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Optimal Environmental Regulation in the Presence of Sustainable Finance

지속가능금융하에서 최적환경규제

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Foreword

As environmental stewardship assumes a central role in achieving global sustainability, comprehending the interplay between environmental policy and finance is of paramount importance. This report, spearheaded by Hoseok KIM, Chief Research Fellow in the Division for Green Transition, delves into the intricate relationship between sustainable finance and environmental regulation, providing a valuable perspective on the evolving trajectory of Korea's environmental strategy.

The authors meticulous research navigates the complex landscape of sustainable finance, highlighting its profound impact on shaping corporate conduct and environmental outcomes. By scrutinizing the nuances of optimal environmental regulation in the face of green consumerism and market-driven sustainability endeavors, this study sheds light on the pathways through which Korea can effectively pursue its environmental objectives.

The findings of this report are particularly relevant as Korea, along with many nations, strives to reconcile economic growth with ecological preservation. The author's rigorous analysis makes a significant contribution to this ongoing discourse, offering indespensible insights and theoretical frameworks to policymakers, industry leaders, and environmental stakeholders.

We extend our deepest gratitude to the author for his dedication and expertise in producing this comprehensive analysis. The work embodies the Korea Environment Institute's unwavering commitment to promoting sustainable development and safeguarding environmental integrity.

Lee, Changhoon,

President,

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Executive Summary

1. Introduction

- This study offers essential insights into environmental economics, highlighting the importance of integrating firms‘ voluntary abatement efforts encouraged by sustainable finance, into the framework of optimal environmental regulation. It makes a significant contribution to the literature by examining the interplay between traditional environmental policy and sustainable finance.
- Methodological Approach:
  - The study commences with an exhaustive literature review focused on optimal environmental regulation. This review encompasses an examination of issues associated with the second-best setting, focusing on environmental taxes.
  - Theoretical Analysis: The study advances with a theoretical analysis of the impact of sustainable finance on firm behavior. This segment entails a thorough exploration of how sustainable finance influences firms‘ decisions in optimizing production and emissions for profit maximization.

2. Optimal Environmental Regulation

- Chapter 2 provides a thorough examination of optimal environmental regulation, covering both its theoretical basis and practical applications.
  - The chapter discusses the challenges in implementing optimal environmental regulation effectively, focusing on issues such as asymmetric information, the interaction with existing tax systems, and the importance of technological innovation in addressing environmental issues.
- The chapter examines the concept of a “second-best“ setting, where ideal market efficiency conditions are not present. This part highlights the complexities and necessary considerations for formulating and implementing environmental policies in such scenarios.

3. Sustainable Finance

- Chapter 3 characterizes sustainable finance as the incorporation of sustainability-related aspects, notably Environmental, Social, and Governance (ESG) factors, into the decision-making and investment strategies of financial markets and institutions.
  - The chapter discusses how sustainable finance serves as an incentive for firms to employ in sustainable practices. Green bonds, social impact investing, and ESG-integrated asset management, are tools of sustainable finance.
- The chapter reviews previous studies on the impact of sustainable finance on corporate behavior. It highlights the potential for sustainable finance to motivate voluntary environmental improvements by firms.

4. The Model

- Chapter 4 introduces a theoretical model that incorporates sustainable finance into the framework of optimal environmental regulation. The model analyzes how sustainable finance influences a firm's production decisions and environmental emissions.
  - A key aspect of the model is the environmental performance metric (g), which measures a firm's greenness compared to an industry benchmark. The model thoroughly explores how variations from this benchmark affect firms' operational and environmental decisions.
  - The model considers both market and regulatory risks, examining their impact on a firm's market position and production costs. Additionally, it incorporates consumer preferences, assessing how a firm's productivity and environmental performance impact its revenue. This model offers a comprehensive understanding of the diverse factors influencing a firm's production decisions and environmental outcomes within the framework of sustainable finance.
- This chapter presents detailed mathematical formulations and theoretical analyses, illustrating the interaction between optimal environmental regulation and sustainable finance. It clarifies how firms adapt their strategies for maximizing profit in response to their environmental performance and market conditions, including environmental taxes and sustainable finance mechanisms.

- Ambiguity in Sustainable Finance's Impact on Abatement
  - Greener firms: For firms greener than the industry average, sustainable finance paradoxically leads to increased emissions. This is due to financial incentives and lower costs under sustainable finance, which drive higher production levels and greater input use, resulting in increased emissions.
  - Less-green firms: Firms less green than the benchmark tend to reduce emissions under sustainable finance, as they face higher costs, leading to decreased production and emissions. This reflects the economic pressures from sustainable finance on these firms to lower their emissions.
- Voluntary Abatement in the Absence of Regulation
  - The analysis shows that less green firms can achieve emission reductions under sustainable finance, even without explicit regulatory mandates. This is due to the economic pressures and market mechanisms inherent in sustainable finance, which encourage emission reductions through market-based incentives and cost considerations.
- Synergistic Influence in Sustainable Finance
  - There is a synergistic relationship between the market's preference for greener firms and the adjustment factor based on a firm's relative greenness. A higher preference for green firms amplifies the impact of the firm's greenness on its cost structure and market positioning, motivating firms to adopt greener practices.
- Green Consumerism
  - The model demonstrates that voluntary abatement by firms is influenced by market dynamics, especially consumer preferences for sustainability. This green consumerism can drive firms to voluntarily reduce emissions, emphasizing the critical role of consumer choices in promoting environmental responsibility.
  - This effect occurs independently of regulatory or government-led initiatives, highlighting green consumerism as a powerful tool for achieving environmental goals.

5. Data Insight on Greenness Distribution

- Chapter 5 presents a data analysis examining the distribution of firms' environmental performance (g) using data from Korean companies. It focuses on Greenhouse

Gas (GHG) intensity as a key metric to assess environmental performance and its variations across different industry sectors.

- The analysis shows a heterogeneous distribution of emissions-intensive firms across different industrial sectors, with higher GHG intensity concentrated in a few specific segments. This suggests that targeted environmental regulations in these sectors could significantly reduce overall emissions, highlighting the effectiveness of sector-specific approaches in GHG mitigation.
- Skewness in GHG Intensities Across Firms
  - There is a noticeable asymmetry in GHG intensity among companies, with a small number of firms responsible for a large portion of emissions. This imbalance is important for regulatory authorities to consider when adjusting environmental regulations or developing sustainable finance strategies.
  - The findings indicate that policies targeting high-emission companies might set lower benchmarks for less-polluting firms, potentially reducing their incentives for environmental innovation and transition to greener technologies.
- Disparities in GHG Intensity Among SMEs
  - Small and Medium-sized Enterprises (SMEs) tend to have higher GHG intensity compared to larger firms. Factors like less efficient technologies, smaller operational scales, and limited resources for emission reduction contribute to this disparity.
  - As the focus on sustainability grows, SMEs face challenges in accessing finance, especially in a sustainable finance-dominated environment. This situation calls for specialized financial mechanisms and policies to help SMEs overcome obstacles in achieving sustainable operations.

6. Conclusions

- Chapter 6 consolidates insights from both theoretical and data analyses, focusing on the interplay between sustainable finance and optimal environmental regulation. It emphasizes the integration of sustainable finance and its effectiveness in environmental regulation and explores the consequent policy implications.
- Aligning Environmental Regulation with Sustainable Finance Impact

- The dynamic intersection of sustainable finance and environmental regulation affects the efficacy of regulatory measures.
- Regulatory authorities need to closely monitor how sustainable finance influences corporate environmental strategies, especially in relation to established benchmarks.
- Understanding variations in environmental outcomes due to sustainable finance is crucial for regulators, as is staying informed about trends among investors and financial institutions.

○ Enhancing Transparency in Sustainable Finance Benchmarks

- The benchmark level of greenness is vital in shaping investment decisions and regulatory compliance, influencing environmental outcomes.
- Regulators must ensure accurate determination and transparent disclosure of sustainable finance benchmarks to align financial assets or investments with ESG criteria.

○ Enhancing Support for SMEs for a Sustainability Transition

- SMEs, often facing challenges in aligning with sustainable practices, need dedicated financial mechanisms and policy measures.
- Policies should facilitate access to sustainable finance, offer incentives for adopting sustainable practices, and provide guidance on environmental management.

○ Sector-Specific Approaches to Harmonize Environmental Regulation and Sustainable Finance

- Recognizing the varied environmental performance across sectors is crucial for effective regulation.
- Regulatory frameworks should include sector-specific incentives and benchmarks to encourage sustainable practices, particularly in high-impact sectors.
- Compliance costs should be equitable across sectors to avoid disproportionate burdens and encourage innovation and green technology adoption.

Keywords: Optimal Environmental Regulation, Sustainable Finance, Sustainable Finance Benchmark, Sustainable Development, Climate Change

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1 Introduction

1.1. Background

Externalities and optimal environmental regulation

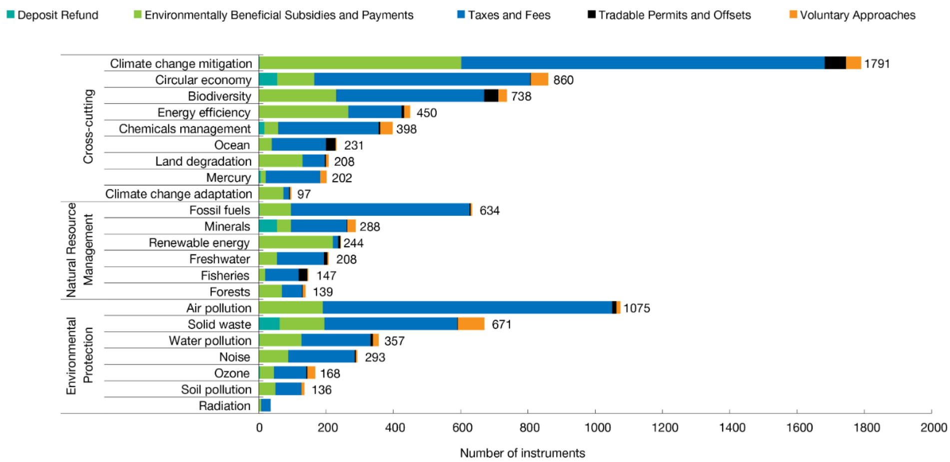
Environmental economics, fundamental to modern environmental policy, categorizes environmental issues as externalities. Externalities are defined as costs or benefits impacting societal welfare but not factored into the decision-making of consumers or producers. In this framework, a firm might produce pollution, a negative externality, leading to external costs not borne by the firm. This results in an economically inefficient overproduction of pollution.

To maximize social welfare, a key measure of overall economic efficiency, it is essential to include untraded costs or benefits in the calculation of social costs or benefits. This process entails determining who should bear these costs or benefits in decision-making. Arthur Pigou, in his landmark 1920 work, introduced the concept of the Pigouvian tax, set at the marginal external cost of pollution at the optimal emission level. This tax addresses externalities by aligning the tax with the marginal external cost of pollution, subtly raising production costs for polluting firms and incentivizing them to reduce pollution (Pigou, 1920).

The optimal emission level is defined as the quantity of emissions that maximizes social welfare. The optimal emission level is the amount of emissions that maximizes social welfare. Optimal environmental regulation aims to achieve this level through government intervention, thereby enhancing economic efficiency (Helfand, Berck, and Maull, 2003, p.270). This theoretical framework is the framework for implementing and evaluating a variety of environmental policies, including pollution taxes, cap-and-trade systems, and direct regulations designed to meet environmental policy targets.

Figure 1 presents a detailed examination of the environmental policy instruments implemented in 130 countries, categorized by the environmental domains they address. The Figure 1 highlights the widespread use of taxes & fees as well as tradable permits and offsets, which are key elements of traditional environmental economics. These instruments are employed across various domains, including efforts to mitigate the impacts of climate change, promote circular economy practices, and conserve biodiversity. The prevalence of these tools reflects the significant role that the principles of environmental economics play in the formulation of environmental policies on a global scale.

Figure 1. Policy instruments by type and environmental domain



Source: OECD (2023), "Policy Instruments for the Environment Database", p.9, accessed on December 1, 2023.

Theoretical challenges of optimal environmental regulation

Arthur Pigou's Pigouvian tax and the concept of internalizing externalities laid the groundwork for theoretical models of optimal environmental regulation. However, translating these models into effective real-world policies is fraught with complex theoretical and practical challenges. These challenges often necessitate adopting second-best solutions, compromises that are optimal given the constraints, rather than pursuing the theoretical ideal.

A significant body of research in environmental economics grapples with these challenges. Economists strive to refine the concept of optimal regulation in second-best settings, developing alternative theoretical frameworks and policy approaches that account for these real-world complexities. Addressing these challenges is crucial for developing effective and efficient environmental policies that achieve their intended goals.

Sustainable finance as a new theoretical issue

With the emergence of sustainable finance, a new dimension has been added to this complex landscape. Investors are increasingly considering environmental performance in their capital allocation decisions, providing firms with financial incentives to voluntarily reduce their environmental footprint. Green consumerism has emerged in many countries and this is another aspect that encourage firms to improve environmental performance voluntarily. This shift in firms' behavior has substantial implications for environmental regulation, potentially enhancing or undermining the effectiveness of traditional regulatory instruments.

The relationship between firms' behavior and sustainable finance has received increasing attention from markets and policymakers over the years. Table 1 shows the increasing trend in sustainable investing. This interest is driven partly by the significant influence of green investments on the environmental impacts of business activities and partly by the way sustainable finance introduces new constraints and incentives that shape the environmental performance of businesses.

Table 1. Global growth of sustainable investing strategies 2016-2020

	2020	2018	2016	GROWTH 2016-2020	COMPOUND ANNUAL GROWTH RATE
Impact/community investing	$352	$444	$248	42%	9%
Positive/best-in-class screening	$1,384	$1,842	$818	69%	14%
Sustainability-themed investing	$1,948	$1,018	$276	605%	63%
Norms-based screening	$4,140	$4,679	$6,195	-33%	-10%
Corporate engagement and shareholder action	$10,504	$9,835	$8,385	25%	6%
Negative/exclusionary screening	$15,030	$19,771	$15,064	0%	0%
ESG integration	$25,195	$17,544	$10,353	143%	25%

Source: GSIA (2020), p.11.

1.2. Objectives and approach

Objectives

This study investigates the interplay between sustainable finance and optimal environmental regulation. We develop a theoretical model to understand how firms' profit-maximizing decisions are influenced by market demand, regulatory policies, and sustainable finance. Our analysis highlights the circumstances in which sustainable finance can complement or replace traditional environmental regulation, providing crucial insights for policymakers and investors alike.

This report contributes significantly to the existing literature on optimal environmental regulation and sustainable finance. First it introduces a comprehensive theoretical framework that captures the interaction between these two elements. Second, using our model, we examine the specific conditions where sustainable finance can either complement or substitute for environmental regulation. Lastly, we propose policy recommendations for policymakers contemplating the formulation of environmental regulations in the context of sustainable finance.

Approach

The relationship between firms' behavior and sustainable finance has garnered increasing attention from financial markets and investors over the years. This growing interest stems from the significant influence of green investments on the environmental impacts of business activities and the new constraints and incentives created by sustainable finance that affect the environmental performance of businesses.

The primary objective of this report is to provide policymakers with a guide to updating regulatory frameworks in the presence of voluntary abatement efforts by firms designed to enhance their access to markets and finance. To achieve this objective, the report adopts a two-pronged approach.

In the first part, we survey the body of existing literature that explores the economics of "optimal environmental regulation," focusing on key issues in achieving optimal settings in a second-best economy. This overview provides a foundation for the subsequent analysis of the effects of sustainable finance on firm behavior.

In the second part, we conduct a theoretical analysis on the effect of sustainable finance on firms' behavior under various conditions. This analysis is based on a stylized model of a firm that faces both environmental and sustainable finance constraints. The model is used to examine how sustainable finance can affect the firm's choice of inputs, production levels, and environmental performance. This is then complemented by a data analysis.

The report concludes with a discussion of implications for policy carried by analysis. The discussion focuses on the potential impact of sustainable finance on the effectiveness of environmental regulation.

1.3. Structure of the study

Chapter 2 reviews the theory of optimal environmental regulation and various previous studies that address key issues the theory should adapt to more realistic settings. The chapter begins with an overview of environmental economics and the concept of optimal environmental regulation. It then discusses key issues in optimal environmental regulation, such as imperfect competition, the interaction between environmental regulation and other taxes, induced technological change, and the impact of asymmetric information on environmental regulation. Finally, the chapter discusses the policy applications of optimal environmental regulation.

Chapter 3 reviews the concept of sustainable finance from a microeconomic perspective and identifies aspects that will be incorporated into the theoretical model presented in Chapter 4. The chapter begins by providing an overview of the general concept of sustainable finance, including its main features, sustainability-related risks, and the concept of greenium. It concludes with a discussion on the demand for sustainable assets, the shift of real investment towards green firms, and the implications of sustainable finance for the theoretical framework of optimal environmental regulation.

Chapter 4 develops a theoretical model that incorporates environmental taxation and sustainable finance, analyzing the interactions between optimal environmental regulation and changes in firm input and production choices driven by sustainable finance.

The chapter starts by introducing the base model, which represents the standard model of optimal environmental taxation. It then integrates sustainable finance into the model through two approaches. First, it models demand as a function of the firm's environmental performance. Second, it models the cost of production as a function of the firm's environmental performance. The chapter concludes with a discussion on the results and implications of the model.

Chapter 5 presents the data analysis. The chapter begins by describing the data used. It then analyzes the distribution of environmental performance, denoted by g, of firms grouped by sectors and size. The chapter concludes with a discussion of the insights and lessons learned from the analysis.

Chapter 5 delves into the data-driven analysis of environmental performance, or greenness, across various firms. It begins by detailing the data sources and types used in the study. The core of the chapter is dedicated to analyzing the distribution of firms' environmental performance with a specific emphasis on differences across sectors and firm sizes.

Chapter 6 concludes the report. The chapter summarizes the findings of the report, discusses policy recommendations, and identifies topics for future research.

2 Optimal Environmental Regulation

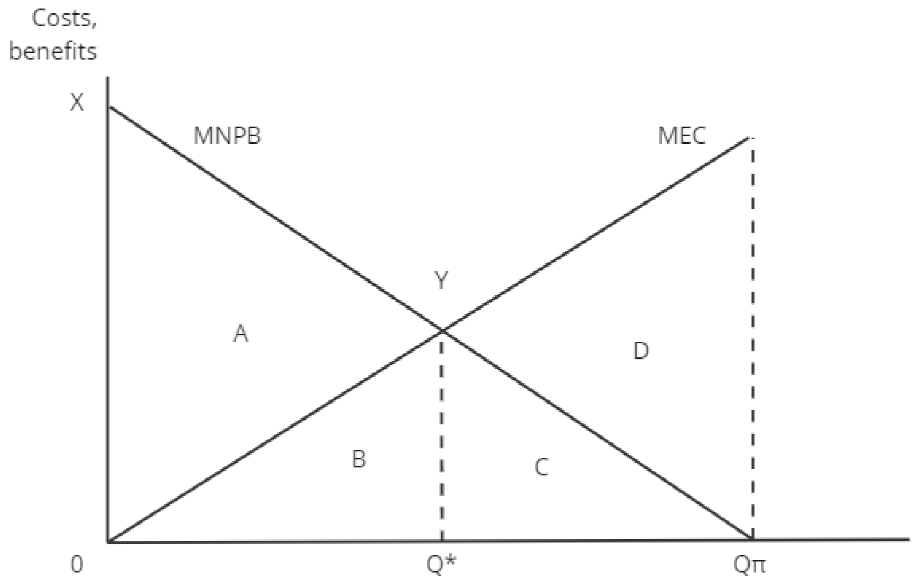
2.1. Externalities and optimal environmental regulation

The concept of externalities and the need for government intervention in environmental economics have been rigorously examined in the literature. Taxes have long been acknowledged in economics as a means to address environmental problems associated with externalities. Pigou (1920) identified taxation as the instrument capable of aligning prices with marginal social cost, thereby internalizing externalities. Pigouvian taxation aims to minimize the social costs of pollution while maximizing the net benefits of economic activities. These regulations aim to internalize the negative externalities generated by polluting activities, aligning with the concept of optimal environmental regulation. In this chapter, we explore the concept of environmental regulation, focusing on environmental taxes as representative instruments for achieving the optimal level of pollution.

A fundamental aspect of the economic definition of pollution, or 'externality,' is the understanding that physical pollution does not necessarily correspond to 'economic' pollution. Furthermore, even if 'economic' pollution exists, its complete 'elimination' does not necessarily equate to social optimality. This concept is illustrated in Figure 2, as discussed by Pearce and Turner (1990, p.63).

In Figure 2, the polluter's activity level, denoted as Q, is represented on the horizontal axis, while costs and benefits are displayed on the vertical axis. MNPB stands for 'marginal net private benefits.' An intuitive way to understand MNPB is to consider that the polluter incurs costs and receives benefits from the activity that causes pollution. The private net benefit is the difference between revenue and cost. MNPB represents the additional net benefit gained from changing the activity level by one unit. MEC refers to 'marginal external cost,' which is the value of the additional damage caused by pollution from the activity represented by Q. It is shown as increasing with the output Q.

Figure 2. Economics definition of optimal pollution



Source: Pearce and Turner (1990), p.63.

The optimal level of externality is identified where MNPB equals MEC. Since these curves are marginal, the areas under them represent total values. The area under MNPB is the total net private benefit for the polluter, and the area under MEC is the total external cost. Maximizing net social welfare, the sum of all benefits minus all costs, should be society's objective. In this context, the largest net benefit area is found in triangle OXY, establishing Q* as the optimal activity level. Consequently, Q* becomes the optimal level of pollution as well. The economic damage at Q*, depicted by area OYQ* (or area B in Figure 2), represents the optimal level of externality.

Mathematically, this optimal point is derived as follows: At Q*,

MNPB = MEC

MNPB = P - MC (where MC is the marginal cost of production)

Solving for P, we get:

P = MC + MEC (P equals the sum of marginal private cost and MEC, also known as marginal social cost (MSC))

Thus, when MNPB equals MEC, P equals MSC. The condition "price equals marginal social cost" is crucial for achieving Pareto optimality. To internalize the externality, a Pigouvian tax (t) is set at the MEC level. Imposing this tax effectively shifts the marginal social cost curve upwards, aligning it with the private cost curve and restoring Pareto efficiency.

This mathematical framework forms the basis for optimal environmental regulation, aiming to determine the optimal level of government intervention to maximize social welfare. Choosing the right policy instrument, such as Pigouvian taxes, cap-and-trade systems, or direct regulations, requires careful consideration of factors like economic efficiency, fairness, and practical implementation costs.

Sandmo (1975) integrates the theory of optimal taxation with the application of indirect taxation, specifically Pigovian taxes, to mitigate negative external effects. In an ideal first-best scenario, Sandmo posits that the optimal tax on a good generating externalities should align with the Pigovian principle, effectively internalizing the externality. However, in a more realistic second-best setting, where the government must rely on other distortionary taxes for revenue, the Pigovian principle is adapted to these constraints.

2.2. Optimal environmental regulation in second-best settings

A series of studies have addressed various issues of optimal environmental regulation in second-best settings, where ideal conditions are not present. The key issues explored include:

- Interaction between Environmental Regulation and Other Taxes: This research examines the interplay between environmental policies and existing tax systems.
- Environmental Regulation under Imperfect Competition: These studies focus on how market structures that differ from perfect competition influence the effectiveness and design of environmental regulations.
- Impact of Asymmetric Information on Environmental Regulation: These

studies explore the challenges arising from information asymmetries between regulators and firms.

- Challenges of Incomplete Compliance with Environmental Regulations: This research delves into the issues associated with partial compliance by firms and explores strategies to improve enforcement and adherence.
- Role of Endogenous Technological Change in Environmental Regulation: This area investigates the impact of technological advancements on the effectiveness of environmental regulations.

By reviewing these studies, we can develop a comprehensive understanding of the factors that influence optimal environmental regulation. This understanding is crucial for devising effective strategies and policies that address the unique challenges presented in second-best settings.

2.2.1. Interaction between environmental regulation and other taxes

This section examines the complex interplay between existing taxes, such as labor and consumption taxes, and optimal environmental regulation. Key points include:

- Impact of Labor and Other Taxes on Environmental Regulation
- Environmental Taxes and Market Inefficiencies
- The Double Dividend Hypothesis
- Interaction with Consumption Taxes
- Income Taxes and Compliance Costs

Impact of labor and other taxes on environmental regulation

Existing taxes, like those on labor, can significantly influence the optimal level of environmental regulation. For instance, labor taxes that distort the labor market may necessitate a lower level of environmental regulation than would otherwise be optimal (Bovenberg and Ploeg, 1994).

Environmental taxes and market inefficiencies

The presence of pre-existing distortionary taxes introduces market inefficiencies, which in turn affect the social welfare implications of environmental policies (Bovenberg and De Mooij, 1994, p.1085). Bovenberg and Goulder (1996) demonstrated that environmental taxes could be used to offset the deadweight loss created by other taxes, such as consumption taxes. This offsetting effect can lead to an increase in output and a decrease in prices, thereby enhancing consumer welfare.

The Double Dividend Hypothesis

The Double Dividend Hypothesis posits that environmental taxes can serve dual purposes: They can reduce pollution and generate revenue that can be used to offset the deadweight loss from other distortionary taxes. Bovenberg and Goulder (1996) extended this idea by showing that the optimal level of environmental taxation can be higher when other distortionary taxes are present. Their work suggests that environmental taxes can be strategically used to mitigate the inefficiencies introduced by other forms of taxation, thereby increasing consumer welfare.

Interaction with consumption taxes

The design of environmental taxes must consider their interaction with other forms of taxation. For instance, if an environmental tax is levied on a good already subject to a consumption tax, the overall price impact depends on the relative magnitudes of the two taxes. This complexity necessitates a nuanced approach to policy design to ensure that the dual objectives of environmental protection and economic efficiency are met (Barthold, 1994, p.145).

Income taxes and compliance costs

Cremer et al. (1998) explored how the presence of income taxes could affect the optimal level of environmental regulation. They argued that if income taxes compensate firms for environmental compliance costs, the optimal level of regulation could be lower, as income taxes themselves introduce a deadweight loss.

2.2.2. Imperfect competition

In markets characterized by imperfect competition, such as monopoly or oligopoly conditions, the optimal level of government intervention for environmental regulation differs from that in perfectly competitive markets. This section explores how market power and imperfections can influence the design and efficacy of environmental policies.

In a perfectly competitive market, the optimal government intervention aligns with the marginal social cost of the externality. However, in markets with imperfect competition, where firms have market power, the optimal level of intervention changes. For example, a monopolist's output reduction due to market power can lead to lower pollution levels, affecting the optimal tax rate for pollution.

Imperfect competition introduces additional complications to the design design of optimal environmental policy. The presence of market power, whether in the form of monopoly, oligopoly, or monopolistic competition, affects the effectiveness of government interventions.

The optimal tax rate for pollution varies across different market structures. In a monopoly, the optimal tax rate aligns with the marginal social damage. However, in a Cournot oligopoly, the optimal tax rate is lower than the marginal social damage. In a monopolistically competitive market, the optimal tax rate is even lower, as firms would aim to reduce output to maximize profits (Requate, 2006, p.17).

2.2.3. Asymmetric information and uncertainty

The presence of asymmetric information and uncertainty introduces significant challenges in formulating and executing optimal environmental regulation (Spulber, 1988). This section explores the implications of such asymmetry on taxation, compliance, and firm strategy, and suggests potential remedies.

Information asymmetry and suboptimal taxation

Firms often have more detailed information about their pollution control costs than regulators, leading to suboptimal taxation levels. Regulators may set tax rates lower than the socially optimal level due to an information disadvantage. This gap can result in environmental taxes that are insufficient to address the true level of pollution (Jebjerg and Lando, 1997, p.280).

Strategic behavior and regulatory evasion

Firms may exploit information asymmetry to their advantage, for instance, by under-reporting emissions levels. This behavior can lead to regulatory evasion, where firms avoid the full cost of stringent regulations. Additionally, firms may use their informational advantage to lobby for more lenient environmental standards (Cai and Li, 2020, p.539).

Demand elasticity and policy stringency

The elasticity of demand for firms' products is a critical factor in determining the optimal environmental policy. Studies have shown that higher demand elasticity implies that even small price increases can lead to significant reductions in demand, thereby reducing output and pollution. Consequently, markets with higher demand elasticities may require more stringent environmental policies to effectively manage pollution levels (McConnell, 1997, p.383).

To counter the distortions introduced by asymmetric information, policy instruments such as performance-based regulation, mandatory disclosure requirements, and economic incentives can be deployed. These mechanisms can enhance compliance and enable regulators to set more accurate levels of environmental taxation.

2.2.4. Incomplete compliance with environmental regulations

Incomplete compliance with environmental regulations is a significant challenge in achieving optimal environmental outcomes. Despite the government's authority to regulate pollution, not all polluters adhere to these regulations, leading to what is known as incomplete compliance. This non-compliance undermines the effectiveness of environmental policies and hinders the achievement of desired levels of environmental protection (Heyes, 2000, p.107).

Reasons for incomplete compliance with environmental regulations

Several factors contribute to why firms might not fully comply with environmental regulations: The high costs of compliance. Environmental regulations can be costly to implement, especially for small businesses.

- High Implementation Costs: Complying with environmental regulations can be expensive, particularly for small businesses. The costs associated with implementing these regulations, such as upgrading equipment or changing operational processes, can be a significant financial burden (Harford, 1978, p.27).
- Perceived Low Risk of Detection: Some firms may believe that the likelihood of being caught for non-compliance is low. This perception can reduce their incentive to comply with environmental regulations (Chua, Kennedy, and Laplante, 1992, p.241).

Firms might assess that the risks and potential penalties associated with non-compliance are less burdensome than the costs of adhering to the regulations. They may calculate that, even if caught and penalized, the overall financial impact would be less severe than the expense of full compliance.

Addressing incomplete compliance

The issue of incomplete compliance with environmental regulations can be addressed through a variety of means, including:

- Enhanced Enforcement: Increasing the frequency and rigor of inspections can help in detecting cases of non-compliance. Regular and thorough monitoring ensures that firms adhere to environmental standards (Nyborg and Telle, 2006, p.1).
- Stricter Penalties: Raising the penalties for non-compliance acts as a deterrent, making regulatory violations more costly for firms. Higher fines and sanctions can encourage adherence to regulations (Garvie and Keeler, 1994).
- Financial Assistance for Compliance: Offering financial support, particularly to small and medium-sized enterprises, can facilitate compliance. This assistance can help cover the costs associated with implementing environmentally friendly practices and technologies (Aragón-Correa et al., 2008, p.92).
- Voluntary Compliance Programs: Collaborating with firms to develop voluntary compliance programs can promote adherence to regulations without the need for strict enforcement. These programs can include incentives for

proactive compliance and environmental stewardship (Khanna and Damon, 1999, p.3).

By employing these strategies, governments can improve compliance rates and enhance the overall effectiveness of environmental regulation. This comprehensive approach ensures that environmental policies are not only enforced but also supported by the industry, leading to more sustainable environmental outcomes.

2.2.5. Technological change and environmental regulation

This section examines how both market-driven (endogenous) and policy-induced technological changes necessitate adjustments in environmental regulations. Technological change significantly impacts the optimal level of environmental regulation, requiring a dynamic approach to policy-making (Jaffe, Newell, and Stavins, 2003, p.461).

Endogenous technological change

Endogenous technological change, driven by market forces, can have varying effects on the environment. Innovations that reduce emissions, for example, may lessen the need for stringent regulations. However, not all market-driven technological advancements are beneficial to the environment, and some may even exacerbate environmental problems (Gillingham, Newell, and Pizer, 2008, p.2734).

Induced technological change

Induced technological change, driven by government policies, can be effective in fostering environmental improvements. Its effectiveness hinges on factors such as the stringency of regulations, the availability of technological substitutes, and the current level of technological development (Liu and Yamagami, 2018, p.279).

3 Sustainable Finance

3.1. The general concept of sustainable finance

3.1.1. The rise of sustainable finance

Awareness of Sustainability-Related Risks by the Financial Sector

The increasing awareness of sustainability-related risks, such as climate change and biodiversity loss, has prompted significant players in the financial markets to fundamentally reassess their asset preferences. These risks, which have tangible impacts on businesses and economies, are leading to a marked shift in financial markets towards greener assets.

Greener assets are becoming increasingly popular among investors for several reasons. Firstly, they are perceived as less risky compared to traditional assets, primarily due to their lower exposure to sustainability-related risks. Secondly, greener assets are considered more socially responsible investments. There is a growing trend among investors and consumers to favor companies that have a positive impact on society, making greener assets an appealing option for these goals.

The shift towards greener assets carries several positive implications for the financial system. It helps mitigate the risk of financial instability by reducing exposure to sustainability-related risks in financial markets. Additionally, it contributes to achieving sustainable development goals by directing capital towards businesses addressing sustainability challenges. This shift aligns with various sustainable finance initiatives, such as the United Nations Principles for Responsible Investment, which advocate integrating environmental, social, and governance (ESG) factors into investment decision-making.

Reduced sustainability risks

Greener assets represent investments in companies committed to environmental stewardship, employing greener technologies and processes to minimize their environmental impact. These companies typically possess substantial reputational capital, making them attractive to consumers, investors, and regulatory bodies. Their reduced vulnerability to sustainability-related risks is attributed to several key advantages:

- Reputation enhancement: Companies engaged in environmental conservation enhance their brand image, attracting conscientious consumers (Majeed et al., 2022).
- Regulatory compliance: Adherence to environmental best practices eases compliance with evolving regulations, reducing the risk of sanctions (Aragón-Correa et al., 2008).
- Cost efficiency: Sustainable practices can lead to significant savings, particularly in energy consumption and waste management (Henriques, and Catarino, 2017).
- Innovation and growth: Investing in sustainable technologies can lead to new opportunities, spurring innovation and long-term growth (Foerster, 2015).

Shift in Investor Sentiment and ESG Integration

The movement towards sustainable finance is characterized by an increasing preference for greener assets. These assets are investments in companies committed to environmental stewardship, which employ greener technologies and processes to minimize their environmental impact. Such companies often boast significant reputational capital, enhancing their appeal to consumers, investors, and regulatory bodies alike. In this evolving financial landscape, investment portfolios are assessed not just on the basis of financial performance but also on sustainability attributes. This paradigm shift is grounded in the belief that companies prioritizing sustainability are less susceptible to environmental, market, and regulatory risks, thereby positioning themselves more favorably for long-term financial success.

3.1.2. Definitions of sustainable finance

UNEP Statement of Commitment by Financial Institutions for Sustainable Development

The UNEP Statement of Commitment by Financial Institutions on Sustainable Development served as the foundational backbone of the Finance Initiative, established following the Rio Earth Summit in 1992. By signing this Statement, financial institutions publicly acknowledged the significant role of the financial services sector in fostering a sustainable economy and lifestyle. They committed to integrating environmental and social considerations into all aspects of their operations. For more historical context, read about the background of UNEP FI.[1)]

> "We members of the Financial Services Sector recognize that economic development needs to be compatible with human welfare and a healthy environment. To ignore this is to risk increasing social, environmental and financial costs. We further recognize that sustainable development is the collective responsibility of governments, businesses and individuals. We are committed to working collectively toward common sustainability goals"[2)].

UN Principles for Responsible Investment

The United Nations Principles for Responsible Investment (UN PRI), launched on 27 April 2006, represent a significant development in global financial markets. The UN PRI aims to integrate environmental, social, and corporate governance (ESG) considerations into investment decision-making, aligning finance with sustainable development principles. This initiative promotes better long-term investment returns and sustainable market practices, urging global institutional investors and their partners to adopt these principles. Central to the UN PRI are six overarching principles that emphasize the integration of ESG factors into investment activities.[3)]

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1) UNEP FI (n.d.), "About Us", accessed on December 4, 2023.

2) UNEP (1992), "UNEP Statement of Commitment by Financial Institutions (FI) on Sustainable Development", accessed on December 3, 2023.

3) UN (April 27, 2006), "Secretary-General Launches 'Principles for Responsible Investment' Backed by World's Largest Investors", accessed on November 4, 2023.

> "The PRI defines responsible investment as a strategy and practice to incorporate environmental, social and governance (ESG) factors in investment decisions and active ownership. There are many terms—such as sustainable investing, ethical investing, and impact investing—associated with the plethora of investment approaches that consider ESG issues. Most lack formal definitions, and they are often used interchangeably. A key to understanding how responsible investment is broader than these concepts is that where many make moral or ethical goals a primary purpose, responsible investment can and should be pursued by the investor whose sole focus is financial performance, as well as those looking to build a bridge between financial risk/opportunities and outcomes in the real world"[4].

The launch of the UN PRI has been instrumental in promoting sustainable finance among investors. It has shifted the market focus from short-term gains to long-term, sustainable factors affecting a company's financial health. By prioritizing ESG considerations, the PRI fosters collaboration among investors to support well-regulated markets and sustainable development, significantly influencing investment practices worldwide.

OECD[5]

According to the OECD (2023), the term sustainable finance broadly encompasses efforts to align financial flows and products with sustainable development pathways. This alignment involves the integration of ESG factors into financial products and services. However, the essential elements that constitute ESG factors and the methodologies for assessing them differ across jurisdictions[6].

EU

The European Union (EU) has defined sustainable finance as the economic activities that contribute substantially to one or more of six environmental objectives: climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, the transition to a circular economy, pollution

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4) UN PRI (2021), "Principles for Responsible Investment", accessed on November 1, 2023.

5) OECD (March 6, 2021). "Developing Sustainable Finance Definitions and Taxonomies", accessed on December 1, 2023.

6) OECD (2023), "Policy Instruments for the Environment Database", p.9, accessed on December 1, 2023.

prevention and control, and protection and restoration of biodiversity and ecosystems. The EU's definition of sustainable finance is based on the Taxonomy Regulation, which was promulgated in June 2020. The Taxonomy Regulation sets a framework for defining which economic activities can be considered sustainable under EU law. The term "green finance" is more narrowly focused on financial products that have a positive impact on the climate or environment compared to a "business as usual" scenario. Definitions may include objectives, taxonomies, exclusion criteria, indicators, and ratings to assess the "greenness" of a financial product.[7)8)]

> "Sustainable finance generally refers to the process of taking due account of environmental, social and governance considerations when making investment decisions in the financial sector, leading to increased longer-term investments into sustainable economic activities and projects. Environmental considerations refer to climate change mitigation and adaptation, as well as the environment more broadly, such as preserving biodiversity, preventing pollution and promoting the circular economy. Social considerations refer to issues of inequality, inclusiveness, labor relations, investment in human capital and communities, and human rights issues. The governance of public and private institutions, including management structures, employee relations and executive remuneration, plays a fundamental role in ensuring the inclusion of social and environmental considerations in the decision-making process."[9)]

UK

In the United Kingdom, the 2021 roadmap "Greening Finance: A Roadmap to Sustainable Investing" provides insights into the meaning of "sustainability" in a financial context. Here, sustainability is seen as being related to three key factors: Environment, Social and Governance. The environment factor concerns the pathways

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7) "Climate finance" generally refers to financing that supports actions aimed at climate change mitigation and adaptation. The United Nations Framework Convention on Climate Change (UNFCCC) defines climate finance as financing that aims to reduce emissions and enhance the resilience of human and ecological systems to negative climate impacts (UNFCCC Standing Committee on Finance, 2014).

8) European Commission (n.d.), "EU Taxonomy for Sustainable Activities", accessed on December 1, 2023.

9) European Commission (n.d.), "Overview of Sustainable Finance", accessed on December 1, 2023.

through which organizations impact and are impacted by climate change as well as broader environmental issues, such as biodiversity. Global reporting standards are emerging that are underpinned by international agreements on underlying climate policy. The social aspect includes factors ranging from modern slavery to international development. Global consensus on reporting standards may take longer to form, but there are existing frameworks which may provide a basis for future global standard setting. Finally, the governance relates to how a company is controlled and directed. It is the longest most well-established area of investor engagement, and extensive disclosure is already provided by companies through existing corporate law and other requirements (HM Government, 2021, p.6).

3.1.3. Sustainability-related risks

Sustainability-related risks in the context of sustainable finance refer to the financial risks that financial institutions (FIs) face due to the 'non-financial performance' related to the sustainability of a company or an asset. These risks encompass uncertain environmental, social, or governance (ESG) events or conditions that, if they occur, could materially negatively impact an FI's business model, strategy, sustainability strategy, and its ability to achieve goals, create value, and influence its decisions and those of its business relationships regarding sustainability matters (EFRAG, 2022, p.11).

Traditionally, financial institutions (FIs) have focused on managing well-established risks like credit, liquidity, and market risks. However, a new category of threats has emerged in recent years: environment-related financial risks. Table 2 provides a detailed breakdown of these risks, categorized into 24 different sub-categories, each capable of triggering various financial and operational risks for FIs. These include credit default, market valuation losses, liquidity issues, and operational disruptions.

In this study, sustainable finance is defined as the strategic decision-making process of capital providers that takes into account the sustainability-related risks associated with an asset, with a particular focus on environmental factors. This approach underscores the importance of integrating ESG considerations into investment decisions, aiming to foster sustainable development and responsible business practices.

Table 2. Environment-related financial risks

Financial Risks for FIs / Environmental risks		Market Risk	Credit Risk	Liquidity Risk	Other risks
Physical Risks	**Sub-categories**				
Extreme weather events	Tropical cyclones/Typhoons	❶	❶		❶
	Floods		❷	❷	❷
	Winter storms				
	Heat waves		❸		❸
	Droughts		❹		
	Wildfires		❺		
	Hailstorms				
Ecosystems pollutions	Soil degradation and pollution		❻		
	Water pollution				
	Marine pollution				
	Environmental accidents	❼	❼		❼
Sea-level rise					
Water scarcity					
Deforestation					
Desertification					
Transition Risks	**Sub-categories**				
Public policy change	Energy transition policies	❽	❽		
	Pollution control regulation				
	Polices on resource conservation				
Technological changes	Clean energy technologies	❾	❾		
	Energy saving technologies				
	Clean transportation				
	Other green technologies				
Shifting sentiment		❿	❿	❿	
Disruptive business model					

Source: NGFS (2020), p.7.

3.2. Empirical studies

3.2.1. Environmental performance and asset returns

Recent studies have increasingly focused on measuring the impact of environmental factors on financial risks and opportunities, as well as the financial outcomes of integrating Environmental, Social, and Governance (ESG) considerations by investors and financial institutions. These studies provide insights into why sustainable finance is increasingly preferred by capital providers, demonstrating the financial benefits and risk mitigation associated with environmentally conscious investment decisions.

Monasterolo and de Angelis (2020) observed that the announcement of the Paris Agreement (PA) led to a perception of reduced risk in low-carbon portfolios. The paper analyzes the stock market reaction to the PA and its impact on low-carbon and carbon-intensive indices in the EU, US, and global stock markets. After the PA, the correlation between low-carbon and carbon-intensive indices decreases, indicating a change in market behavior. The overall systematic risk for low-carbon indices consistently decreases, suggesting that financial markets are pricing the PA and recognizing the value of low-carbon assets. The study provides evidence that stock market investors began seeing low-carbon assets as more appealing after the PA, as evidenced by higher weights of low-carbon indices within optimal portfolios. However, it also notes that investors have yet to significantly penalize carbon-intensive assets, suggesting that the impact of the PA on public equity markets has not yet led to a broad reorganization of portfolios around green assets.

Ramelli et al. (2021) found that investors rewarded companies with responsible climate strategies and that environmental activism affected high-polluting sectors negatively. The first Global Climate Strike in March 2019 led to a decrease in the stock prices of carbon-intensive firms, likely due to increased public attention to climate activism. Financial analysts downgraded their longer-term earnings forecasts of carbon-intensive firms after the strike. The stock price effects point to an evolution in investor expectations with regards to environmental preferences and future climate regulation, suggesting that brown firms may face increased cost of capital as climate activism intensifies. The timing of the stranding of high-polluting assets is influenced not only by new regulations but also by shifting environmental norms in society at large. The paper's findings are relevant for corporations, investors, and policymakers, highlighting the need for high-carbon intensity firms to anticipate increased costs of capital and for investors to consider the stock market effects of upcoming climate-policy actions.

Pedersen, Fitzgibbons, and Pomorski (2021) illustrates that in markets with diverse investor types, including ESG-motivated, ESG-aware, and ESG-unaware investors, the optimal investment allocation leads to an ESG-efficient frontier. This frontier represents the highest attainable Sharpe ratio for each ESG level, highlighting the dual role of ESG scores in providing firm fundamental information and influencing investor preferences. The study concludes that responsible investing impacts equilibrium asset prices, as evidenced by the ESG-adjusted capital asset pricing model.

Pástor, Stambaugh, and Taylor (2021) describes how green assets typically have negative alphas, while brown assets have positive alphas. The study finds that sustainable investing can lead to higher returns for investors and positive social impacts. Sustainable companies often have advantages such as lower costs, higher sales, and stronger management teams, leading to better returns. Additionally, the growing demand for sustainable assets is driven by factors like increasing awareness of environmental and social costs, alignment with personal values, and belief in long-term investment opportunities in sustainable assets.

Pástor, Stambaugh, and Taylor, L. A. (2022) empirically tests sustainable investing theories, finding that recent high returns on green assets were driven by fears of unexpected shocks, such as worsening environmental conditions, rather than expectations of strong returns. The study reveals that green assets have outperformed brown assets in recent years due to unexpected events like adverse climate news. The paper employs a two-factor asset pricing model featuring a green factor and suggests that small stocks underreact to climate news.

Cheng et al. (2023) analyze the effects of excluding high-emitting “brown” firms from investment indices. Their findings indicate that such exclusion leads to lower stock prices and higher capital costs for these firms, potentially reducing their investments. This creates a feedback loop, affecting both stock prices and corporate investment. In a modeled scenario with diverse investor types, the study shows a 7.1% decrease in stock prices for the most polluting firms, contrasting with a 1% increase for non-excluded firms. This results in a 27 basis-point rise in the cost of capital for the most polluting firms. The study concludes that the exclusion of high-emitting firms makes green assets more attractive, as their inclusion in indices positively impacts their stock prices and reduces their cost of capital. Conversely, brown assets face higher costs and reduced investments due to their exclusion, highlighting the significant influence of sustainable investment strategies on these firms.

3.2.2. Greenium

Greenium (the green premium) is the difference between the yield on a green bond and the yield on a conventional bond with similar characteristics. When the yield on a green bond is lower than that of a conventional bond, a positive greenium occurs. This phenomenon often arises because investors are prepared to pay a premium for green bonds. They might do so either due to their belief in the worth of the environmental benefits these bonds offer or to support the growth of the green bond market. Conversely, a negative greenium happens when the yield on a green bond exceeds that of a conventional bond. This situation can arise from insufficient demand for green bonds or investor skepticism regarding the actual environmental benefits of these bonds (Ando et al., 2023, p.4).

The concept of greenium remains a topic of debate in financial markets. Research in this area has produced mixed findings, with some studies identifying the presence of greenium under specific conditions or in certain markets.

Zerbib (2019) contributed to this discourse by examining the effect of pro-environmental preferences on bond prices. The study found a small negative premium associated with green bonds compared to conventional bonds, particularly in financial and low-rated bonds. This suggests that while investors have pro-environmental preferences, these do not significantly affect bond prices, indicating a willingness to invest in green assets without a substantial premium. The findings imply that environmental considerations, while valued, do not strongly deter investors from supporting the green bond market's growth. The study underscores a positive sentiment towards environmentally friendly investments, reflecting a broader acceptance of sustainable finance without the necessity of high financial incentives.

Ma et al. (2020) conducted an analysis on green bonds, focusing on the yield differential known as the greenium compared to conventional bonds. Their findings indicate that the greenium generally fluctuates around zero, with an average of approximately -7 basis points (bps). This suggests that, on average, green bonds do not consistently offer higher yields compared to conventional bonds. The study revealed that some green bonds exhibit lower volatility than their non-green counterparts, indicating a potential perception among investors that green assets might be less risky. Additionally, the paper notes a lagging effect between the greenium and financial market stress, suggesting that green bonds could be more resilient during systemic crises. This resilience might make green bonds an attractive option for investors seeking to hedge risk while aligning their investments with environmental and climate goals.

Fatica et al. (2021) explored the pricing dynamics of green bonds and found that companies issuing green bonds generally benefit from lower funding costs, particularly when their environmental commitment is perceived as credible. The study noted that while supranational entities and corporations often command a premium for their green bonds, financial institutions do not. This distinction is attributed to the different roles these institutions play in funding low-carbon activities. The study also highlighted the influence of external reviews and market access frequency on green bond pricing. Furthermore, it was observed that banks issuing green bonds tend to reduce funding to more polluting sectors, reflecting a strategic shift towards environmentally friendly investments.

Alessi et al. (2020) conducted a study on European stocks, uncovering a significant negative greenium linked to a “greenness and transparency” factor. This factor, defined by corporate greenhouse gas (GHG) emissions and the quality of environmental disclosures, indicates a risk premium associated with firms’ environmental performance and transparency. The study highlights that investors consider factors like transparency, credibility, and climate responsibility, in addition to a company’s direct environmental impact. The “greenness and transparency” factor is proposed as a tool for assessing portfolio exposure to risks associated with the low-carbon transition and for hedging against these risks.

Pietsch and Salakhova (2022) conducted a comprehensive study on the “greenium” associated with green bonds in the Eurozone from 2016 to 2021. Analyzing a broad database with daily option-adjusted spreads (OAS), their research reveals three significant findings about the greenium. Firstly, they identified a consistent greenium of around 4 basis points, which is statistically significant at the 10% level. Secondly, the extent of the greenium is closely linked to the perceived “greenness” of the bonds, influenced by factors such as external reviews and the environmental commitment of issuers. Bonds from green sectors or those issued by banks affiliated with the United Nations Environmental Program Finance Initiative (UNEP FI) were found to have a more significant greenium. Lastly, the study observed an evolution in the greenium over time, becoming more pronounced, possibly due to increasing climate concerns. This trend indicates a growing investor preference for green assets, valuing not only financial returns but also a commitment to sustainability. However, the study also prompts a discussion on the cost-effectiveness of green bonds, weighing the administrative costs of issuance against their benefits.

Ando et al. (2023) provide empirical evidence establishing the existence and quantifying the size of the sovereign greenium, which denotes the cost-saving and extended maturity advantages associated with green bonds in comparison to conventional bonds. Their research highlights an upward trend in the greenium, particularly noticeable in Euro-denominated green bonds. This suggests a growing preference among sovereign bond investors for green assets, allowing governments to issue bonds with longer maturities at reduced borrowing costs. However, the study also raises pertinent questions regarding the cost-effectiveness of green bonds. It prompts inquiries into whether the administrative costs of issuance outweigh the financial benefits and whether these bonds effectively fulfill their intended environmental objectives.

Alessi, Ossola, and Panzica (2023) delve into the evolution of the "greenium," a risk premium associated with a firm's environmental sustainability, carbon emissions, and transparency. Employing a dynamic asset pricing model that adjusts over time, the study incorporates corporate greenhouse gas emissions and the quality of their environmental disclosures. The findings reveal that investors in the European equity market exhibit a willingness to accept lower returns for investments in environmentally sustainable and transparent assets, particularly when these assets contribute to making credible progress toward a low-carbon economy. Noteworthy events, such as the Paris Agreement, the first Global Climate Strike, and the announcement of the EU Green Deal, were found to have a positive impact on the greenium. Conversely, increases in the prices of fossil fuels and critical minerals necessary for the low-carbon transition are associated with a rise in the greenium, signifying that more polluting firms are perceived as less risky under such circumstances.

3.2.3. Household sustainable finance

Aron-Dine, S. et al. (2022) delves into the realm of sustainable investing, drawing from data sourced from a comprehensive survey of German households. Complemented by a quantitative asset pricing model that accounts for the diversity of investors, this study sheds light on the landscape of sustainable investments. Notably, it uncovers that approximately one-third of households in Germany have embraced green investments, collectively constituting 11% of their household wealth. Currently, green investments carry a level of risk, with equity being the primary avenue, while green bank accounts remain a rarity. What emerges is a fascinating spectrum of preferences for both secure and high-risk green assets across the wealth spectrum, exerting variable influences on the demand for such assets. Intriguingly, this analysis unveils that nonpecuniary advantages and hedging needs presently drive up the cost of green equity for firms. Nevertheless, the surge in sustainable investing has led to a reduction in the relative risk premium on green equity, diminishing it by approximately 1 percentage point. This shift is chiefly attributable to the increased awareness among investors regarding green stocks, resulting in higher bidding for these assets. Furthermore, there is a growing appetite among households for green bank accounts, a phenomenon that holds the potential to significantly augment the landscape of green finance. Notably, findings from a randomized control trial (RCT) integrated into the survey suggest that enhanced awareness of climate finance could potentially trigger a further surge in green equity investment.

3.3. Implications for the theoretical framework

The empirical evidence presented in the previous section sheds light on the multifaceted interactions between sustainable finance, environmental performance, and real economic outcomes. This comprehensive review of the literature serves as a robust empirical foundation underpinning a crucial aspect of the theoretical model to be discussed in the subsequent chapter.

From an environmental policy perspective, these findings advocate for an integrated approach, emphasizing that environmental regulation should not function in isolation but rather be meticulously crafted in alignment with the dynamics of financial markets. This alignment is imperative, as it significantly influences the profit-maximizing behavior of emitters.

The empirical discoveries enrich our comprehension of the intricate interplay between sustainable finance and environmental regulation. They underscore the necessity of a holistic strategy that marries regulatory measures with the dynamics of financial markets, offering invaluable insights into the optimization of environmental policies.

4 The Model

4.1. Basic framework

In this chapter, we present the fundamental framework for analyzing a firm's profit-maximizing behavior under various regulatory, product market, and financial market conditions.

Market

Our model operates within a monopolistic competition environment, where firms differentiate their products to compete. Each firm confronts a demand curve with a downward slope, and within this context, firms act as price takers in input markets. The market's inverse demand function is represented by $p(y)$, where p is a continuously differentiable function with a downward slope concerning output y, and $p'(y) < 0$. For the sake of clarity and simplicity, we assume a linear demand curve.

$$p(y),\ p'(y) < 0$$

Production, inputs, and costs

Our focus is on a firm that employs a composite input z priced at ω per unit. To streamline the exposition, we posit that the firm's production function is linear, represented by $y = f(z) = \theta z$, with $\theta > 0$ indicating the firm's level of productivity.

Incorporating these relationships, the cost function in terms of output y and productivity θ simplifies to:

$$c(y, \theta) = \frac{\omega}{\theta} y$$

The cost function can be expressed in terms of the input z:[10)]

10) For a detailed discussion on derived factor demand, the reader is referred to Biondi (2022).

$$c(z) = \omega z$$

Given the linear production function, marginal production costs remain constant and are denoted as:

$$c' = \frac{dc(y,\theta)}{dy} = \frac{\omega}{\theta}$$

Profit-maximizing output

Let us define the firm's profits as a function of output y and productivity θ:

$$\pi(y,\theta) = p(y)y - c(y,\theta) = p(y)y - \frac{\omega}{\theta}y$$

The firm aims to maximize its profit by choosing an output level y_0 where the marginal revenue equals the marginal cost:

$$\frac{d\pi}{dy} = p(y) + p'(y)y - \frac{\omega}{\theta} = 0$$

Rearranging the terms for the condition of profit maximization, we have:

$$p(y) + p'(y)y = \frac{\omega}{\theta}$$

Solving for the firm's optimal output level y_0, the result is:

$$y_0 = \frac{\omega - \theta p(y)}{\theta p'(y)}$$

This optimal output y_0 is indicative of the firm's production decision when it is solely driven by profit maximization, without considering the externalities of production. It is positively correlated with the firm's productivity θ, but negatively correlated with the input price ω.

Profit-maximizing input and emission

Given the production function $y = \theta z$, the input is derived as $z = y/\theta$. Substituting the profit-maximizing output y_0 into this expression gives us the corresponding optimal input level z_0. The optimal input level z_0 is:

$$z_0 = \frac{y_0}{\theta} = \frac{(\omega - \theta p)}{\theta^2 p'}$$

This equation indicates that the optimal input level z_0 is a function of both the price per unit of input and the productivity of the firm. The level of input used by the firm will adjust in response to changes in these parameters.

Each firm emits effluents e as a byproduct of production. The emissions level is set at $e = (1-g)z$, where g quantifies the firm's environmental performance or 'greenness,' with g ranging from 0 (no greenness) to 1 (full greenness). A higher g implies a more environmentally friendly production process with lower emission intensity.

Given the optimal input level z_0, we determine the profit-maximizing emission level e_0:

$$e_0 = (1-g)z_0 = (1-g)\frac{\omega - \theta p}{\theta^2 p'}$$

In this framework, since the demand function's slope p' is negative by assumption, the value of e_0 will be positive as long as the expression $\omega - \theta p$ remains negative. This condition aligns with the economic principle that firms will only produce if prices cover average cost, ensuring positive profit. Hence, e_0 reflects the level of emissions associated with profit-maximizing production that takes into account firm greenness factor, or g.

When recalculated in relation to the marginal cost c', the optimal input level z_0 and the corresponding emissions level e_0 are redefined as follows:

$$z_0 = \frac{c' - p}{\theta p'}$$

$$e_0 = (1-g)z_0 = (1-g)\frac{c' - p}{\theta p'}$$

These formulations illustrate the interplay between market dynamics, the firm's technological efficiency, and its environmental considerations in determining optimal input and emissions levels. Holding the greenness factor g constant, an increase in the market prices or a decrease in marginal costs c' leads to higher levels of both inputs and emissions. Conversely, an enhancement in productivity (higher θ or a more elastic demand curve (more negative p') results in fewer inputs and lower emissions levels.

Furthermore, adjusting the firm's greenness factor g incrementally directly reduces both inputs used and emissions levels, assuming other market and technological parameters remain constant. This relationship reinforces the findings in the literature on optimal pollution control in markets with imperfect competition, as explored by works such as Requate (2006).

4.2. Government intervention: Environmental taxation

Here we now include the impact of an optimal environmental tax, denoted as τ^*, on the firm's profit-maximizing output and emissions. The tax is introduced as a response to market failures caused by environmental externalities, and it is designed to internalize these externalities, thus aiming to maximize social welfare. The tax τ^* is applied per unit of emissions e produced by the firm.

With the imposition of the environmental tax, this cost function is modified to include an additional term that accounts for the tax on emissions. The cost function, incorporating the tax, is then:

$$\begin{aligned} c_{\tau^*}(y,\theta) &= c(y,\theta) + \tau^* e \\ &= \frac{\omega}{\theta} y + \tau^* (1-g) \frac{y}{\theta} \\ &= \frac{\omega + \tau^* (1-g)}{\theta} y \end{aligned}$$

The inclusion of τ^* in the cost function means that for each unit of output produced, the firm incurs an additional cost proportional to its emissions. This additional cost raises the firm's marginal cost of production, leading to a decrease in both output and emissions as the firm adjusts to the tax burden. The new cost function therefore reflects the firm's attempt to balance its production decisions with the added cost of environmental taxation.

Profit-maximizing output under environmental taxation

In the context of an environmental tax regime, the firm's profit function, denoted as $\pi_{\tau^*}(y,\theta)$, is redefined to account for the tax burden. The function is expressed as:

$$\pi_{\tau^*}(y,\theta) = p(y)y - c_{\tau^*}(y,\theta)$$

$$= p(y)y\frac{\omega+\tau^*(1-g)}{\theta}y$$

In this equation, the first term represents the firm's total revenue generated from selling its output. The second term embodies the total costs incurred in production, which now includes both the conventional production cost (represented by ω) and the additional environmental tax.

The environmental tax component, $\tau^*(1-g)$, is a product of the tax rate τ^* and the firm's emissions intensity, represented by $(1-g)$. This formulation captures how the tax effectively raises the firm's cost of production for each unit of output, factoring in its environmental impact.

To identify the profit-maximizing output level in the presence of an environmental tax, we differentiate the modified profit function π_{τ^*} with respect to output y and equate it to zero:

$$\frac{d\pi_{\tau^*}}{dy} = p(y) + p'(y)y - \frac{\omega+\tau^*(1-g)}{\theta} = 0$$

Solving for the output level that maximizes profit under this tax regime, we derive:

$$y^* = \frac{\omega+\tau^*(1-g)-\theta p(y)}{\theta p'(y)}$$

y^* signifies the firm's optimal output level when subjected to environmental taxation. This level is adjusted downward in response to the increased marginal cost resulting from the tax. The extent of the output reduction depends on several factors: the productivity parameter θ, the demand elasticity p', and the firm's environmental performance, denoted by g. A higher productivity θ, a less elastic demand curve (that is, a smaller absolute value of $|p'|$), or a greater emphasis on environmental sustainability (higher g) will typically lessen the output's responsiveness to changes in the tax rate τ^*.

Comparing y_0 *and* y^*

In the scenario without the environmental tax, the firm's profit-maximizing output level is $y_0 = (\omega - \theta p)/(\theta p')$. However, with the imposition of the environmental tax, the new optimal output level adjusts to $y^* = (\omega + \tau^*(1-g) - \theta p)/(\theta p')$.

To elucidate the impact of the tax, we compare y_0 and y^*:

$$y_0 - y^* = \frac{\omega - \theta p - (\omega + \tau^*(1-g) - \theta p)}{\theta p'}$$

$$= -\frac{\tau^*(1-g)}{\theta p'}$$

This expression verifies that the introduction of the environmental tax leads to a reduction in the optimal output level. The extent of this decrease is influenced by the tax rate τ^*, the firm's environmental performance g, and the slope of the demand function p'. Given that p' is negative, the term $-\frac{\tau^*(1-g)}{\theta p'}$ is non-negative, which confirms that $y^* \leq y_0$, indicating a decrease in output due to environmental taxation.

(a) For a completely environmentally friendly firm ($g = 1$), implying zero emissions, the difference $y_0 - y^*$ becomes zero. This is expected as such a firm would not be subject to the environmental tax, leaving its optimal output level y^* unaffected.

(b) For firms with partial greenness ($0 \leq g < 1$), $y_0 - y^*$ is positive, signifying that the optimal output level y^* with environmental taxation is lower than the output level y_0 without taxation. This scenario represents the typical impact of an environmental tax on firms that generate emissions, thereby necessitating a reduction in output to minimize tax liability.

Profit-maximizing input and emissions under environmental taxation

The firm's optimal input level z^* corresponding to the output level y^* under environmental taxation is derived as:

$$z^* = \frac{y^*}{\theta} = \frac{\omega + \tau^*(1-g) - \theta p}{\theta^2 p'}$$

This equation indicates that z^* is influenced by the tax rate τ^*, the environmental performance parameter g, the productivity parameter θ, and the demand elasticity p'. A higher tax rate τ^* reduces z^* by increasing the marginal cost of production, whereas a higher greenness level g effectively reduces the tax burden, potentially increasing z^*.

Comparing z_0 and z^*

To understand the impact of the environmental tax on the firm's input decision, we compare the optimal input level without taxation (z_0) and with taxation (z^*). The difference $z_0 - z^*$ is calculated as follows:

$$z_0 - z^* = \frac{\omega - \theta p}{\theta^2 p'} - \frac{\omega + \tau^*(1-g) - \theta p}{\theta^2 p'}$$

$$= -\frac{\tau^*(1-g)}{\theta^2 p'}$$

Given that τ^* is non-negative, the constraint of g within the interval [0,1], the negative slope of the demand function p', and the positive productivity parameter θ, it is evident that:

$$-\frac{\tau^*(1-g)}{\theta^2 p'} \geq 0$$

This inequality confirms that $z_0 - z^*$ is non-negative, implying that the optimal input level z^* under environmental taxation is less than or equal to the optimal input level z_0 in the absence of taxation. Therefore, environmental taxation effectively leads to a reduction in the input level used by the firm, aligning with the policy's objective to internalize environmental externalities.

Emissions

To determine the optimal level of emissions e^* in the context of the environmental tax τ^*, we use the previously derived optimal input level z^* in the emissions equation. The optimal emission level e^* is then given by:

$$e^* = (1-g)z^* = (1-g)\frac{\omega + \tau^*(1-g) - \theta p}{\theta^2 p'}$$

To assess the impact of the environmental tax on emissions, we compute the difference between the initial emissions level without the tax (e_0) and the emission level with the tax (e^*):

$$e_0 - e^* = (1-g)\frac{\omega - \theta p}{\theta^2 p'} - (1-g)\frac{\omega + \tau^*(1-g) - \theta p}{\theta^2 p'}$$

$$= -\frac{(1-g)^2 \tau^*}{\theta^2 p'}$$

Given that the tax rate τ^* is non-negative, the environmental performance g is bounded between 0 and 1, the demand slope p' is negative, and the productivity parameter θ is positive, the inequality.

$$-\frac{(1-g)^2 \tau^*}{\theta^2 p'} \geq 0$$

is always satisfied. The equality is true when $g = 1$, which corresponds to a scenario where the firm is entirely 'green' and does not emit pollutants. In this case, the environmental tax has no effect on emissions since there are none. However, for firms with $0 \leq g < 1$, representing partial greenness, the environmental tax effectively reduces the level of emissions.

4.3. Sustainable Finance

4.3.1. Green consumerism

In the realm of sustainable finance, green consumerism emerges as a pivotal force influencing capital allocation dynamics. An increasing number of consumers are showing a preference for products from environmentally responsible or 'greener' firms. This trend does not merely represent a shift in cultural attitudes; it is a real economic phenomenon that necessitates a new understanding of financial and market risk that incorporates sustainability. Such risks are increasingly being quantified and recognized in policy frameworks such as the Task Force on Climate-related Financial Disclosures (TCFD).

It is critical that participants in the capital markets grasp this shift in consumer preferences, especially investors and financial institutions, as it provides strong incentives to factor in a firm's environmental performance, or 'greenness,' into investment decisions.

To incorporate the effects of green consumerism and sustainability-related financial risk in our analysis, we have adapted the demand function $p(y)$. The modified pricing function is now:

$$p(y)+\gamma(g-\bar{g})$$

Here, $\gamma \geq 0$ signifies the market's preference for products from environmentally friendly firms. The introduction of $\bar{g}$ as a benchmark level of greenness in the market is instrumental. This benchmark serves as a standard for assessing the environmental performance of individual firms.

The role of $\bar{g}$ is essential as it provides a reference point against which a firm's greenness g is measured. Firms exceeding this benchmark ($g > \bar{g}$) are perceived as outperforming the average market standard in terms of environmental sustainability, potentially commanding a price premium. Conversely, that fail to meet the benchmark ($g < \bar{g}$) are viewed as environmentally underperforming relative to the market, possibly incurring a price discount.

The integration of γ and g into the demand function allows our model to more effectively capture market reactions to environmental sustainability. This modification is critical for examining the interaction between environmental taxation and sustainable finance, providing insights into the broader implications of firms' strategic decisions and market behavior.

4.3.2. Sustainable finance and environmental performance

In our model, sustainable finance principles are integrated by linking the market price of a firm's inputs to its level of environmental performance. This relationship affects both the firm's revenue, conceptualized as 'market risk,' and its tax obligations, referred to as 'regulatory risk.' The modified input price is represented as:

$$\omega - \alpha(g - \bar{g})$$

Here, $\alpha \geq 0$ acts as the greenness-adjustment parameter. It quantifies the extent to which capital providers are willing to offer a premium for assets of greener firms or, conversely, apply a discount to those of less environmentally friendly firms. This parameter reflects the increasing importance that sustainable finance considerations hold in shaping market dynamics.

Within the scope of our model, the firm's environmental performance level g is treated as exogenously determined. This assumption simplifies the discussion by focusing on how sustainable finance influences optimal environmental regulation.

Definition: Sustainable finance

In our model, sustainable finance is fundamentally linked to the parameter α, which signifies the market's adjustment to a firm's environmental performance. We define sustainable finance as the condition where $\alpha > 0$. This occurs under two specific circumstances: either when there is a market preference for environmental sustainability ($\gamma > 0$), or when environmental taxation is in effect ($\tau > 0$). The relationship is formalized as:

$$\alpha > 0 \;\; \textit{if} \;\; \gamma > 0 \;\; \textit{or} \;\; \tau > 0$$

This definition emphasizes the synergy between market dynamics, consumer preferences, regulatory measures, and the allocation of financial resources in the context of environmental sustainability. It recognizes that sustainable finance is not just a standalone concept but an integrated response to market and regulatory incentives to promote greener practices in business operations.

By associating α with both γ and τ, the model acknowledges that sustainable finance is a multi-dimensional construct, influenced by both consumer behavior and policy interventions. It highlights how financial decisions are increasingly being shaped by environmental considerations, reflecting a shift towards more responsible and sustainable economic activities.

4.3.3. Profit maximization with sustainable finance

Revenue and cost under sustainable finance

In our model, which integrates sustainable finance principles, we modify the price function $p(y)$ to simultaneously reflect the firm's environmental performance g and the market's willingness to pay a premium for green behavior. This adjustment is embodied in the parameter γ:

$$p(y)+\gamma(g-\bar{g})$$

This requires us to redefine the revenue function $R(y)$ to capture the green consumerism effect:

$$R_{\gamma}(y)=(p(y)+\gamma(g-\bar{g}))y$$

The updated revenue function $R_{\gamma}(y)$ explicitly incorporates consumer preferences towards environmentally responsible products, as indicated by the parameter γ. This parameter serves as an indicator of the market's propensity to reward or penalize firms based on their environmental performance.

The term $\gamma(g-\bar{g})$ within the revenue function signifies the market premium or discount applied based on the firm's environmental performance level g. A firm with a higher g, compared to the market benchmark $\bar{g}$, is likely to benefit from greater consumer favor, leading to increased revenue. In contrast, a lower g suggests a diminished consumer preference, which could translate into lower revenue.

Incorporating γ and g into the revenue function allows our model to effectively demonstrate the financial consequences of a firm's environmental conduct, especially in terms of revenue generation. This aspect of the model underscores the growing influence of consumer choices in shaping corporate behavior and highlights the direct financial incentives firms have to enhance their environmental performance.

In this part of our model, we refine the cost function $c(y, \theta)$ to integrate the impacts of the optimal environmental tax τ^* and the sustainable finance parameter α. This integration illustrates how these two key factors influence the firm's production costs. We begin by considering the baseline cost function under the optimal environmental tax τ^*:

$$c_{\tau^*}(y, \theta) = \frac{\omega + \tau^*(1-g)}{\theta} y$$

Here, the cost function incorporates the environmental tax, where τ^* is levied per unit of emissions, and g represents the firm's environmental performance.

Next, we introduce the sustainable finance parameter α. This parameter reflects the financial market's response to the firm's environmental performance in comparison to the industry benchmark $\bar{g}$. Accordingly, the adjusted input price ω is modified to:

$$\omega_\alpha = \omega - \alpha(g - \bar{g})$$

In this model, a firm's environmental performance exceeding the benchmark ($g > \bar{g}$) results in a reduced input prices, providing a financial incentive to pursue environmentally sustainable practices. On the other hand, a performance below the benchmark ($g < \bar{g}$) leads to increased input prices, indicating a financial penalty for weaker environmental sustainability.

In integrating these components, we obtain the revised cost function, which accommodates the influences of both sustainable finance and optimal environmental taxation:

$$c_{\tau^*, \alpha}(y, \theta) = \frac{\omega - \alpha(g - \bar{g}) + \tau^*(1-g)}{\theta} y$$

This function illustrates the interaction between the firm's environmental performance g, the environmental tax rate τ^*, and the sustainable finance parameter α in shaping the firm's production costs.

The marginal cost function c'_{α, τ^*} is constant:

$$\frac{dc_{\tau^*,\alpha}}{dy} = c'_{\alpha,\tau^*} = \frac{\omega - \alpha(g - \bar{g}) + \tau^*(1-g)}{\theta}$$

This function incorporates the effects of both environmental taxation and sustainable finance on the firm's production decisions, as detailed below:

Greenness-Adjusted Input Pricing: The term $\alpha(g-\bar{g})$ in the cost function accounts for the adjustment in input prices due to sustainable finance. With α being non-negative, it reflects the financial market's response to the firm's environmental performance. A firm performing above the industry benchmark ($g > \bar{g}$) benefits from lower input costs, indicating a financial incentive for superior environmental performance. Conversely, a firm performing below the benchmark ($g < \bar{g}$) does not incur additional costs due to α.

Environmental Taxation: The term $\tau^*(1-g)$ represents the effective tax burden on the firm, modulated by its level of greenness. Greener firms (g close to 1) experience a lower tax burden, aligning with the principle of internalizing the societal costs of pollution and incentivizing environmentally responsible practices.

Profit-maximizing output under sustainable finance

In our extended model, the revenue function $R_{\gamma,\alpha}(y)$ is shaped by consumer preferences for green products and the market's response to the firm's environmental performance. It is formulated as:

$$R_{\gamma,\alpha}(y) = (p(y) + \gamma(g - \bar{g}))y$$

Concurrently, the cost function $c_{\tau^*\cdot\alpha}(y,\theta)$ incorporates the impacts of both the optimal environmental tax and the sustainable finance parameter:

$$c_{\tau^*,\alpha}(y,\theta) = \frac{\omega - \alpha(g - \bar{g}) + \tau^*(1-g)}{\theta} y$$

Thus, the profit function $\pi_{\tau^*,\alpha}(y)$, which represents firm profitability after considering sustainable finance and environmental taxation, is given by:

$$\pi_{\tau^*,\alpha}(y) = R_{\gamma,\alpha}(y) - c_{\tau^*,\alpha}(y,\theta)$$

$$= \left(p(y) + \gamma(g - \bar{g}) - \frac{1}{\theta}(\omega - \alpha(g - \bar{g}) + \tau^*(1 - g)) \right) y$$

This profit function integrates two critical features of our model:

Green Premium and Greenness-Adjusted Pricing: This part of the function captures the market premium for environmentally superior products (γ) and the risk-adjusted input pricing (α). The term $\gamma(g - \bar{g})$ reflects the revenue boost from consumer preference for greener products, while $\alpha(g - \bar{g})$ adjusts the firm's input costs based on its environmental performance.

Environmental Taxation: The component $\tau^*(1 - g)$ in the function represents the effective tax burden on the firm. This burden is modulated by the firm's environmental performance g, with greener firms experiencing a reduced tax impact.

To ascertain the output level y_1 that maximizes profit under the influences of sustainable finance and environmental taxation, we differentiate the profit function $\pi_{\tau^*,\alpha}(y)$ with respect to output y and set it to zero:

$$\frac{d\pi_{\tau^*,\alpha}}{dy} = p(y) + yp'(y) + \gamma(g - \bar{g}) - \frac{\omega - \alpha(g - \bar{g}) + \tau^*(1 - g)}{\theta} = 0$$

Rearranging and solving this equation for y_1 gives us:

$$y_1 = \frac{\omega - \alpha(g - \bar{g}) + \tau^*(1 - g) - \theta p(y) - \theta\gamma(g - \bar{g})}{\theta p'(y)}$$

This optimal output level y_1 illustrates the interplay between sustainable finance and environmental taxation in the firm's strategic decisions:

- Sustainable Finance Impact: The term $\alpha(g - \bar{g})$ reflects the market's adjustment to the firm's relative environmental performance. A higher α for firms with $g > \bar{g}$ (greener than the benchmark) leads to reduced costs, influencing their output decisions positively. Conversely, for firms with $g < \bar{g}$, it implies higher costs, potentially leading to reduced output.
- Environmental Taxation Impact: The term $\tau^*(1 - g)$ represents the effective tax burden under environmental taxation. Firms with a higher

greenness level (g) experience a lower tax burden, encouraging them to increase production.

Impact of sustainable finance on output

To understand how sustainable finance and environmental taxation influence a firm's profit-maximizing output, we analyze the difference $y_1 - y^*$. After determining the expressions for y_1 (output under sustainable finance) and y^* (output under traditional finance), the difference can be expressed as:

$$y_1 - y^* = -\frac{\alpha(g - \bar{g}) + \theta\gamma(g - \bar{g})}{\theta p'}$$

The sign and magnitude of $y_1 - y^*$ depend on the firm's environmental performance relative to the sustainable finance benchmark $(g - \bar{g})$. We consider three scenarios:

(a) High Greenness ($g > \bar{g}$):

- In this scenario, both $\alpha(g - \bar{g})$ and $\theta\gamma(g - \bar{g})$ are positive, indicating favorable market and financial responses indicating a favorable reaction by capital market participants. With $p' < 0$ (downward-sloping demand curve), the result $y_1 - y^*$ becomes positive. This suggests that firms with superior environmental performance tend to increase their output under sustainable finance compared to environmental taxation. The increase is driven by incentives such as a green premium in pricing and reduced input costs due to positive sustainable finance mechanisms.

(b) Low Greenness ($g < \bar{g}$):

- For firms with $g < \bar{g}$, $\alpha(g - \bar{g})$ and $\theta\gamma(g - \bar{g})$ are negative, reflecting market and financial disincentives for lower environmental performance. Consequently, $y_1 - y^*$ becomes negative, suggesting that such firms are likely to reduce their output under sustainable finance compared to environmental taxation. This reduction is due to increased cost burdens and possibly lower market prices, which discourage higher production levels.

(c) Industry Benchmark ($g=\bar{g}$):

- When a firm's greenness level is at the industry benchmark ($g=\bar{g}$), the terms $\alpha(g-\bar{g})$ and $\theta\gamma(g-\bar{g})$ both become zero, leading to $y_1-y^*=0$. This indicates that firms at the benchmark maintain the same profit-maximizing output level under both sustainable finance and environmental taxation. This situation reflects equilibrium, where the firm's environmental performance aligns with both market expectations and regulatory requirements.

Profit-maximizing input and emissions under sustainable finance

To determine the optimal input level z_1 under sustainable finance, we utilize the previously derived expression for y_1. The formula for z_1 is:

$$z_1=\frac{\omega-\alpha(g-\bar{g})+\tau^*(1-g)-\theta p-\theta\gamma(g-\bar{g})}{\theta^2 p'}$$

This expression for z_1 illustrates how the firm's optimal input choice is influenced by a combination of factors within the model. An increase in the greenness-adjustment coefficient α, a higher environmental tax rate τ^*, or an elevated green premium γ tend to decrease the demand for input. On the other hand, an increase in the market size parameter ω or a higher environmental performance g will increase it.

The difference between the optimal input levels under sustainable finance z_1 and without it z^* is:

$$z_1-z^*=\frac{-\alpha(g-\bar{g})-\theta\gamma(g-\bar{g})}{\theta^2 p'}$$

The sign of z_1-z^* depends on the relative environmental performance of the firm ($g-\bar{g}$):

- For greener firms ($g>\bar{g}$), $\alpha(g-\bar{g})$ and $\theta\gamma(g-\bar{g})$ are positive. Given that $p'<0$, this results in $z_1-z^*>0$, implying an increase in input demand under sustainable finance.
- For less green firms ($g<\bar{g}$), these terms are negative, leading to $z_1-z^*<0$,

indicating a decrease in input demand under sustainable finance.

Impact of sustainable finance on emissions

The optimal level of emission under sustainable finance, e_1, is derived by multiplying the optimal investment level z_1 with $(1-g)$:

$$e_1 = (1-g)\frac{\omega - \alpha(g-\bar{g}) + \tau^*(1-g) - \theta p - \theta\gamma(g-\bar{g})}{\theta^2 p'}$$

The difference $e_1 - e^*$ illustrates the effect of sustainable finance on the firm's emission decisions in comparison to traditional finance:

$$e_1 - e^* = (1-g)\left(\frac{-\alpha(g-\bar{g}) - \theta\gamma(g-\bar{g})}{\theta^2 p'}\right)$$

- For firms where $g > \bar{g}$ (greener than the benchmark): Here, $\alpha(g-\bar{g})$ is positive. Since p' is negative, this leads to an increase in e_1 compared to e^*, as the negative terms in the numerator reduce the absolute value of the fraction. Therefore, $e_1 - e^*$ is positive, indicating an increase in emissions under sustainable finance for greener firms. This increase is attributed to the greater scale of production and use of inputs incentivized by sustainable finance.
- For firms where $g < \bar{g}$ (less green than the benchmark): In this scenario, $\alpha(g-\bar{g})$ is negative, which decreases the value of e_1 compared to e^*. As a result, $e_1 - e^*$ is negative, implying a reduction in emissions under sustainable finance for less green firms. This is due to the increased cost burden, leading to reduced production and input use.

The sign of $e_1 - e^*$ is positive for greener firms ($g > \bar{g}$) and negative for less green firms ($g < \bar{g}$). This outcome highlights the complex impact of sustainable finance on emissions, which are dependent on a firm's environmental performance relative to the industry benchmark.

5 Data Insights on Greenness Distribution

5.1. Overview

5.1.1. Insights from theoretical modeling

In this chapter, we extend the theoretical insights from Chapter 4 into a practical, data-driven context. We empirically analyze the impact of sustainable finance on the effectiveness of optimal environmental regulation in actual industrial environments.

The theoretical model developed in Chapter 4 suggests that deviations in the firm's emissions levels from the optimal level (denoted as $e_1 - e^*$) are fundamentally influenced by the firm's greenness level (g) in relation to the industry benchmark ($\bar{g}$). This indicates that sustainable finance can significantly alter the effectiveness of optimal environmental regulation, depending on a firm's relative environmental performance.

For firms that are greener than the benchmark ($g > \bar{g}$), sustainable finance mechanisms provide economic benefits that, counter-intuitively, result in increased emissions. This outcome arises due to the combination of reduced production costs and higher market prices facilitated by sustainable finance and green consumerism, which together incentivize higher levels of production. Consequently, these greener firms end up emitting more despite their environmentally friendly practices.

Role of sustainable finance

Sustainable finance mechanisms wield a significant influence on firm-level production decisions, impacting both their firm input usage and emissions. This impact is especially noticeable among firms whose greenness levels significantly deviate from the industry benchmark (g compared to $\bar{g}$). These variations demonstrate how sustainable finance can drive differential responses in production and environmental strategies.

Distribution of greenness

The overall effectiveness of optimal environmental regulation under sustainable finance is tied to the spectrum of greenness levels within an industry. This range of environmental performance levels among firms plays a crucial role in determining the collective influence of sustainable finance on overall environmental impact.

5.1.2. Data analysis approach

This study's data analysis focuses on examining key financial and environmental metrics from a selected group of Korean companies. The data encompasses critical indicators such as revenue, cost of goods sold (CoGS), energy usage, and GHG emissions.

At the heart of this analysis is the evaluation of GHG intensity. We use this as a stand-in for the term $(1-g)$ in our theoretical model, where g symbolizes the corporate environmental performance, and $e=(1-g)z$ represents the emission intensity.

Our primary goal in scrutinizing GHG intensity across a swatch of Korea companies is to assess the overall impact of current environmental policies on industry-wide emissions. This is especially crucial for regulatory authorities tasked with understanding the environmental effects of existing regulations and sustainable finance initiatives.

This methodological approach allows us to bridge the gap between theory and practice. By applying the theoretical constructs of Chapter 4 to real-world data, we aim to explore the tangible effects of sustainable finance on corporate emissions. This empirical examination is vital not just for validating the theoretical framework but also for informing policy decisions in the realm of environmental regulation and sustainable finance.

5.2. Data description

The Korea Emissions Trading Scheme

The establishment of the Korea Emissions Trading Scheme (K-ETS) in 2015 signified a major step in South Korea's climate policy. This system holds the distinction of being the first comprehensive and obligatory ETS in East Asia. The K-ETS plays a crucial role in the management of approximately 74% of the country's GHG emissions, aligning with South Korea's ambitious goal of achieving carbon neutrality by 2050, as outlined in the "Carbon Neutral Framework Act" of 2021. The K-ETS encompasses a diverse range of sectors, including power generation, industrial manufacturing, buildings, waste management, transport, and domestic aviation, encompassing a total of 684 major GHG emitters. This system mandates a minimum auction of 10% of allowances and offers free allocation for Energy-Intensive, Trade-Exposed (EITE) sectors based on production costs and trade intensity benchmarks. In 2021, the scope of the scheme expanded to include domestic financial intermediaries and other third-party entities.[11]

The K-ETS sets specific criteria for inclusion, with companies emitting over 125,000 tCO2 annually and facilities with emissions exceeding 25,000 tCO2 per year falling within its purview. Furthermore, it takes into account indirect emissions resulting from electricity consumption using the same criteria. Preceded by the Target Management System (TMS), which targeted smaller entities not covered by the K-ETS, this emissions trading scheme emerged from the "Framework Act on Low Carbon, Green Growth" of 2010.[12]

Data sources and variables

The dataset for this study is compiled from two primary sources. The first source entails information on greenhouse gas emissions and energy usage. This data, which pertains to the year 2022, was made public by the National GHG Management System (NGMS). It encompasses detailed statistics on emissions and energy usage for a total of 244 factories and 469 companies operating under the K-ETS. From this extensive sample, our study opted to focus on 163 companies, representing 48 sectors.

The second source pertains to revenue information. Specifically, income statements for the aforementioned 163 companies were procured from the Data Analysis, Retrieval and Transfer System (DART), which is overseen by the Financial Supervisory Service of Korea (FSS).[13]

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11) ICAP (June 17, 2022), "Korea Emissions Trading Scheme", accessed on December 1, 2023.

12) Korean Law Information Center (April 4, 2010), "Framework Act on Low Carbon, Green Growth," accessed on December 1, 2023.

Table 3. Sectors represented in the selected company sample

Sector code	Sector name		Obs
S01	Primary Nonferrous Metal Manufacturing	NonFerrous	4
S02	Primary Steel Manufacturing	Steel	15
S03	Building Construction	Constr	1
S04	Rubber Product Manufacturing	Rubber	3
S05	Grain Processing and Starch Products Manufacturing	GrainProc	3
S06	Metal Foundry	Foundry	2
S07	Basic Pharmaceutical and Biologic Product Manufacturing	Pharma	0
S08	Basic Chemical Manufacturing	ChemBasic	16
S09	Other Metal Product Manufacturing	MetalProd	1
S10	Other Textile Product Manufacturing	Textile	1
S11	Other Food Manufacturing	FoodOther	4
S12	Other Chemical Product Manufacturing	ChemOther	2
S13	Wood Product Manufacturing	WoodProd	4
S14	Dairy and Edible Ice Product Manufacturing	Dairy	2
S15	Tobacco Manufacturing	Tobacco	1
S16	Road Freight Transport	RoadFreight	4
S17	Slaughtering, Meat Processing and Preservation	MeatProc	1
S18	Semiconductor Manufacturing	SemiCon	3
S19	Spinning and Processing Thread Manufacturing	Spinning	1
S20	Real Estate Rental and Leasing	RealEstate	1
S21	Fertilizer, Pesticide and Disinfectant Manufacturing	FertPest	1
S22	Non-Alcoholic Beverage and Ice Manufacturing	BevNonAlc	1
S23	Petroleum Refining	PetroRefine	1
S24	Ship and Boat Building	ShipBuild	4
S25	Cement, Lime, Plaster and Other Product Manufacturing	Cement	10
S26	Alcoholic Beverage Manufacturing	BevAlc	1
S27	Fuel Gas Manufacturing and Pipeline Supply	GasFuel	1
S28	Glass and Glass Product Manufacturing	Glass	4
S29	Amusement Park and Other Recreation Services	AmuseServ	1
S30	Land Passenger Transport	LandPass	1
S31	Pharmaceutical Manufacturing	PharmaMfg	1

13) FSS (n.d.), “DART”, accessed on December 10, 2023.

Table 3. (Continued)

Sector code	Sector name		Obs
S32	Primary Battery and Accumulator Manufacturing	Battery	5
S33	New Automotive Parts Manufacturing	AutoParts	6
S34	Automotive Engine and Vehicle Manufacturing	AutoMfg	3
S35	Electric Telecommunications	Telecom	2
S36	Electricity Business	Electricity	1
S37	Electric Motor, Generator, and Power Conversion Device Manufacturing	ElecEquip	1
S38	Electronic Component Manufacturing	ElecComp	7
S39	General Retail	Retail	4
S40	Steam, Cold/Hot Water and Air Conditioning Supply	HVAC	1
S41	Computer Programming, System Integration and Management	CompSys	1
S42	Special Purpose Machinery Manufacturing	SpecMach	1
S43	Pulp, Paper and Cardboard Manufacturing	Paper	14
S44	Waste Management	WasteMgmt	2
S45	Plastic Product Manufacturing	Plastic	3
S46	Synthetic Rubber and Plastic Material Manufacturing	SynthRubPlas	6
S47	Air Passenger Transport	AirPass	6
S48	Chemical Fiber Manufacturing	ChemFiber	5

Source: The author.

The data analysis in our study is based on a dataset that comprises a broad range of variables. These variables provide information about the companies that are being examined. The variables include the following:

- Company Identifier: This is a unique alphanumeric code that is assigned to each company for the purpose of identification.
- Sector Code: This code categorizes each company into its respective industry sector.
- Greenhouse Gas Emissions (GHG_tCO2): This metric represents the total greenhouse gas emissions of a company, measured in tons of CO2 equivalent. It plays a crucial role in assessing the environmental impact of the company.

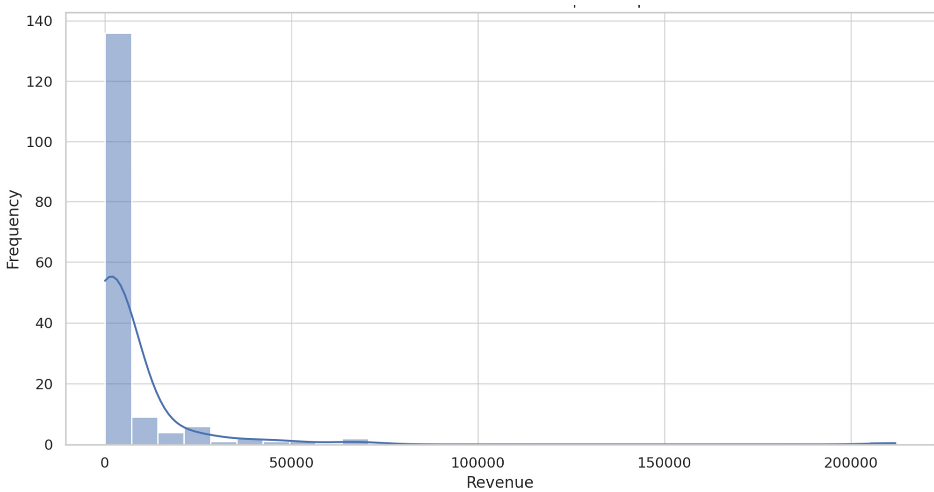
- Energy Usage (Energy_TJ): This variable indicates the total energy consumed by the company, measured in terajoules (TJ). Evaluating a company's operational efficiency and environmental footprint relies significantly on energy consumption.
- Revenue: The total revenue generated by the company during the reporting period is expressed in Billion Korean Won (KRW). This financial indicator helps in understanding the economic scale and performance of the company.
- Cost of Goods Sold (CoGS): This refers to the direct costs associated with the production of the goods sold by the company. The costs are reported in units of KRW 1 Billion. Assessing the production efficiency and profitability of the company heavily relies on this factor.
- SME Status: This variable indicates whether the company is classified as a Small and Medium-sized Enterprise (SME). Understanding the regulatory impacts of companies based on firm size and especially the impacts SMEs may face compared to larger corporations is crucial.

Table 4. Summary statistics for the variables

Variable	Obs	Mean	Std. dev.	Min	Max
Revenue	163	6460.97	19606.6	69.9047	211868
CoGS	163	5544.76	16185.7	11.8118	152589
GHG_tCO2	163	983948	2928718	429	28500741
Energy_TJ	163	12233.2	29834.7	6	222877
GHG_int	163	725.526	1780.88	0.74133	9990.89

Source: The author.

Figure 3. Revenue distribution of sample firms



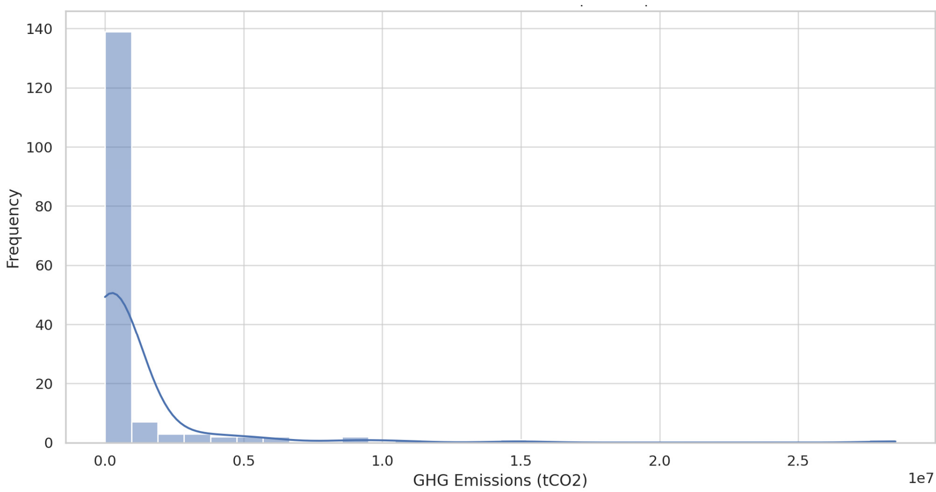
Note: Revenue in KRW 1 billion.
Source: The author.

Figure 3 illustrates the distribution of revenue among the companies included in the sample. It displays a pattern that is skewed to the right. This skewness suggests that the majority of the companies in the sample have reported lower revenues, while only a small number posted very high revenues.

The wide range covered by the x-axis, which represents revenue, draws attention to the significant differences in firm size within the dataset, which range from very small entities to much larger ones. The height of the bars in the graph represents the frequency of companies falling into specific revenue brackets.

The fact that the taller bars are concentrated towards the lower end of the revenue spectrum confirms that the majority of companies in this sample have lower revenues.

Figure 4. GHG emissions distribution of sample companies



Note: GHG emissions in tCO2.
Source: The author.

Figure 4 illustrates the distribution of GHG emissions among the sample. The graph displays a right-skewed shape, indicating that the majority of companies emit GHGs at lower levels. This pattern suggests a concentration of lower emissions levels among most of the companies, with a few outliers exhibiting notably elevated emissions.

The x-axis represents GHG emissions measured in metric tons of carbon dioxide (CO2), and the wide range of values demonstrates the diverse emission profiles within the dataset. This diversity may arise from variations in corporate sizes, operational scope, and industrial sector, all of which influence environmental impacts in different ways.

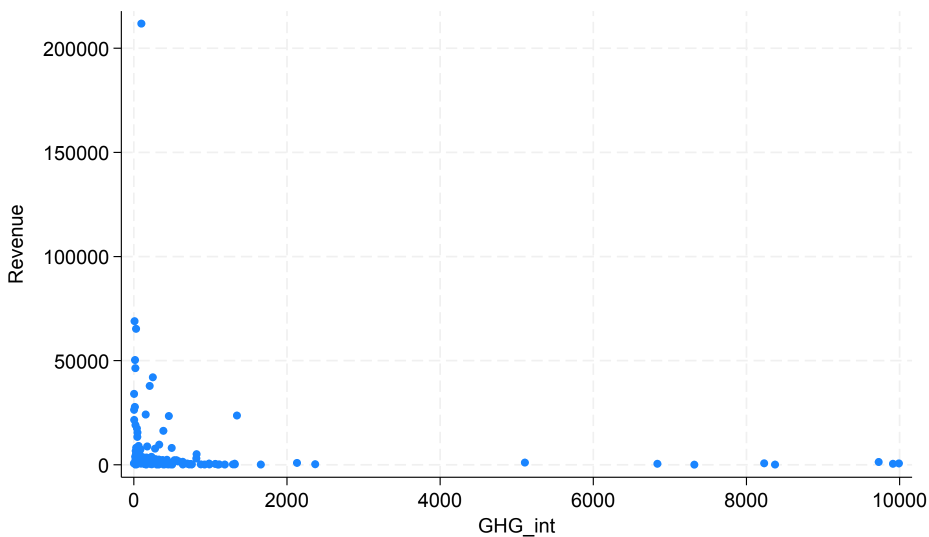
The distribution also implies the presence of emission-heavy industries, such as manufacturing or energy production in the sample. On the other hand, the service industry and other sectors with traditionally lower levels of emissions occupy to the lower end of the emissions range.

5.3. Results

GHG intensity distribution

Figure 5 displays the correlation between the revenue of companies and their GHG intensity, which is measured in tCO2 per KRW 1 billion. The scatter plot illustrates a clustering of data points towards the lower end of the GHG intensity scale, indicating that most companies emit fewer emissions per unit of revenue. The analysis suggests that emissions-intensive firms are not distributed uniformly throughout the sample.

Figure 5. Distribution of GHG intensity and its relationship to revenue



Note: Revenue in Billion KRW, GHG_int in tCO2/Billion KRW.
Source: The author.

Table 5. GHG intensity ($tCO2$/KRW 1 billion)

Sector code	Obs	Mean	Std. dev.	Min	Max
S01	4	169.74	226.77	15.69	500.24
S02	15	1315.29	2708.25	21.09	9913.32
S03	1	110.84		110.84	110.84
S04	3	323.65	325.15	104.95	697.29
S05	3	177.49	194.79	20.42	395.46
S06	2	1036.79	878.91	415.31	1658.28
S07	0	-	-	-	-
S08	16	252.82	281.82	17.52	819.12
S09	1	99.66		99.66	99.66
S10	1	432.24		432.24	432.24
S11	4	201.77	137.74	36.32	347.32
S12	2	283.25	298.99	71.83	494.66
S13	4	203	174.32	82.06	460.24
S14	2	393.48	54.39	355.02	431.94
S15	1	94.89		94.89	94.89
S16	4	410.58	590.25	78.58	1294.73
S17	1	453.18		453.18	453.18
S18	3	352.46	498.19	9.19	923.87
S19	1	75.35		75.35	75.35
S20	1	44.87		44.87	44.87
S21	1	492.09		492.09	492.09
S22	1	722.24		722.24	722.24
S23	1	101.9		101.9	101.9
S24	4	99.62	118.39	35.97	277.11
S25	10	996.88	2239.99	24.87	7319.46
S26	1	160.716		160.716	160.716
S27	1	3.58218		3.58218	3.58218
S28	4	237.706	219.045	4.07155	457.012
S29	1	441.768		441.768	441.768
S30	1	84.2559		84.2559	84.2559
S31	1	753.853		753.853	753.853
S32	5	244.626	159.856	59.2634	495.013
S33	6	799.427	883.385	20.8213	2368.27
S34	3	228.368	356.565	0.74133	639.298
S35	2	4883.58	6850.24	39.7361	9727.43
S36	1	6836.8		6836.8	6836.8
S37	1	421.842		421.842	421.842
S38	7	162.439	113.825	30.2322	325.556
S39	4	989.533	848.572	96.6723	2130.78
S40	1	375.603		375.603	375.603
S41	1	93.0427		93.0427	93.0427

Table 5. (Continued)

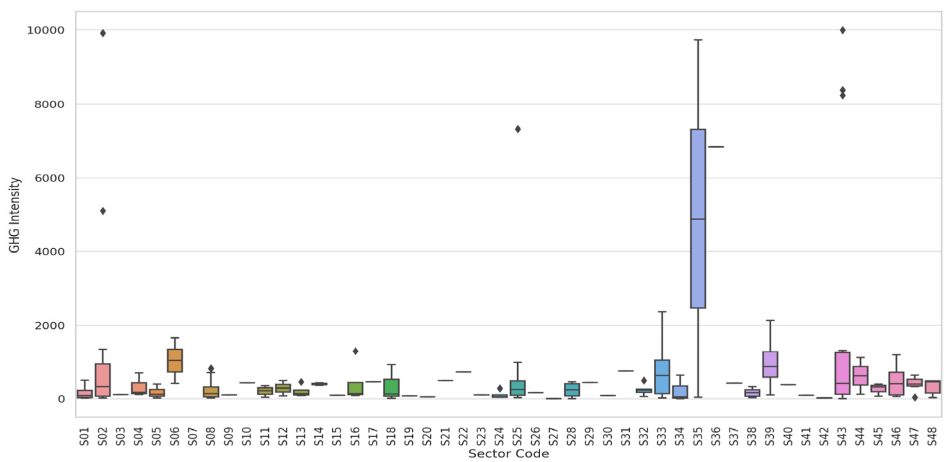
Sector code	Obs	Mean	Std. dev.	Min	Max
S42	1	19.6757		19.6757	19.6757
S43	14	2214.67	3644.56	3.75167	9990.89
S44	2	615.127	706.504	115.553	1114.7
S45	3	258.543	175.451	61.731	398.563
S46	6	477.5	449.167	51.2497	1187.35
S47	6	396.48	210.784	41.3507	638.973
S48	5	319.867	213.455	30.0877	480.035

Source: The author.

GHG intensity by sector

Figure 6 depicts GHG intensity across industrial sectors, each contained within its respective box. The line situated at the center of each box signifies the median GHG intensity, providing a snapshot of the central emission intensity within each sector. This organized arrangement enables a direct comparison, shedding light on sectors with elevated median GHG intensities—indicating higher emissions in relation to revenue—as well as sectors with more moderate emission intensities. The visualization effectively highlights the variation in emission efficiency among sectors, directing attention towards potential targets for policy-driven environmental enhancements.

Figure 6. GHG intensity by sector (GHG_int in tCO2/KRW 1 billion)

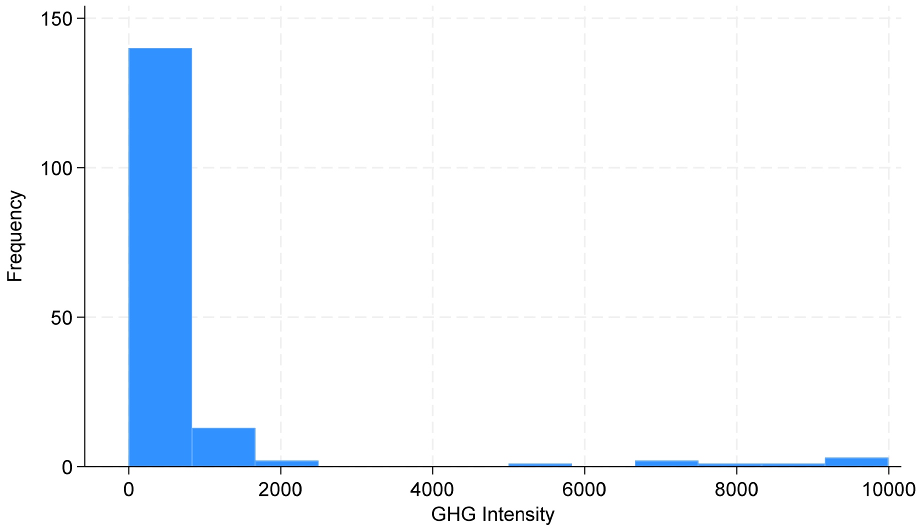


Source: The author.

Skewness in the GHG intensity distribution

The distribution of GHG intensities among the companies is highly skewed, indicating that a small number of firms contribute disproportionately to overall emissions. This skewness has implications for the effectiveness of sustainable finance mechanisms.

Figure 7. Distribution of GHG intensity across companies (tCO2/KRW 1 billion)



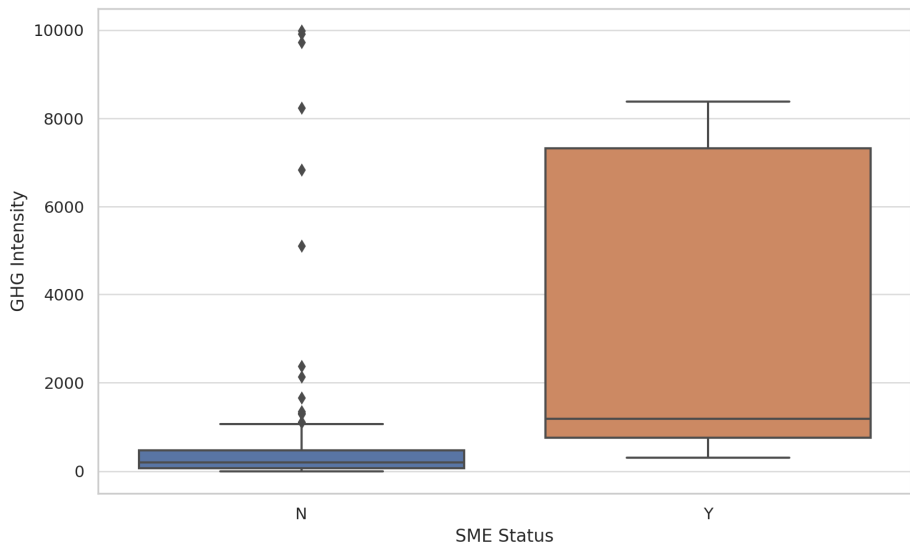
Note: GHG intensity in tCO2/ KRW 1 billion.
Source: The author.

SMEs and GHG intensity

The evaluation of GHG intensities reveals that SMEs, on average, have higher emissions per unit of output when compared to larger enterprises. This could be attributed to various factors such as less efficient technologies, smaller operational scale, and/or fewer resources to invest in emission reduction measures. This finding underscores the need for tailored policy measures that can help SMEs transition to greener operations.

The box plot delineates a clear divergence in GHG intensity between SMEs and their larger counterparts. SMEs demonstrate a more substantial spread in emissions intensity, as seen through a higher median and an extended interquartile range, indicating a higher average GHG intensity. This variation points to a heterogenous emissions profile among SMEs. Contributing factors may include limited access to state-of-the-art technologies, a lack of scale benefits, or insufficient capital for green investments. This disparity accentuates the importance of designing nuanced policy interventions that can effectively assist SMEs in enhancing their environmental performance and align SMEs' operations with broader sustainability objectives.

Figure 8. GHG intensity distribution by SME status



Note: GHG intensity in tCO2/Billion KRW.
Source: The author.

6 Conclusions

6.1. Summary of key findings

6.1.1. Theoretical

Ambiguity in the Impact of Sustainable Finance on Abatement

The influence of sustainable finance on emissions abatement is complex and can vary significantly based on a firm's environmental performance in relation to the sustainable finance benchmark ($\bar{g}$). Our analysis reveals the following key insights:

- For Greener Firms ($g > \bar{g}$): Sustainable finance, while incentivizing greener practices, paradoxically leads to an increase in emissions for firms that are already greener than the industry average. This is due to the way in which the financial incentives and lower costs of sustainable finance allow for higher levels of production and greater use of inputs. Put simply, for greener firms, sustainable finance mechanisms drive an expansion in output, resulting in increased emissions.
- For Less-Green Firms ($g < \bar{g}$): Conversely, firms that are less green than the benchmark tend to reduce their emissions under sustainable finance. This occurs as these firms face higher costs, leading to a decrease in production and, subsequently, reduced emissions. This effect reflects the economic pressures exerted by sustainable finance on less green firms, incentivizing them to reduce their emissions levels.

These findings underscore the need for carefully designed sustainable finance mechanisms that balance incentives and pressures to achieve the desired environmental outcomes. It highlights the importance of tailoring sustainable finance strategies to specific levels of environmental performance to ensure that intended abatement goals are met effectively.

Voluntary abatement in the absence of environmental regulation

Our analysis reveals that in the context of sustainable finance, a firm's voluntary abatement activities, quantified by $e_0 - e_1$, can be significant even in the absence of governmental intervention (i.e., when $\tau = 0$).

$$e_0 - e_1 = (1-g)\frac{\alpha(g-\bar{g}) + \theta\gamma(g-\bar{g})}{\theta^2 p'}$$

For Less-Green Firms ($g < \bar{g}$), both $\alpha(g-\bar{g})$ and $\theta\gamma(g-\bar{g})$ are negative. Given that p' is negative, the overall expression $e_0 - e_1$ becomes positive. This indicates that emissions under sustainable finance (e_1) are lower than emissions in the absence of sustainable finance (e_0) for these firms.

The positive value of $e_0 - e_1$ signifies a reduction in emissions for less-green firms under the influence of sustainable finance. This outcome is a consequence of the economic pressures and market mechanisms inherent in sustainable finance, which encourage emission reductions even without explicit regulatory mandates. It demonstrates that less green firms can indeed achieve emission reductions driven by market-based incentives and cost considerations.

Synergistic influence of α and γ in sustainable finance

There is a synergistic relationship between α and γ in the context of sustainable finance. A higher value of γ amplifies the impact of α on the firm's environmental decisions.

This interaction can be observed in the equation for e_1:

$$e_1 = (1-g)\frac{\omega - \alpha(g-\bar{g}) + \tau^*(1-g) - \theta p - \theta\gamma(g-\bar{g})}{\theta^2 p'}$$

In this equation, a higher value of γ (representing the market's preference for greener firms) amplifies the impact of α (the adjustment factor based on a firm's relative greenness).

The term $\theta\gamma(g-\bar{g})$ augments the influence of $\alpha(g-\bar{g})$ on the firm's cost structure and market positioning. Essentially, as γ increases, it not only directly affects the firm's revenue through market preference but also indirectly enhances the financial implications of the firm's greenness level as dictated by α.

This interplay between α and γ underscores the need for a strategic approach when designing sustainable finance mechanisms. The effective alignment of these parameters can significantly motivate firms to adopt greener practices by offering tangible financial benefits for improved environmental performance.

It is crucial for policymakers and financial institutions to consider both parameters in tandem when evaluating or implementing sustainable finance initiatives. The combined effect of α and γ can be a powerful tool in driving cross-sectoral environmental improvements.

The role of green consumerism

Our theoretical model demonstrates that the degree of voluntary abatement a firm undertakes is intrinsically linked to the green preference parameter, γ. Specifically, a higher γ value, indicative of a market that favors green products, is associated with a more larger decrease in emissions among firms that are greener than the market average, symbolized by $g > \bar{g}$. This reduction in emissions occurs independently of any regulatory or government-led initiatives.

This key theoretical insight underscores the influence of market dynamics, particularly consumer preferences, on the environmental outcomes of firms. It suggests that the market's increasing preference for sustainability can drive firms to reduce their emissions voluntarily, highlighting the critical role of consumer choices in steering corporate behavior towards greater environmental responsibility. This aspect of green consumerism serves as a powerful tool for achieving broader environmental goals, functioning alongside, or even in the absence of, formal regulatory mechanisms.

6.1.2. Data analysis

Sectoral Patterns of GHG Intensity

The data analysis indicates a heterogeneous distribution of emissions-intensive firms across industrial sectors. Notably, elevated GHG intensity is primarily clustered within a small subset of segments. This implies that targeted regulatory measures focused on these specific sectors could produce substantial reductions in overall emissions. Such findings underscore the potential efficiency of sector-specific environmental regulations in mitigating GHG emissions on a broader scale.

Skewness in GHG intensities across firms

The data analysis demonstrates a noticeable asymmetry in the distribution of GHG intensity among companies. We can observe in the analytical results that a small number of companies are responsible for a significant proportion of emissions. It is crucial that regulatory authorities considering adjustments to environmental regulations or building new sustainable finance strategies have an awareness of this imbalance. The results suggest that policies and financial measures aimed at high-emissions companies may establish lower benchmarks for less-polluting firms, potentially weakening incentives for such firms to pursue environmentally friendly innovation and transition to greener technologies or methods.

Disparities in GHG Intensity among SMEs

The data analysis reveals that SMEs are generally more GHG-intensive than larger firms. Several factors may contribute to this disparity, such as the use of less efficient technologies, smaller operational scale, and limited financial resources to invest in emission reduction strategies. This highlights another potential obstacle for SMEs as the global focus on sustainability intensifies. SMEs already face barriers to accessing finance, but it may prove even more difficult to them to secure funding in an environment in which sustainable finance is the dominant paradigm. This situation underscores the urgent need for financial mechanisms and policies specifically tailored to address the unique obstacles SMEs face in achieving sustainable operations.

6.2. Policy implications

Aligning environmental regulation with the impact of sustainable finance

The intersection of sustainable finance and environmental regulation is a dynamic landscape where the efficacy of regulatory measures is influenced by corporate financial incentives. As sustainable finance initiatives can influence corporate environmental strategies, it is essential for regulatory authorities to engage in vigilant oversight of these changes. This involves a detailed assessment of how firms adapt to the incentives provided by sustainable finance, especially in terms of their environmental performance relative to established benchmarks. It is crucial for regulators to understand the variations in environmental outcomes resulting from these adaptations. Furthermore, staying informed about sustainable finance trends among investors and financial institutions is imperative for predicting and guiding industry-wide environmental progress, ensuring that financial incentives align with desired environmental goals. This strategic alignment will facilitate the advancement of comprehensive and effective environmental regulations that are can respond to the evolving dynamics of sustainable finance.

Enhancing transparency in sustainable finance benchmarks

The role of the benchmark level of greenness, denoted as $\bar{g}$, is crucial in shaping the investment decisions and regulatory compliance of firms, which in turn drives environmental outcomes and the efficacy of environmental policies. As a core element of our theoretical framework, $\bar{g}$ functions as a sustainable finance benchmark, setting a reference point for assessing financial assets or investments against environmental, social, and governance (ESG) criteria.

It is imperative for the regulatory authorities to ensure that $\bar{g}$ is not only accurately determined but also transparently disclosed and communicated to relevant stakeholders. Such disclosure also benefits regulatory bodies as it facilitates the evaluation and adjustment of environmental regulations in accordance with environmental and sustainable development goals.

This study highlights the importance of implementing measures that necessitate relevant actors to disclose and effectively communicate sustainable finance benchmarks. By doing so, regulators and policymakers can better harmonize investment activities with broader sustainability objectives. Transparent benchmarks act as a catalyst for greener corporate behavior and more impactful environmental policy.

The EU's approach to sustainable finance benchmarks exemplifies a strategic alignment with its ambitious climate goals, including significant GHG emissions reduction and a transition towards a low-carbon economy. These benchmarks are grounded in robust scientific research, drawing from authoritative sources like the Intergovernmental Panel on Climate Change (IPCC) to ensure that their objectives are evidence-based and effective.

Table 6. The minimum requirements of the two EU Climate Benchmarks

	EU Climate Transition Benchmark (EU CTB)	EU Paris-Aligned Benchmark (EU PAB)
Risk-oriented minimum standards		
Carbon intensity reduction -> at inception (vs. parent index)	30%	50%
Scope 3 phase-in	2-4 years	2-4 years
Baseline exclusion	Yes (controversial weapons / societal norms violators)	
Activity exclusion	No	- Coal (1%+ revenues), - Oil (10% + revenues), - Natural gas (50% + revenues), - Electricity producers (50% + revenues)
Opportunity-oriented minimum standards		
Exposure to high impact sectors	Minimum exposure at least equal to parent benchmark value	
Year-on-year self-decarbonization	7%	7%
Disqualification from label	2 consecutive years of misalignment	

Source: EU (2019), p.17.

EU sustainable finance benchmarks are designed not just to measure performance but also to actively mitigate sustainability-related and climate transition risks. They are strategic tools that direct capital towards sustainable investments, facilitating the discovery and promotion of opportunities that contribute to the sustainability and climate goals of the region.

These benchmarks are distinguished by their integration of comprehensive Environmental, Social, and Governance (ESG) disclosure mandates. Such transparency is crucial for illuminating the impact of investment decisions on the transition to a sustainable economy. They serve as both a gauge and an impetus, motivating firms to elevate their ESG performance. For the investment community and financial analysts, these benchmarks provide a clear, consistent, and forward-looking framework to guide decision-making that is in line with long-term sustainability and climate resilience.

The EU's initiative is an instructive model, demonstrating the power of well-defined and scientifically backed benchmarks to steer both corporate behavior and investment practices towards a more sustainable future.

Table 7. EU minimum disclosure requirement: Equity benchmarks

Disclosures	Rationale for inclusion
Overall ESG	
- Average ESG rating (relative to securities covered by ESG research) - Overall ESG ratings of top ten index constituents by weighting in index - Total weighting of index constituents not meeting the principles of the UN Global Compact (conduct-related controversy screen)	Provide investors with further information about portfolio exposure to risks and opportunities not yet fully reflected in the market valuation. Controversy screening based on UN Global Compact is commonly applied in ESG ratings industry.
Environmental	
- Average Environmental rating of index (E component of ESG rating) (relative to securities covered by ESG research) - High emitting sector exposure (% of total weighting) - Carbon intensity - Reported vs estimated emissions (%)	Sector exposures provides visibility on climate-related transition and technology risks and opportunities captured by the benchmark portfolio.
- Portfolio exposure to green economy as measured by % of green revenues or Capex Exposure to climate-related physical risks	Carbon intensity associated with the index portfolio is commonly used by investors for their own reporting purposes.
Social	
- Average Social rating of index (S component of ESG rating) (relative to securities covered by ESG research) - Total weighting of index constituents in controversial weapon sector or tobacco - Controversial weapons definition - Tobacco % - Tobacco Definition - Number of companies in the index involved in social violations	Negative screening for controversial weapons and involvement in the tobacco industry is commonly applied by investors.
Governance	
- Governance rating of index (G component of ESG rating) (relative to securities covered by ESG research) - Average degree (%) of board independence - Average degree (%) of board diversity	Corporate governance KPIs are easily quantifiable and well understood by investors and reporting companies.

Source: EU TEG (2019), p.20.

Strengthening support for SMEs in transitioning to sustainability

The data analysis from our study provides some evidence that that Korean SMEs are generally more GHG-intensive than generally have higher GHG intensities compared to larger firms, suggesting that they may face unique to challenges in implementing making their operations more environmentally friendly operations.

Current environmental policies, particularly those focused on climate action, tend to concentrate on large-scale emitters, potentially overlooking the aggregate impact of SMEs. Considering the pervasive role of SMEs in the national economy and their cumulative environmental footprint, it is imperative that climate policy frameworks expand to inclusively address the needs of these smaller businesses.

To bridge this gap, there is a pressing need for the development and implementation of dedicated financial mechanisms and policy measures that cater specifically SMEs in helping them surmount the challenges of transitioning to a more environmentally sustainable business. Such measures should facilitate better access to (sustainable) finance, offer incentives for adopting sustainable practices, and provide guidance on effective environmental management.

Sector-specific strategies for harmonizing environmental regulation and sustainable finance

In advancing toward a sustainable industry, it is crucial for regulatory authorities to recognize the heterogeneous nature of environmental performance across different sectors. Traditional market-based policy instruments, such as uniform emission taxes, are designed to equate marginal abatement costs across all emitters, which will maximize economic efficiency. However, this approach may yield unexpected outcomes within the context of sustainable finance, where the primary goal is to foster a green transition across diverse industries. For regulatory frameworks to be truly effective, they should incorporate a sector-specific understanding that:

- Identifies sectors with varying levels of environmental impact and acknowledges the unique challenges and opportunities for emission reduction within each.
- Designs fiscal and regulatory incentives that are specifically targeted to encourage sustainable practices in higher-impact sectors.

- Facilitates the adoption of sustainable finance benchmarks that are sector-sensitive, thereby providing clear guidance for investment in green transitions.
- Ensures that compliance costs are equitable across sectors, avoiding disproportionate burdens on any single industry while maintaining a competitive market environment.
- Encourages innovation and the adoption of green technologies through tailored support and incentives, particularly in sectors that are traditionally resource-intensive.

6.3. Discussions

This study, while rigorous in its examination of the intersection between sustainable finance and environmental policy, acknowledges certain limitations. Future research following the line of inquiry pursued by this study could address these limitations.

Consideration of static greenness levels

In the theoretical framework of this report, the greenness level (g) of firms is treated as a static and exogenous factor. This assumption allows for a focused analysis of the immediate impact of sustainable finance and green consumerism on optimal emission levels under existing environmental policies. However, in reality, the greenness level of a firm is dynamic and can be enhanced through sustainable investments over time. Future studies could explore this dynamic aspect, examining how environmental policies interact with sustainable finance to influence firms' long-term investment decisions in sustainability. This could provide a more comprehensive view of how firms could adjust their environmental performance in response to policy and market forces.

Assumption of constant market demand

The model assumes that market demand remains constant even as consumers and financiers show a preference for greener firms. This theoretical setting implies that environmental regulations have not been updated to reflect the nuances of sustainable finance. The study maintains this stance to concentrate on the essential question of how environmental policies should be revised in light of how market participants value firms' environmental performance (g). Further research could relax this assumption to explore how changes in consumer preferences and the behavior of financial markets, influenced by sustainable finance, could alter market demand and in turn, affect environmental policy efficacy.

In conclusion, the discussions herein highlight critical areas where the current research could be expanded. These limitations offer fertile ground for subsequent inquiries to build upon the findings of this study, contributing to the development of environmental policies that are better attuned to the realities of sustainable finance and investment.

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Executive Summary in Korean

지속가능금융하에서 최적 환경규제

최적환경규제 이론은 환경 문제와 관련된 부정적 외부성을 내부화함으로써 경제적 효율성을 극대화하는 데 그 목적이 있다. 이 이론은 정보의 비대칭성, 기존 세금과의 상호작용, 기술변화, 준수 문제 등 다양한 현실 이슈를 반영하며 발전해 왔다. 본 연구는 지속가능금융의 개념을 환경규제 모델에 통합하여 전통적인 최적환경규제 이론의 유효성을 확장하고자 하였다. 지속가능금융하에서 투자자와 금융기관은 자산 관리 의사 결정에 지속 가능성과 관련된 위험을 고려한다. 이러한 변화는 기업에게 환경적 영향을 줄이도록 하는 추가적 동기를 부여한다.

이 연구는 이론적 모델을 통해 지속가능금융이 기업의 감축 활동에 미치는 영향과 이것이 최적환경규제에 미치는 영향을 분석한다. 또한 데이터 분석을 통해 실제 산업의 녹색성 분포를 살펴보고 환경정책의 유효성 측면에서의 함의를 고찰한다.

주요 연구 결과는 다음과 같다. 첫째, 지속가능금융은 기업의 추가적 감축 활동을 유인할 수 있다. 둘째, 이러한 영향은 지속가능금융 벤치마크와 기업의 녹색성 수준에 의존한다. 이러한 결과는 환경규제와 지속가능발전을 조화롭게 하는 데 있어 중요한 시사점을 제공한다.

주제어 : 최적환경규제, 지속가능금융, 지속가능금융 벤치마크, 지속가능발전, 기후변화

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Major Publications

- A Study on the Advancement of ESG Practices and the Enhancement of Environmental Regulation Efficiency in Korea (국내 ESG 고도화 및 환경규제 효율화 연구) (2023)
- Developing Policies to Promote ESG Information Disclosure for SMEs (중소기업 ESG 정보공개 지원정책 개발) (2022)
- Aligning Public Environmental Finance with Sustainable Development to Enhance Green Economy Transition (녹색경제 전환을 위한 지속가능한 환경재정 구축 방안) (2018)

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