rice organizations enhance their competitive edge. The case study also sheds light on the key factors influencing the adoption of technologies and utilization of the appellation of origin.

5.5.1. Designation of origin

Rice farmers' organizations initially employed the designation of origin as a means of differentiation and appropriation of benefits. Through this strategy, stakeholders were able to emphasize the quality of rice resulting from its unique production processes, topography, and climate conditions. While the designation of origin is often seen as a mechanism for protection, the existing literature primarily highlights its role in consumer behavior and product differentiation rather than as a mechanism for appropriation (Menapace et al., 2011; Oberthür et al., 2011; Verlegh & Steenkamp, 1999).

The designation of origin, which acts as an instrument for differentiation, affects perceived quality, consumer attitudes, and the likelihood of purchase (Verlegh & Steenkamp, 1999). In the context of the producers of Meseta de Ibagué, we observed that the designation of origin enabled consumers, both industrial and final, to associate rice with superior quality. Consequently, this association results in higher selling prices.

Designation of origin serves as a mechanism for both benefit appropriation and protection. In the context of Meseta de Ibagué, it serves to exclude rice producers outside the region from marketing their product as "rice from Meseta de Ibagué". Additionally, it allows for imitation of the rice production process among rice producers within the plateau, which aids in positioning the product in the market. To implement the designation of origin, specific production standards were established, which only organizations within the Meseta de Ibagué can meet. These standards encompass the use of specific seed varieties, chemical-free production, and traditional irrigation practices that are unique to the area. This standardization has facilitated knowledge transfer and made the production method accessible to other farmers (Hurmelinna-Laukkanen & Yang, 2022).

5.5.2. Marketing strategies as complementary assets

Marketing strategies are among the most studied complementary assets in the literature (Lin & Wang, 2015; Teece, 1986; Zhou, 2019). Our chapter shows that using the designation of origin as a single strategy is an insufficient mechanism for benefit appropriation. Rice producers complemented the appellation of origin with different marketing strategies. Organizations use different distribution channels to reach consumers.

Marketing helps firms capture value by effectively promoting and selling innovative products and services (Holgersson and Granstrand, 2022). Marketing activities, such as branding, advertising, and sales efforts, contribute to the successful commercialization of innovations, enabling firms to generate revenue and profits from their investments in innovation (Fischer & Henkel, 2012). Additionally, marketing activities can create customer awareness, demand, and loyalty, which further contributes to the appropriation of benefits from innovation. Therefore, marketing plays a vital role in maximizing the value and impact of innovation by facilitating successful adoption and commercialization in the market.

5.5.3. What enabled the adoption of technologies and the use of designation of origin?

We identified four factors that contributed to the improved adoption of technologies and the use of the designation of origin. Our findings add to the existing literature on the drivers of eco-innovation by providing new insights into the drivers that promote the adoption of technologies aimed at reducing environmental impact.

The first factor we identified is that the majority of rice enterprises in Meseta de Ibagué are family businesses with a legacy of rice production spanning three to four generations. The literature on family businesses examines how succession within a family influences organizational performance. Studies have revealed negative effects on business growth when transitioning to the second generation, whereas positive effects have been observed when transitioning to the third generation. Moreover, no significant effects of succession on firm profitability have been found (Molly et al., 2010).

In the case study, rice producers' family businesses demonstrated a strong sense of ownership and responsibility for the organization's success. They perceive themselves as part of the longstanding tradition of rice producers and feel a duty to carry the family business forward. This sense of legacy and inherited trade creates significant pressure for businesses to succeed and fosters a long-term perspective in pursuing benefits.

Land ownership is another influential factor that affects rice farmers' investment decisions regarding technologies and their pursuit of competitive advantage. Farmers who own land are more inclined to adopt new technologies. On the other hand, farmers who rent land choose not to make improvements because they believe such investments would primarily benefit the landowner rather than themselves (Ramírez & Bedoya, 2019).

The Natural Resource-Based View (NRBV) has made significant progress in understanding the relationship between pollution prevention, product stewardship, sustainable development, and corporate profitability (Hart & Dowell, 2011). This literature emphasizes that effective resource management can lead to competitive advantage when organizations gain preferential or exclusive access to crucial but limited resources. Building on this perspective, we demonstrate that the unique topographic and climatic conditions of a specific area represent valuable and irreplaceable resources that offer firms a distinct advantage that is difficult for others to replicate. These resources, combined with the area-specific production methods, such as irrigation management, have formed the foundation of competitive advantage for these organizations. While rice producers' organizations had been capitalizing on these resources in their product development, it was through the designation of origin that this distinctiveness became visible to stakeholders.

5.6. Conclusions

This chapter has explored how rice farmers' organizations in Colombia appropriate the benefits of their production process by combining designation of origin and marketing strategies. We have shown that Designation of origin serves as a mechanism for differentiation and protection by transforming the reputation of rice into a higher price. However, we have also argued that the designation of origin alone is not sufficient for benefit appropriation and that it needs to be complemented by marketing strategies that promote and sell the product to different segments of consumers.

Our chapter has some limitations that suggest avenues for future research. First, our chapter is based on a single case study, which limits the generalizability of our findings. Future research could conduct comparative studies across different regions or countries to examine how different contexts affect the appropriation of benefits from eco-innovation based on the use of designation of origin. Second, our chapter focuses on rice as a staple crop, which may have specific characteristics that influence its market dynamics and consumer preferences. Future research could explore other types of crops or products that may have different implications for eco-innovation and appropriation.

Chapter 6

6. Conclusions

This thesis aims to provide a better understanding of the processes and motivations of eco-innovation in firms when using appropriability mechanisms and complementary assets, as well as the appropriation of the benefits derived from such eco-innovations. To achieve this, we integrate the eco-innovation literature with the profiting from innovation framework in four empirical chapters.

Eco, green, and environmental innovation research has drawn policy and scholarly interest because of its potential contribution to global environmental challenges through developing less polluting and resource-consuming technologies and practices (Díaz-García et al., 2015b; Horbach, 2016; Karakaya et al., 2014; Karimi Takalo et al., 2021; Kemp & Oltra, 2011; Pacheco et al., 2017). Diverse disciplines using multiple frameworks have contributed to eco-innovation studies, which makes it difficult to achieve a common definition and framework.

Firms developing and adopting eco-innovations create value both for the firm and for society in the form of environmental externalities. Despite advances in the field of eco-innovation, there is still a lack of understanding of how firms capture value from their eco-innovations by implementing appropriability strategies. Advancing in the understanding of the relationship between eco-innovation and appropriability allowed us to provide insights and theoretical contributions grouped into three areas: i) the role of appropriability in eco-innovation, ii) eco-innovation and complementary assets, and iii) eco-innovation and public policy.

6.1. Appropriability of Eco-innovation

This thesis expands the discussion on innovation appropriability to eco-innovation. We contribute to the eco-innovation literature by integrating it with the profiting from innovation framework to better understand how a firm's appropriability mechanisms and complementary assets affect eco-innovation.

We demonstrate that formal and informal mechanisms promote eco-innovation and, particularly, that informal mechanisms stimulate it to a greater extent than formal ones. In industries where environmental technologies are widely disseminated and firms engage in coopetition and open innovation strategies, statutory mechanisms based on law and enforced by courts or administrative bodies can hardly protect eco-innovations. Commercial uncertainty is also more likely to make formal mechanisms less attractive to protect eco-innovation because of higher costs in legal actions that may fail to protect technology. Thus, knowledge protection through a firm's internal resources (complementary assets) and informal mechanisms is more likely to drive eco-innovation than mechanisms that only enforce IPRs. When a firm uses its own internal resources to protect its knowledge, it is more likely to adopt eco- innovations compared to relying on formal institutions that enforce intellectual property rights. This means that when a firm takes active steps within its organization to keep its knowledge and ideas secret or uses other informal ways to protect them, firms have a better chance to eco-innovate.

Since collaboration and the search for external knowledge affect eco-innovation (Cheng & Shiu, 2020; De Marchi, 2012; Ghisetti et al., 2015; Nuryakin et al., 2022; S. Zhang et al., 2022), we contribute in this direction by providing evidence on the role of knowledge sourcing in cleaner production and end-of-pipe eco-innovations and how firms' potential for value appropriation affects the relationship between the breadth of knowledge and eco-innovation. Firms can use appropriability mechanisms to both stimulate external collaboration and protect internal knowledge, depending on effective knowledge management at different stages of production. By collaborating with suppliers to access external knowledge and using appropriability mechanisms to protect the transformation process, a firm can improve its inputs while keeping its knowledge separate and protected, providing a competitive advantage. Firms can successfully eco-innovate by differentiating and integrating appropriability and openness strategies (Hurmelinna-Laukkanen & Yang, 2022; Lauritzen & Karafyllia, 2019). As a result, a firm can manage its appropriability and openness strategies by differentiation and integration to increase its success in eco-innovation.

Firms developing cleaner production technologies face a continuous improvement process. The development of cleaner production involves increasing productivity and efficiency using inputs without increasing emissions per unit of output. In other words, the firm continuously searches for ways to produce more using fewer inputs and generating less waste. The constant search for efficiency requires permanent collaboration with actors (e.g., universities and research centers) providing information on new technologies. In summary, a firm eco-innovating towards cleaner production integrates eco-innovation into its organizational and production processes. Moreover, firms require specific information for adopting end-of-pipe technologies that control and treat specific wastes and manage each type of waste. For example, filters and scrubbers are air pollution control devices that remove some particulates from company exhausts. Wastewater treatment systems remove pollutants from wastewater so that firms can discharge them into effluent. Each type of solution requires specific expertise for which a firm relies on certain actors.

We show that firms that simultaneously use the breadth of knowledge sources and appropriability mechanisms at different stages of the production process strengthen their adoption of cleaner production eco-innovation. Linking suppliers to the production process enables a firm to share its knowledge and skills about the environmental standards of inputs and materials needed to reduce waste generation, while safeguarding its input and material transformation stage by using design complexity or trade secret strategies (Chiou et al., 2011). Accessing external knowledge through collaboration with suppliers and protecting the transformation process through appropriability mechanisms can increase a firm's potential for eco-innovation.

6.2. Eco-innovation and Complementary Assets

The Profiting from Innovation framework emphasizes the importance of complementary assets in value capture and suggests that innovators should focus on developing and controlling complementary assets to capture a larger share of the value they create. We expand the role of complementary assets for eco-innovation by providing evidence on how these assets can strengthen a firm's appropriability mechanisms to eco-innovate.

We demonstrate that a firm's marketing capabilities work as a complementary asset that amplifies the influence of formal and informal appropriability mechanisms on eco-innovation. The moderating effect of marketing investment on eco-innovation depends on the cumulative effect of appropriability mechanisms. High marketing investments reduce the likelihood of eco-innovation compared to low marketing investments, particularly for small firms using distinct formal mechanisms.

Complementary assets play a fundamental role in the process of appropriability and value appropriation of eco-innovation. We show evidence that when firms have little control over the selling price of their final product, using appropriability mechanisms alone does not necessarily allow them to appropriate the value of product improvement. Complementary assets such as marketing strategies are required to access consumer segments that are willing to pay a higher value for the products.

6.3. Eco-innovation and Public Policy

Our thesis also contribute to the public policy literature on eco-innovation by identifying which appropriability mechanisms effectively incentivize and secure rent appropriation from eco-innovation. Particularly, the idea that informal mechanisms and complementary assets are more effective in securing expectations of value capturing is relevant because it means there is no need to enforce the patent system strongly, one of the factors that have led to diminishing social value creation and wealth distribution from innovation. We demonstrated that firms still have informal mechanisms to appropriate rents without legally excluding competitors using technical knowledge or impeding society from benefiting from eco-innovation.

Moreover, we have argued that environmental spillovers associated with eco-innovation alleviate the tension between higher rent private appropriation and public value creation, as environmentally friendly technologies, by definition, create social value. This might not be the case with other kinds of technologies in which associated social benefits are not direct or when appropriability strategies are so effective that firms manage to exclude society from reaping the benefits of innovation.

Although previous literature has discussed other mechanisms for balancing profit maximization and social welfare, such as corporate taxes, redistribution schemes, or policies aimed at reducing inequalities created by innovation, we believe our work modestly contributes to the public policy literature by proposing a line of research focused on analyzing the role of appropriability strategies and complementary assets in creating social and capturing private value from innovation.

6.4. Policy and Managerial Recommendations

This thesis provides recommendations for firm strategy and eco-innovation policy. Since appropriability strategies can drive eco-innovation in firms, incentivizing the use of appropriability mechanisms can lead to further innovation towards non-polluting and cleaner technologies. Firms' appropriability strategies should go beyond statutory mechanisms, with a particular emphasis on mechanisms such as industrial secrecy and complexity in design. Firm-level appropriability policies, especially those that facilitate the use of non-statutory appropriability mechanisms, can facilitate further development of eco-innovations by providing greater confidence to managers about the appropriability of their innovations. Moreover, informal mechanisms appear to have a stronger influence on eco-innovation, and their cumulative effect does not decrease the likelihood of eco-innovation when combined with marketing investments.

The use of appropriability strategies drives the adoption of environmental technologies, as there appears to be no distinction on particular environmental technologies, such as end-of-pipe or cleaner production technologies. However, cleaner production technologies are considered more socially desirable than end-of-pipe technologies due to their resource efficiency and ability to reduce emissions at the source. Thus, firms seeking to transition from end-of-pipe to cleaner production technologies can rely on the resources and capabilities gained through collaboration with external sources of knowledge and through the use of appropriability mechanisms. This accumulation of knowledge and resources can facilitate the transition to eco-innovations with greater environmental impact. In terms of policy, the promotion of appropriability instruments that block the firm's collaboration with external sources of knowledge may deteriorate this transition to cleaner technologies.

We find that ownership mechanisms strengthen eco-innovation when combined with complementary assets, such as marketing investments. Managers have several ways that they can combine with appropriability mechanisms to increase the value capture of eco-innovation. The decision to eco-innovate must be aligned with deciding which mix of appropriability strategy and complementary assets is the most effective to obtain the greatest economic value.

Regarding public policy, our results suggest that governments can demand that technologies developed by firms with public financing must be of public knowledge and freely available without being subject to any exclusive property rights such as patents or industrial designs. Contrary to recent advice, governments do not need to enforce intellectual property rights (IPRs) that impede knowledge sharing and technological advancement, either globally or strongly, especially in developing countries. The profiting from innovation framework and our chapter demonstrates that in a weak appropriability regime, firms can use informal mechanisms and complementary assets to secure rent appropriation without diminishing social value.

6.4. Limitations and Future Research Lines

This thesis has several theoretical and empirical limitations. As in other studies, the concept of eco-innovation used in chapters 3 and 4 facilitates the operationalization of the variables and, although it is based on a definition of eco-innovation that is widely accepted in the literature, it restricts the scope of analysis. The environmental component of eco-innovation, i.e., its impact on the environment, is relegated to a not necessarily intentional effect of the firm. Part of this limitation was resolved in the qualitative study by using a more intentional connotation to the environmental benefits of eco-innovation. This leads to future studies incorporating an intentional component of eco-innovation in their operationalization.

Another limitation is related to the use of appropriability mechanisms. Innovation surveys focus more on firms' use of formal than informal mechanisms, placing more emphasis on statutory mechanisms than on those that rely on firm resources. This limits the scope of the results and the development of hypotheses to compare both types of mechanisms. The use of databases or surveys that allow for a broader spectrum of informal mechanisms could help to corroborate the results of this thesis.

The use of a single case study limits the generalizability of our findings. Future research could undertake comparative analyses across different regions or countries, examining the influence of context on the appropriation of benefits from eco-innovation. Furthermore, our research centers on rice as a staple crop, a choice influenced by its distinct characteristics impacting market dynamics and consumer preferences. Subsequent studies could delve into alternative crops or products, each presenting unique implications for eco-innovation and the processes of appropriation.

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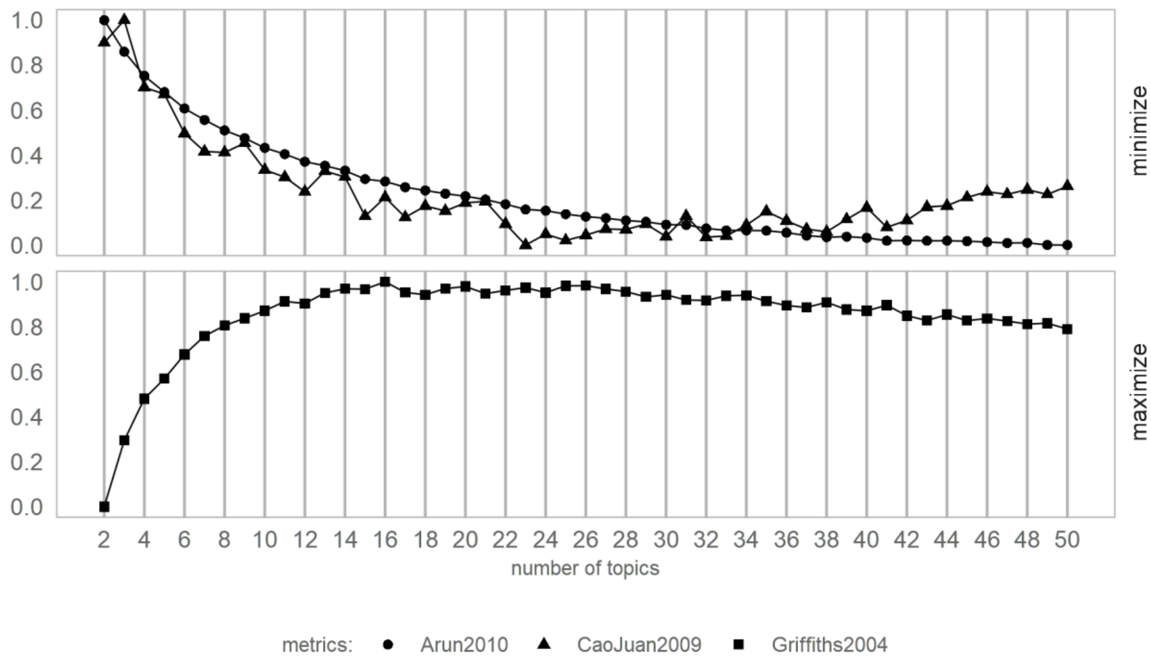
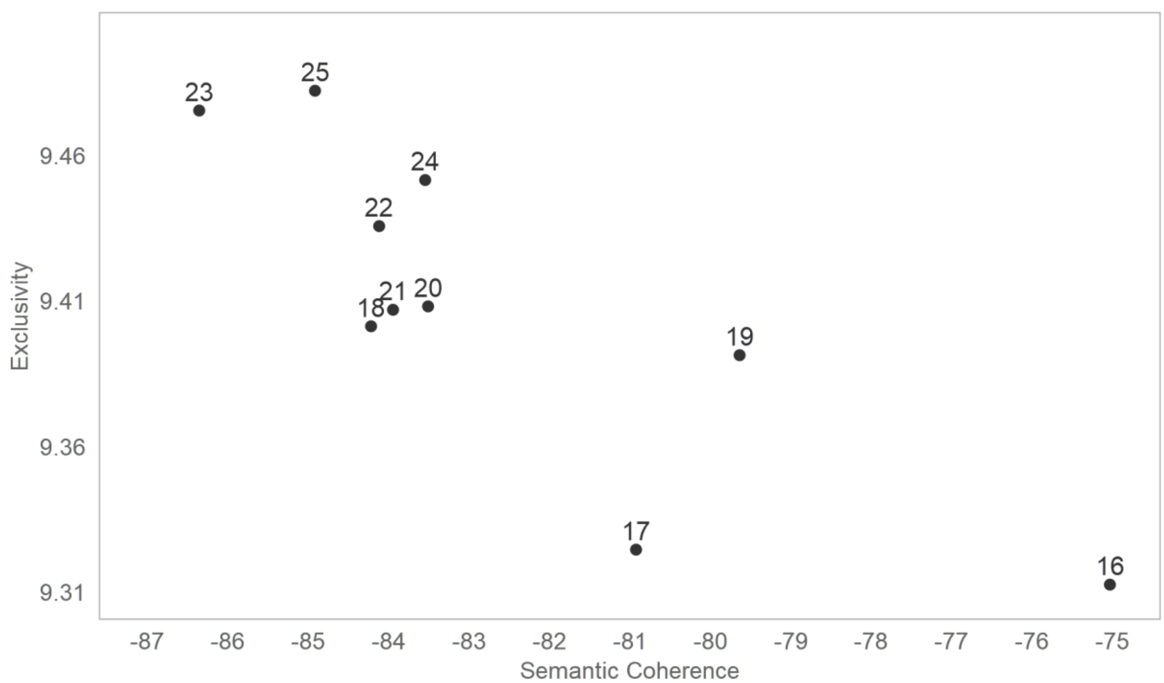
Appendix

Appendix 1. Criteria for topic choice used in chapter 2.

A-1. Range of optimal topic number.



A-2. Topic's score of semantic coherence and exclusivity.



Appendix 2. Topics and related terms used in chapter 2.

Topic	Topic label	Probability	FREX
1	**competitive advantage**	green, green_innovation, firm, performance, environmental, resource, manufacturing, management, advantage, competitive	competitive, advantage, green_innovation, capability, performance, manufacturing, green, corporate, capabilities, resource
2	**eco-innovation types**	eco_innovation, product, innovation, company, technology, processes, eco, firm, environmental, innovative	eco_innovation, eco, processes, drivers, product, company, benefits, radical, incremental, service
3	**environmental regulation**	regulation, policy, env_innovation, firm, technology, environmental, innovation, patent, country, hypothesis	porter, stringency, abatement, patent, incentives, stringent, hypothesis, regulation, induced, patenting
4	**green innovation geography**	development, green_innovation, province, technology, environmental, regulation, green, regional, economic, innovation	province, regions, spillover, regional, inhibitory, yangtze, outward, agglomeration, city, upgrading
5	**cleaner energy**	emission, energy, technology, carbon, reduction, policy, renewable, innovation, reducing, reduce	emission, reduction, renewable, carbon, wind, reducing, fossil, energy, solar, photovoltaic
6	**supply-chain management**	chain, supply, supplier, management, sustainable, environmental, profit, industry, green_innovation, manufacturer	chain, manufacturer, supply, logistics, retailer, laboratory, supplier, trial, gscm, revenue
7	**decoupling emissions from growth**	country, environmental, policy, technology, emission, economic, growth, carbon, impact, eco_innovation	gdp, decentralization, gross, neutrality, quantile, income, domestic, co2, kuznets, targets

Topic	Topic label	Probability	FREX
8	**stakeholders and institutions**	firm, pressure, environmental, innovation, institutional, regulation, stakeholder, env_innovation, resource, impact	pressure, stakeholder, engagement, roles, institutional, certification, copyright, normative, coercive, contingency
9	**small-medium firms**	small, smes, sized, enterprise, policy, barrier, sustainability, economy, innovation, technical	sized, smes, small, mediumsized, sme, barrier, technical, norwegian, embrace, communities
10	**government support**	financial, enterprise, government, environmental, green_innovation, impact, state, green, policy, firm	financial, owned, government, ownership, subsidy, disclosure, stock, state, subsidies, enterprise
11	**corporate social responsibility**	responsibility, social, corporate, emerging, innovation, country, environmental, economies, development, management	responsibility, emerging, economies, multinational, corporations, iso, internationalization, entrepreneurs, corporate, socially
12	**environmental innovation networks**	innovation, social, sustainable, sustainability, development, networks, technology, actors, env_innovation, project	informal, project, actor, formal, actors, networks, interests, collective, entrepreneurship, adaptation
13	**demand-pull and technology-push**	technology, policy, innovation, change, push, pull, env_innovation, climate, energy, diffusion	pull, push, failures, mitigation, complementarities, eis, constitutes, techno, mix, demandpull
14	**attitudes and behaviors**	consumer, perceive, behavior, product, value, environmental, adoption, environment, green, adopt	consumer, perceive, attitudes, willingness, purchase, willing, patient, norms, care, behavior
15	**cleaner goods**	vehicle, electric, car, technology, policy, development, alternative, sustainable, economic, country	electric, vehicle, car, charging, agriculture, agricultural, covid, plans, automotive, alternative

Topic	Topic label	Probability	FREX
16	**absorptive capacity**	firm, capacity, env_innovation, absorptive, environmental, management, innovation, capabilities, knowledge, manufacturing	absorptive, capacity, proactivity, competences, diversity, acquisition, automotive, interorganizational, acquire, linking
17	**end-of-pipe**	waste, policy, sustainable, sustainability, management, recycling, resource, environmental, economy, development	recycling, waste, treatment, options, prevention, water, disposal, nordic, steps, progress
18	**collaboration**	customer, firm, innovation, supplier, product, internal, knowledge, cooperation, partners, collaboration	coordination, partners, customer, involvement, universities, supplier, cooperation, alliances, collaboration, collaborations
19	**culture**	innovation, sustainable, business, company, sustainability, organizational, creation, organization, environmental, environmentally	culture, hospitality, hotels, organization, employee, imperative, creation, operations, publicly, seek
20	**life cycle**	innovation, environmental, reduce, material, life, efficiency, energy, resource, cycle, eco_innovation	material, cycle, life, performed, reduce, linked, clusters, raw, reduction, looks
21	**synergies**	technology, development, innovation, city, sustainable, green, rapid, green_innovation, economic, enterprise	rapid, synergy, city, platform, mobility, urban, ecosystem, space, internet, derive

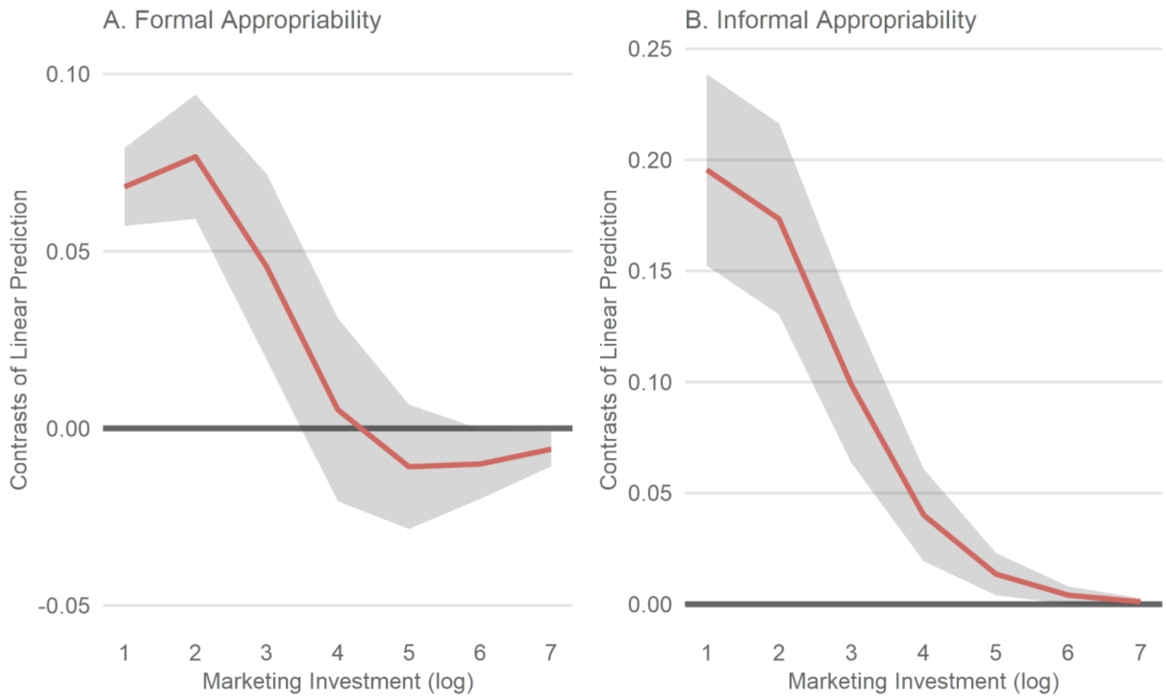
Appendix 3. Marginal effects of independent variables on eco-innovation used in chapter 3.

	dy/dx	St. Err.	z	P>z	95% conf. interval	
Independent						
Formal appropriability	0.06	0.01	10.84	0.00	0.05	0.07
Informal appropriability	0.15	0.02	8.45	0.00	0.12	0.18
Marketlg	0.14	0.01	19.37	0.00	0.13	0.16
Marketlg x Marketlg	-0.02	0.00	-11.06	0.00	-0.02	-0.01
Controls						
$R\&D\ (log)_{t-1}$	0.01	0.00	4.39	0.00	0.00	0.01
$Size\ (log)_{t-1}$	0.08	0.01	15.21	0.00	0.07	0.09
$Sci.Coop_{t-1}$	0.09	0.01	12.78	0.00	0.08	0.10
$Export_{t-1}$	0.01	0.01	1.77	0.08	-0.00	0.02
$Corp_{t-1}$	0.02	0.01	1.82	0.07	-0.00	0.04
$Tech\ transfer\ (log)_{t-1}$	-0.00	0.00	-1.34	0.18	-0.01	0.00
Sector 2	-0.03	0.01	-3.44	0.00	-0.04	-0.01
Sector 3	0.03	0.01	3.57	0.00	0.01	0.05
Sector 4	0.01	0.01	1.57	0.12	-0.00	0.03
Sector 5	0.03	0.01	3.42	0.00	0.01	0.04
Year 2012	0.07	0.01	4.83	0.00	0.04	0.09
Year 2014	0.04	0.01	3.24	0.00	0.02	0.07
Year 2016	0.03	0.01	2.08	0.04	0.00	0.05
Year 2018	0.03	0.01	1.97	0.05	0.00	0.05

Appendix 4. Table and Figures of contrasts of adjusted predictions of appropriability at marketing investment Levels. Used in chapter 3

Marketing inv.	dy/dx	std. err.	P>chi2	95% confidence interval	
Formal Appropriability					
1	0.07	0.01	0.00	0.06	0.08
2	0.08	0.01	0.00	0.06	0.09
3	0.05	0.01	0.00	0.02	0.07
4	0.01	0.01	0.69	-0.02	0.03
5	-0.01	0.01	0.23	-0.03	0.01
6	-0.01	0.01	0.05	-0.02	0.00
7	-0.01	0.00	0.02	-0.01	0.00
Informal Appropriability					
Marketing inv.	dy/dx	std. err.	P>chi2	95% confidence interval	
1	0.20	0.02	0.00	0.15	0.24
2	0.17	0.02	0.00	0.13	0.22
3	0.10	0.02	0.00	0.06	0.13
4	0.04	0.01	0.00	0.02	0.06
5	0.01	0.00	0.01	0.00	0.02

6	0.00	0.00	0.05	0.00	0.01
7	0.00	0.00	0.21	0.00	0.00



Appendix 5. Average marginal effects used in chapter 4.

Cleaner production					
Breadth	dy/dx	std. err.	P>chi2	95% confidence interval	
0	0.002	0.002	0.243	-0.001	0.005
1	0.006	0.002	0.000	0.003	0.009
2	0.011	0.003	0.001	0.004	0.017
3	0.016	0.006	0.003	0.006	0.027
4	0.023	0.008	0.005	0.007	0.039
5	0.030	0.011	0.007	0.008	0.052
6	0.038	0.015	0.009	0.010	0.067
End-of-Pipe					
Breadth	dy/dx	std. err.	P>chi2	95% confidence interval	
0	0.002	0.001	0.077	0.000	0.005
1	0.007	0.001	0.000	0.004	0.009
2	0.012	0.003	0.000	0.006	0.018
3	0.017	0.005	0.001	0.007	0.028
4	0.024	0.008	0.002	0.009	0.040
5	0.032	0.011	0.004	0.011	0.054

6	0.041	0.015	0.005	0.013	0.070