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Integrating ESG Criteria in Supply Chains - Evaluating Responsibility Allocation and Its Impact on Supply Chain's Performance

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Abstract

Diese Masterarbeit untersucht die Verteilung von Verantwortlichkeiten für soziale und ökologische Investitionen zwischen einem Einzelhändler und einem Hersteller in einer zweistufigen Lieferkette. Mit einem spieltheoretischen Modell werden unterschiedliche Zuweisungen von Verantwortung unter zwei Vertragstypen verglichen: dem „Wholesale-Price"-Vertrag und dem „Two-Part Tariff"-Vertrag. Außerdem wird der Einfluss staatlicher Interventionen als weiteres Entscheidungselement betrachtet. Die Resultate verdeutlichen, dass sich sowohl die ökonomische als auch die nachhaltige Leistung durch geteilte Verantwortlichkeiten der Beteiligten in der Lieferkette erheblich verbessert. Vor allem werden die Resultate einer zentral geplanten Lieferkette durch die Verbindung gemeinsamer ESG-Verantwortlichkeiten mit einem „Two-Part Tariff"-Vertrag übertroffen. Die Ergebnisse zeigen, dass eine gleichzeitige Optimierung der nachhaltigen und wirtschaftlichen Leistung in Lieferketten möglich ist, vorausgesetzt, die ESG-Verantwortlichkeiten sind korrekt unter den Teilnehmern der Lieferketten verteilt. Die Arbeit unterstreicht die Bedeutung von Zusammenarbeit, geeigneten Vertragsmechanismen und sowie einer langfristigen Strategie zur Förderung von Nachhaltigkeit in Lieferketten.

Abstract

This thesis examines the allocation of responsibilities for environmental and social investments between a manufacturer and a retailer in a two-stage supply chain. Using a game-theoretic modeling approach, the study compares different responsibility structures under two types of contract: a wholesale-price contract and a two-part tariff contract. The analysis is further extended by including governmental intervention. The results demonstrate that shared responsibilities between supply chain partners result in superior economic and sustainable performance compared to individually assigned Environmental, Social and Governance (ESG) responsibilities. In particular, combining shared ESG responsibilities with a two-part tariff contract leads to outcomes that exceed those of the centralized benchmark scenario. Findings demonstrate that optimizing sustainable and economic performance in supply chains is not mutually exclusive, provided that ESG responsibilities are properly allocated between supply chain participants. The study emphasizes the importance of cooperation, proper contract design, and long-term strategic thinking in achieving sustainability goals in supply chains.

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Acronyms

3PL Third Party Logistics. 15, 20

CLSC Closed Loop Supply Chain. 15, 19, 20

CSR Corporate Social Responsibility. 5, 7, 10, 13, 14

CSRD Corporate Sustainability Reporting Directive. 12

ESG Environmental, Social and Governance. ii, vi, 1–8, 10–13, 18, 21, 22, 26, 28–31, 33–35, 37, 39, 47–49, 51, 58, 60, 64, 68–74, 132, 135, 136, 138

GSCM Green Supply Chain Management. 9, 14

LTT (Linear) Two-part tariff contract. vi, viii, 17, 25, 29, 32, 52–58, 60, 63–73

SSCM Sustainable Supply Chain Management. 3, 5, 8, 9, 11, 12, 14, 15, 17

TBL Triple Bottom Line. 5, 7, 8, 17, 21

WP Wholesale price contract. 17, 37–42, 45–48, 50–52, 55, 63, 66, 69, 71–73, 132, 135, 136, 138, 141

1. Introduction

1.1. Motivation

In recent years, sustainability has become an increasingly important focus for organizations around the world, driven by a growing awareness of Environmental, Social and Governance (ESG) factors. Companies play a critical role not only in driving economic performance, but also in influencing the wider social and environmental landscape. As Burritt and Schaltegger (2010, p. 96) note, "No sustainable development is possible without a sustainable development of corporations." Therefore, how businesses are managed plays a crucial role in shaping the future of both the economy and society.

The growing importance of ESG is influenced by several factors, such as changes in legislation, increasing pressure from investors, and the need to protect brand reputation. Regulatory requirements are pushing companies toward greater transparency in ESG reporting, while socially conscious investors are looking to align their financial decisions with their ethical values (Baid and Jayaraman, 2022). As a result, companies today are more focused on integrating sustainability into their supply chains while also maintaining economic profitability.

One of the main challenges is to strike a balance between sustainable practices and economic goals, especially given the complexities of modern supply chain networks. For example, Apple, one of the world's largest technology companies, works with over 785 suppliers in more than 30 countries (Apple Inc., 2024). This extensive network illustrates how difficult it can be for organizations to ensure ESG compliance throughout the entire supply chain. With products distributed to numerous retailers worldwide, it becomes challenging to monitor and enforce environmental and social standards across all partners.

In the past, supply chains have focused mainly on reducing costs, improving quality, and speeding up delivery times. However, as Baid and Jayaraman (2022) points out, modern supply chains must also consider issues such as child labor, human rights abuses, corruption, and environmental impacts. Addressing these challenges requires collaboration among all members of the supply chain, as they cannot be resolved by a single company alone.

In addition, investments in sustainable practices have grown significantly in the past few years. ESG-focused investment portfolios have become more popular, with investors increasingly looking to support companies that align with their social and environmental values. However, even though there are guidelines for ESG reporting, they are often vague and leave room for misinterpretation, which can enable practices such as greenwashing (Baid and Jayaraman, 2022).

Recent global events, such as the COVID-19 pandemic and the Russia-Ukraine conflict, have further motivated companies to reconsider their business strategies. These disruptions have revealed weaknesses in existing supply chains and emphasized the need for greater resilience (Ivanov, 2024). In addition, they have reinforced the idea that the integration of ESG factors into supply chain management is not just about compliance, but also about ensuring long-term success.

This thesis will explore how ESG aspects can be effectively integrated into supply chains. By examining the challenges and potential solutions, the objective is to provide insight into how organizations can better balance economic performance with their social and environmental responsibilities.

1.2. Research Design and Approach

Overview of Research Structure

This study is structured into five main sections:

1. Introduction: This section provides an overview of the current development in sustainability factors in general and their importance for supply chain management. It highlights the motivations behind the integration of the ESG issues, the challenges companies face, and outlines the objectives of the study.

2. Theoretical Background: This section reviews the existing literature on sustainability, supply chain management, and related concepts to establish a foundation for further analysis. It includes an examination of existing theoretical models that integrate ESG into supply chains, identifying key research findings and gaps.

3. Model Framework: The third section presents the selected theoretical baseline framework in detail. It outlines the model structure and the underlying optimization problem, including key assumptions and mathematical formulations. Furthermore, the section presents the extensions to the model, specifically explaining the adjustments made to the ESG responsibility allocation within the supply chain.

4. Results & Discussion: The fourth section presents the model results related to the economic and sustainable performance of the supply chain. These results are further illustrated using a numerical example. In addition, the section analyzes and compares relevant scenarios in relation to the research questions, assessing the implications of ESG responsibility allocation for supply chain performance from both economic and sustainability perspectives.

5. Conclusion: The final section summarizes the key findings of the study, discusses its limitations, and provides recommendations for future research in this field.

Formulation of Research Questions

The following research questions underlie the study presented here:

1) How can companies effectively integrate two dimensions of ESG criteria into their supply chain operations while still operating profitability?

2) How does the allocation of ESG responsibilities, in particular shared responsibilities between manufacturers and retailers, impact the overall sustainability and utility of the supply chain?

3) What role do coordination mechanisms between manufacturers and retailers play in improving the sustainability and utility of supply chains?

4) How do governmental policies influence the integration of ESG criteria in supply chains and what is their impact on the economic performance and sustainability outcomes of these supply chains?

1.3. Structure of Theoretical Background

This section establishes the academic foundation of the thesis by reviewing key literature on sustainability, ESG criteria, and supply chain management. Due to the breadth of research in this field, the scope is limited to the accounting literature and adjacent subfields relevant to supply chain coordination and ESG integration. The first part introduces theoretical concepts of sustainability, which outline different ESG criteria and their growing importance in business decision-making. It then links these concepts to supply chain management, with particular attention to the principles and challenges of Sustainable Supply Chain Management (SSCM). This includes a review of organizational drivers, such as regulatory compliance and reputational concerns, as well as barriers such as cost pressures and complexity in global supply networks. The final part of the review focuses on existing mathematical models that integrate ESG aspects into supply chain decision-making. The emphasis is placed on game theory and equilibrium-based models, which offer structured approaches for analyzing the strategic behavior of supply chain participants in both decentralized and centralized settings. Game-theoretic models are particularly effective in addressing coordination and competitive dynamics among supply chain members. Moreover, there has been a significant increase in the use of game-theoretic models over the past decade, reflecting their growing relevance in this field (Agi et al., 2021). The insights from the literature form the basis for the conceptual framework used in this thesis. The framework investigates how different responsibility allocations for ESG investments, especially when shared between manufacturers and retailers, impact supply chain performance under two different contractual settings, with and without governmental intervention.

1.4. Structure of Analytical Approach

The selection process of the baseline model framework is based on the following steps.

1. Definition of exclusion criteria for model selection
2. Classification of eligible theoretical models
3. Selection and justification of baseline model framework

4. Analysis and extension of selected model framework

Definition of Exclusion Criteria

In the initial phase of model selection, exclusion criteria were applied as follows:

1) Elimination of Implicit Solutions: Models relying on implicit solutions were disqualified as the dependent variable cannot be separated.

2) Exclusion of Mathematical Programming Models: Computational models employing mathematical programming were omitted from consideration due to the scope of this thesis, which focuses on accessible and easily replicable models.

3) Exclusion of Models Lacking Mathematical Proofs: Models lacking substantial mathematical proofs that hindered their comprehensibility and reproducibility were also eliminated.

4) Ensuring Journal Quality: Models published in journals with a ranking of the *Verband der Hochschullehrer für Betriebswirtschaft e.V.* less than C were disregarded. Only journals with A or B rankings were taken into account to ensure a specific level of quality.

Classification of Existing Models

Taking into account the above mentioned exclusion factors, I identified 27 models which were classified in the next step according to specified criteria such as ESG dimension and parameters, decision variables, supply chain structure, channel structure, competition and coordination(Appendix F). I narrowed the selection down to three theoretical models, all focusing on different aspects of a sustainable supply chain.

Selection and Justification of Theoretical Framework

In the selection phase, the focus was placed on identifying models that explicitly integrate ESG criteria. Hence, it was important to select a model that incorporates multiple ESG criteria rather than focusing on a single aspect. Furthermore, the selection process prioritized models that primarily addressed the integration of ESG issues within the supply chain, such as those that primarily examined pricing strategies in a green supply chain. Furthermore, models with nonquantifiable measurements of ESG were excluded, as they lack objectively measurable targets. Lastly, the selected models were required to consider both, non-cooperative (decentralized) and cooperative (centralized) game scenarios, to facilitate meaningful comparative analysis.

2. Theoretical Background on ESG Issues in Supply Chains

2.1. Foundations of Sustainability

According to Burritt and Schaltegger (2014), a prevailing subjective interpretation of the scope and meaning of terms in the field of sustainability, accounting, and supply chain represents a challenge in research. Hence, a proper definition of relevant terms is required before addressing the topic of SSCM.

2.1.1. Defining Sustainability

Sustainable Development was first introduced in the report 'Our Common Future' from the World Commission on Environment and Development and defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development, 1987, p. 41). This definition is often cited in academic literature (Seuring and Müller, 2008). Since then, in the course of developing sustainable business strategies and measurements, different concepts were introduced, i.e. Triple Bottom Line (TBL), Corporate Social Responsibility (CSR) and ESG. Although these inter-correlating approaches share the goal of an ethical and responsible business practice, they are based on different perspectives on sustainability.

2.1.2. Environment, Social, Governance

The term ESG was first used in the report 'Who cares wins: Connecting the Financial Markets to a Changing World' following an initiative of the United Nation Secretary General and United Nation Global Compact in 2004 in collaboration with the Swiss government. The aim was to improve the integration of ESG factors in capital allocation and portfolio management processes. It states that 'a better inclusion of ESG factors in investment decisions will ultimately contribute to more stable and predictable markets, which is in the interest of all market actors' (United Nations, 2004, p. 19). ESG is a three-pronged framework describing the non-financial outcomes of an organization (Baid and Jayaraman, 2022). Thereby, [E] represents the environmental dimension, [S] represents the social dimension and [G] represents governance. The term ESG is mainly used in the political and legal context.

Environment

The environmental dimension includes factors such as water and waste management or environmentally friendly products, especially with regard to the risks of climate change (United Nations, 2004). In general, environmental aspects are by far the most discussed dimension of ESG, not only among academics but practitioners (Seuring and Müller, 2008). It has become of great importance in the last decade due to the increasing concern for climate change and the reduction of carbon emissions (Lee and Wu, 2014, Burritt and Tingey-Holyoak, 2012).

Social

According to Baid and Jayaraman (2022) the social dimension includes six factors:

(1) Health and well-being
(2) Ethical business practices
(3) Economic equality
(4) Equal opportunity
(5) Human rights and labor standards
(6) Law and regulations

While the environmental dimension is included in almost every sustainability strategy, the social dimension is not always taken into account (Seuring and Müller, 2008). Seuring and Müller (2008) conducted an extensive literature review on papers analyzing environmental and social issues and revealed that the majority (73%) addresses environmental issues compared to 10% considering the social dimension and 16% focussing on both, environmental and social aspects. They identified a key gap in current research, in which sustainable development is frequently limited to environmental performance and the social dimension receives considerably less attention. O'Connor and Labowitz (2017) revealed that most organizations that integrated the social dimension in their framework, only measure the efforts and initiatives, but not the social outcome. This business practice has several reasons (Baid and Jayaraman, 2022):

(1) complexity of the supply chains with sustainability adding complexity
(2) challenge to quantify the social impact
(3) missing motivation of businesses
(4) lack of transparency in social performance of sub-tier suppliers

Possible methodologies to measure social impact are e.g., the cost-benefit analysis, the social return on investment or the well-being valuation (Baid and Jayaraman, 2022).

Governance

According to the report by the United Nations (2004), governance factors refer to corporate governance issues such as board structure and accountability, as well as accounting and disclosure practices. Integrating the governance dimension is thereby seen specifically relevant with regard to enabling environmental and social measurements. Especially

ESG disclosure has become an increasing awareness in recent years (Tsang et al., 2023). Whereas the environmental and social dimensions are both explicitly addressed in the concept of TBL, the third dimension of ESG - governance - is typically only considered indirectly, primarily in relation to the achievement of economic objectives, and is often not mentioned as a distinct factor. A review of the existing literature reveals that governance is rarely examined in depth within the context of sustainable supply chains (Benjamin et al., 2020). The specification of governance and its role in sustainability has only recently gained attention with the growing relevance of the ESG framework. As noted by Benjamin et al. (2020), their study represents one of the first attempts to systematically analyze the relationship between corporate governance variables and sustainable supply chain responsibility. Nguyen and Zuidwijk (2025) point out that supply chain governance still lacks a unified theory, which is attributed to limited research on supply chain collaboration and the lack of well-established supply chain governance practices.

2.1.3. Corporate Social Responsibility

The concept of CSR is traced back to Howard Bowen (1953) (Bowen, 2013), who considered social responsibilities of an organization as an obligation to the society aligning with the concept of a social contract. Due to the lack of standardized criteria and the broad scope of the field, there is no clear definition of CSR in the literature. Dahlsrud (2008) compared 37 different definitions of CSR. They revealed that all definitions are similar in providing a description of a phenomenon. However, the challenge is that none of the definitions offers a framework or guidelines on how to integrate it into business practices. Generally, the definitions consider five different dimensions: stakeholder dimension, social dimension, economic dimension, voluntariness dimension and environmental dimension. Overall, the environmental dimension gets less attention than the other dimensions (Dahlsrud, 2008). However, the key difference between CSR and ESG lies in the aspect of voluntariness. While ESG is based on a framework and linked to legal regulations, the concept of CSR is grounded on ethical values and voluntary actions which are not prescribed by law (Dahlsrud, 2008, Seuring, 2013).

2.1.4. Triple Bottom Line

Whereas originally, the integration of environmental and social criteria was perceived as constraints when maximizing economic objective (Vasileiou and Morris, 2006), the TBL theory is based on a simultaneous consideration of the company, its customers and the environment (Elkington, 1994). The TBL approach relates to three dimensions (1) economic (2) environment (3) stakeholder and society, also referred to as 'profit, planet, people' (Baid and Jayaraman, 2022). The idea of TBL was introduced by Elkington (2002) who stated that the purely financial measurement of a company's performance in terms of profit does not capture the whole value of a firm.

Whereas ESG and CSR focus primarily on sustainability aspects, the concept of TBL takes an economically approach by integrating sustainable factors in an organization's economic performance. This approach is similar to the definition of sustainability of

Seuring and Müller (2008). According to them, sustainability encompasses the inclusion of environmental and social aspects within organizational activities, alongside their integration with traditional economic performance. In fact, multiple researchers refer to the three dimensions of sustainability as environment, social and economic instead of governance as included in the ESG framework (Sinayi and Rasti-Barzoki, 2018, Seuring, 2013).

2.2. Sustainable Supply Chain Management

2.2.1. Supply Chain Management

Supply chains are defined as 'a set of primarily collaborative activities and relationships that link companies in the value-creation process to provide the final customer with the appropriate value mix of products and/or services' (Braziotis et al., 2013, p. 648). Consequently, they differ from supply networks, which consist of a broader and flexible network with active and potential partners (Braziotis et al., 2013). Whereas the definition of a supply chain is uncontroversial, the term of supply chain management is used differently (Mentzer et al., 2001). Mentzer et al. (2001) distinguish between three levels of supply chain complexity. The direct supply chain involves only the core participants: the supplier, the organization, and the customer. The extended supply chain expands this view to include the supplier's supplier and the customer's customer. Finally, the ultimate supply chain encompasses all entities involved in the process, from the initial supplier to the final customer. Customers are thereby also considered as supply chain members. It's important to understand that an organization can be part of multiple supply chains. According to Mentzer et al. (2001, p. 18)

> [...] supply chain management is defined as the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.

According to Handfield and Nichols (1999, p.2), 'supply chain management is the integration of supply chain activities (=associated with the flow and transformation of goods from the raw material stage to the end user) through improved supply chain relationships to achieve a sustainable competitive advantage'.

2.2.2. Concepts of Sustainable Supply Chain Management

The core idea of SSCM is described as to ensure the long-term viability and continuity of a business, as well as to contribute to the future well-being of society (Christopher, 2011, Klassen and Vereecke, 2012). In academic literature, SSCM is often defined as the integration of environmental, social, and economic performance aligning with the concept of TBL (Seuring and Müller, 2008). While SSCM addresses sustainable criteria in supply chains, Green Supply Chain Management (GSCM) focuses only on environmental aspects of sustainability (Xu et al., 2017).

Risk- and Opportunity-related Approach

Schaltegger and Burritt (2014) describe SSCM, as an organizational challenge that requires defined measurements to verify the sustainability of products and services. They define two different approaches managing the SSCM, the risk- and the opportunity-related approach. Whereas the risk-related approach focuses on reducing negative aspects, the opportunity-related approach focuses on creating value. While risk-based management focuses on criteria and rules for required actions, and thus on measurement and compliance issues, opportunity-based management focuses on potential improvements and desired actions, and thus aims to drive innovation. Risk minimization, in particular, plays an important role in supplier evaluation and has gained attention with increasing global sourcing and the associated enhanced complexity of a supply chain. Addressing or evaluating supplier irresponsibility represents a significant risk that organizations must manage (Reuter et al., 2010).

Sustainable Business Strategies

There are three basic SSCM strategies defined in literature. The efficiency strategy aims at creating economic value while reducing the negative social and environmental impacts (von Weizsacker et al., 2009). Related goals concentrate on less waste and less resource consumption during all phases of a supply chain, such as recycling and down-cycling (e.g. closed-loop supply chains). The consistency-based strategy focuses on the substitution of unsustainable materials with natural and harmless materials. This is measured in form of biodegradability of a product or use of renewable energy. The third strategy, the sufficiency-approach, focuses on the reduction or elimination in the process of production or consumption, such as reducing product parts. Although a combination of these three principles complicate the performance measurements, (Schaltegger et al., 2012), it is advised for an optimal all-encompassing SSCM, as these strategies are mostly complimentary instead of exclusive (Schaltegger and Burritt, 2014).
Overall, there are several definitions around SSCMs, which share a common idea. Beske and Seuring (2014) identify five categories of SSCM: orientation, continuity, collaboration, risk management and proactivity. Basically, these categories align with the other approaches with the exception of collaboration, which however is generally considered a key requirement for successful SSCM. In literature, the primary responsibility of SSCM is often attributed to the focal company as illustrated in Figure 2.1 , which is regarded as the most powerful entity within the supply chain. According to Seuring and Müller (2008), the focal company is subject to external pressures and incentives from government, customers, and other stakeholders. When the focal company integrates sustainable practices, it typically requires corresponding efforts from its suppliers (Gimenez and Tachizawa, 2012). Hence, these pressures are often transferred downstream to the company's suppliers. To manage this, two complementary strategies are identified. The first strategy, *supplier evaluation for risks and performance*, focuses on ensuring supplier sustainability through

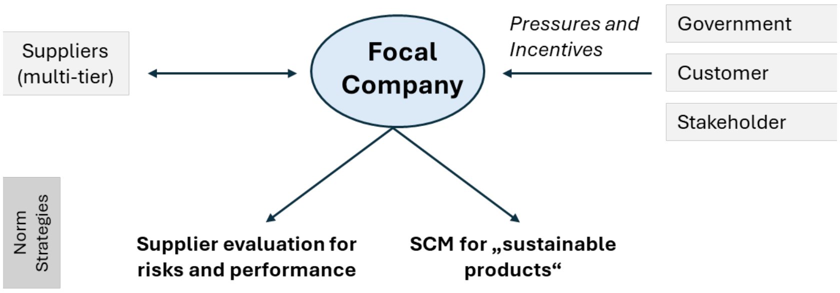


Figure 2.1.: Triggers for Sustainable Supply Chain Management
Source: Own Illustration After Seuring and Müller (2008)

mechanisms such as management systems and supplier audits. The second strategy *SCM for sustainable products* refers to the adoption of products that contribute to environmental and social performance, thereby enhancing competitive advantage and meeting customer expectations (Seuring and Müller, 2008).

2.3. Integrating ESG in Supply Chains

2.3.1. Motivations of Integrating ESG Issues in Supply Chains

Lee and Wu (2014) revealed that combining environmental and economic performance indicators in a unified system allows companies to make more sustainable logistics decisions. With rising internal and external pressure, addressing ESG issues becomes essential for an organization. Internally this includes meeting the expectation of different managerial functions, such as marketing, production. Externally, organizations face pressure from public media, stakeholders, political entities and occasionally market forces. This pressure generates opportunities and/or minimizes risks when it comes to reputation, competitive advantage, political influence and market positioning (Burritt and Schaltegger, 2010).

The Link Between Economic and Sustainable Performance

Generally, studies reveal a positive relationship between CSR performance and future firm value, whereby certain CSR categories, such as e.g., environment and employee have a stronger impact on firm's future value and sustainable performance in form of '[...] competitive advantage, increased brand value and decreased social and environmental risk' (Benjamin et al., 2020, p. 3332). Tsang et al. (2021) revealed that incorporating CSR into executive compensation policies has a positive effect on firm innovation. In addition, previous studies demonstrated that customers not only are more likely to purchase responsible goods and services, but are even willing to pay a higher price for them (Frey et al., 2023). Carter and Rogers (2008) showed that the time is important with regards to sustainable supplier management. Hence, the earlier an organization starts to assess their suppliers on CSR issues, the higher the availability to develop sustainability-related capabilities providing a competitive advantage. Additionally, once

SSCM is implemented, the foundation is set, which may be expanded to include further issues of social and environmental evaluation. Delaying the implementation of SSCM puts organizations at a competitive disadvantage as it improves operational performance in cost, product quality and supply chain security (Carter and Rogers, 2008).

The Concept of Social Responsibility

A significant motivation for companies to integrate ESG principles that has been widely researched is their perceived social responsibility. This idea of responsibility forms the foundation of various theoretical concepts. Legitimacy theory assumes that an organization's economic survival depends on society (Deegan, 2002). Consequently, organizations have an obligation to invest in social and environmental issues to benefit society, as they do not possess unlimited rights to exploit resources. According to legitimacy theory, the disclosure of non-financial information is primarily driven by societal pressure, as organizations rely on societal approval, or a "license to operate", to maintain their legitimacy and continue their operations (Deegan, 2002). This concept was first introduced by Mathews (1993, p.26) under the term 'social contract' (Mathews, 1993). However, the original ideas of a 'social contract' extend back to philosophers like John Locke (1632-1704) or Jean Jacques Rousseau (1712-1778) as stated by Deegan (2002).

Shocker and Sethi (1973, p. 97) provided an application of the concept of social contract within accounting research by stating:

> Any social institution - and business is no exception - operates in society via a social contract, expressed or implied, whereby its survival and growth are based on: 1) the delivery of some socially desirable ends to society in general, and 2) the distribution of economic, social, or political benefits to groups from which it derives its power.

In a dynamic societal context, institutions must continually demonstrate both their legitimacy and relevance by ensuring that their services remain necessary and that the benefits they provide are aligned with societal approval (Shocker and Sethi, 1973). Consequently, whenever the company violates this social contract, its legitimacy is at risk, potentially leading to societal withdrawal of support, such as declining demand for the organization's products (Deegan, 2002).

This key principle of the legitimacy theory overlaps with the foundations of the stakeholder theory. Although these two theories differ in their focus, legitimacy theory emphasizes ethical responsibility to society as a whole, and stakeholder theory adopts a strategic approach, focusing on meeting the expectations of specific stakeholder groups. According to Deegan (2002) they are interrelated and should not be viewed separately. But on which foundation does society or stakeholder groups legitimate an organization's business practice? Organizational activities only impact society's perspective when corresponding information are published highlighting the importance of corporate disclosure (Deegan, 2002).

Compliance with Regulations

When researching external regulations with regards to ESG disclosure, one has to differentiate between the disclosure of the activities of an organization and the disclosure of an organization's supply chain. Whereas voluntary supply chain disclosure has received increasing attention, in both academic and industry literature, little research has focused on supply chain disclosure (Bayne et al., 2022). In 2021, the European Union introduced its first Climate Law, setting legally binding targets aimed at achieving climate neutrality by 2050. Furthermore, the EU recently implemented a series of ESG regulations. The *Sustainable Finance Disclosure Regulation*, which came into force in March 2021, requires financial market participants within the EU to adopt standardized sustainability reporting frameworks. This regulation seeks to improve transparency on how ESG risks are integrated into investment decision-making processes. The *Corporate Sustainability Reporting Directive*, effective from January 2023, broadens sustainability reporting obligations for both EU and non-EU companies, improving the consistency and comparability of disclosed sustainability information. Furthermore, the Corporate Sustainability Due Diligence Directive requires companies to take responsibility for identifying, preventing, and managing negative sustainability impacts throughout their operations and across the entire value chain. Simultaneously, the EU Taxonomy offers a structured definition of environmentally sustainable activities, encouraging a shift toward more sustainable and environmentally aligned investments. From January 2024, companies are required to report on their alignment with the taxonomy's objectives, and from 2025 on, financial institutions must include taxonomy alignment in their non-financial statements, in accordance with Corporate Sustainability Reporting Directive (CSRD) requirements (Directorate-General for Communication, 2024). With constantly new regulations, policies, standards regarding factors on the way, awareness is growing and it is essential for organizations to put effort into initiatives that focus on the integration of ESG factors. According to Serafeim (2020) organizations should treat ESG activities not as a necessary compliance measurement, but more as a strategical investment decision. However, organizations thereby face multiple challenges (Baid and Jayaraman, 2022).

2.3.2. Challenges of Integrating ESG Issues in Supply Chains

Complexity Issues

With the rise of outsourcing over the past decades as response to a cost-focused strategy, supply chain management has taken on a key role in ensuring the sustainability of an organization's product or service. Western companies thereby increasingly source from global suppliers in emerging markets, contributing to the complexity of the supply chain (Reuter et al., 2010). The complexity of the supply chain spanning multiple countries and levels between many suppliers poses a major challenge in integrating issues of ESG (Baid and Jayaraman, 2022; Reuter et al., 2010). This involves ensuring that international suppliers comply with corporate codes of conduct and preventing environmental or social violence (Reuter et al., 2010). In addition to the long geographical distances, cultural and political differences further complicate SSCM (Beske et al., 2008). Addressing sustainable issues thus requires the collaboration of the entire supply chain network instead of individual organizations (Distelhorst and Shin, 2023; Vasileiou and Morris, 2006). However, due to complexity issues, sustainability efforts have typically focused on specific stages within the chain rather than addressing the entire supply chain as a whole (Vasileiou and Morris, 2006).

Knowledge Issues

Previous years showed that measuring sustainability in business practice is a challenging task for managers and accounting researchers due to knowledge problems (Burritt and Tingey-Holyoak, 2012), methodological differences and limitations (Lee, 2012), and lack of applicable tools and understanding (Burritt and Schaltegger, 2010; Lee and Farzipoor Saen, 2012). Organizations often lack the knowledge to effectively design and processes that ensure the sustainable management of their suppliers (Carter and Rogers, 2008). Burritt and Tingey-Holyoak (2012) traced back the knowledge issues to the gap between research and practice of embedded carbon sustainability accounting. They identified increased collaboration between academics and practitioners as a solution to bridge this gap and enable cleaner production.

Lack of Standards - Accounting and Reporting

Although many crucial factors are not directly included in the balance sheet of a company, they are of great importance not at least because of the growing interest in sustainability of investors (Baid and Jayaraman, 2022). Therefore, it is necessary to adopt accounting for the changing environment in the course of globalization, particularly integrating sustainable issues in supply chain management (Burritt and Schaltegger, 2014). Whereas the disclosure of financial information follows strict and well-structured rules that go back a long way, the disclosure of non-financial information and thus ESG is still at the very beginning with the lack of uniform standards (Baid and Jayaraman, 2022). Researchers point out that current disclosure regulations do not yet address the sustainable activities of a company throughout the supply chain, but focus only on an individual entity (Distelhorst and Shin, 2023). According to Baid and Jayaraman (2022) to advance an objective ESG measurement, it is crucial to establish a robust, transparent, and standardized approach to social measurement and reporting that ensures consistency and comparability. Reichelstein (2024) proposes a system for creating a balance sheet and flow statements to track carbon emissions. The goal is to measure and report carbon footprints and assess past, current, and future performance in carbon emissions.

Investment Costs - Transition and Proprietary Costs

Ensuring a balance between sustainability, service quality and economic performance is considered the main challenge of organizations (Lee and Farzipoor Saen, 2012). Ryou et al. (2022) found a relationship between the voluntary disclosure of CSR activities and the intensity of product market competition. According to researchers, companies in highly competitive fields consider CSR reporting not only to reduce the information asymmetry between them and their investors but to see it as the sharing of sensitive information with stakeholders and, therefore, competitors. Ryou et al. (2022, p. 1222) state

> [...] decisions of managers regarding whether and how to report CSR information are likely to involve a trade-off between the benefits of informing market participants, such as customers and investors, and the proprietary costs of informing existing and potential rivals in a competitive environment.

Thus, managers allocate resources differently with increasing competition (investment in advertising instead of reporting activities). Consequently, the study indicates that proprietary costs determine the voluntary reporting intentions of a company's non-financial activities (Ryou et al., 2022).

2.4. Theoretical Models Integrating ESG in Supply Chains

In general, there exists a vast amount of literature about theoretical models analysing GSCM, which has grown significantly over the past 15 years (Chauhan and Singh, 2018). Along with the growing body of literature in this area, several theoretical reviews of models have been published (Seuring, 2013; Chauhan and Singh, 2018; Agi and Hazir, 2019, Agi et al., 2021; De Giovanni and Zaccour, 2022). Seuring (2013) distinguishes between four different categories of quantitative models in SSCM: Life-cycle assessment, equilibrium models, multiple criteria decision making and analytical network models. Notably, the application of equilibrium models solved by a game-theoretic approach has seen significant growth in recent years. Given the substantial number of theoretical models and the intensified research focus in recent years, this study specifically focuses on equilibrium models for the review of theoretical frameworks.

2.4.1. Game-Theoretic equilibrium Models in SSCM

By far the most widely applied solution method of equilibrium models is the game-theoretic approach, which is especially used when analyzing supply chain coordination and competition dynamics. Since 2011, game-theoretic models have been increasingly used to analyze coordination dynamics in SSCM as noted by Agi et al. (2021). Game theory seeks to mathematically and logically determine the optimal actions for achieving the best outcome among all possible choices available to players (Jamali and Rasti-Barzoki, 2018). In addition to classical game-theory methods, which distinguish between cooperative and non-cooperative games (Agi et al., 2021), evolutionary games, mathematical programming models or hybrid models were applied.

One major limitation of classic game theory is the assumption that all players act rationally and that perfect information exists, which is in contrast to real-world situations. In comparison, evolutionary games are based on irrationality, knowledge of the game and sharing of information (Barari et al., 2012). Mathematical programming or hybrid models have the advantage to address more complex supply chain problems. Hsueh (2015) applied a bi-level programming model with a sensitivity analysis for variational inequalities to investigate CSR collaboration in a supply chain and determining the optimal CSR performance levels for each supply chain participant. Fallahpour et al.

(2017) developed a hybrid model with fuzzy preference programming that integrates inconsistency, uncertainty and calculation complexity into their model.

Classic Game-Theory

Conventional game-theory analyses cooperative or non-cooperative games. In a cooperative game, also referred to as centralized scenario, the supply chain members are integrated (Jamali and Rasti-Barzoki, 2018). They act as one unit, collaboratively making decisions with the shared objective of optimizing the performance of the supply chain (Sinayi and Rasti-Barzoki, 2018). Overall, the literature agrees that a cooperation between supply chain participants always leads to a higher supply chain performance in terms of economic, environmental and social aspects making a coordination between supply chain members essential in SSCM (Sinayi and Rasti-Barzoki, 2018; Jamali and Rasti-Barzoki, 2018). In a non-cooperative game, also referred to as decentralized scenario, the supply chain participants act independently and aim to maximize their own performance (Sinayi and Rasti-Barzoki, 2018). Usually, a Stackelberg game is applied, which is characterized by the leader-follower principle. The leader chooses their action first, and the follower makes their decision based on the leader's action. Although there are models that present the Stackelberg game with both the manufacturer as the leader and the retailer as the follower and vice versa, the latter one is rarely used (Jamali and Rasti-Barzoki, 2018). However, some studies also investigated different power structures, e.g., with a Third Party Logistics (3PL) as the leader (Jamali and Rasti-Barzoki, 2019). When a third player is introduced in a two-level supply chain, one distinguishes between two followers, the first and the second (Jamali and Rasti-Barzoki, 2019). As the cooperative scenario is uncontested defined in the literature as the ideal scenario that yields the maximum supply chain performance, previous studies concentrated on how to achieve coordination in a decentralized scenario.

2.4.2. Supply Chain Structure and Strategic Decisions

Supply Chain Characteristics

When analyzing supply chain structures of existing models, one generally distinguishes between a two-level and a three-level supply chain. As the terms imply, a two-level supply chain consists of two channel players, e.g., a manufacturer or supplier and a retailer, while a three-level supply chain involves three channel players. In addition to the manufacturer and retailer, the third player can be the government or a third-party intermediary, creating an indirect channel structure (Jamali and Rasti-Barzoki, 2019). The 3PL may distribute the product from manufacturer to the retailer or collect the end-of-use product from the customer. However, most researchers analyze a two-level supply chain with the manufacturer and the retailer as game players (Jamali and Rasti-Barzoki, 2018; Sinayi and Rasti-Barzoki, 2018). Some studies also consider multiple supply chain members, such as two manufacturers or two suppliers to analyze competitive strategies (Jamali and Rasti-Barzoki, 2019). In the field of SSCM a distinction is made between forward supply chains, which focus on the downstream flow of products towards the end customer, and Closed Loop Supply Chain (CLSC), which incorporate reverse logistics to manage the upstream flow of returned products, thus integrating both forward and reverse processes within a traditional supply chain (Savaskan et al., 2004). Generally, studies analyze both, a centralized scenario and a decentralized scenario, to compare the outcomes. A few studies also consider hybrid scenarios with one supply chain being cooperative and one supply chain being non-cooperative (X. Li and Li, 2016). The majority of models assume endless inventory and complete information between the supply chain members. However, there are also scholars considering financial constraints (Xing et al., 2019) or sustainable constraints (Ding et al., 2016). Moreover, supply chain structures with asymmetric information between supply chain members are examined (Yun et al., 2023; P. Li et al., 2021). Yun et al. (2023) specifically analyzed the impact of asymmetric information combined with contract design in a supply chain consisting of one supplier and two retailers (an incumbent and an entrant). They found that, even under asymmetric information, two-part tariff contracts are typically more beneficial to the entire supply chain, enhancing coordination and sustainability. However, a franchise contract, which includes a two-part tariff contract with an additional revenue-sharing component, benefits the incumbent retailer in high demand variation scenarios.

Competition

Although, the majority of green supply chain models are based on a monopolistic scenario, competition is a realistic factor to include in the analysis. In general, a differentiation in competition between supply chain members of the same supply chain, also referred to as intra-supply chain competition, and competition between multiple supply chains, also referred to as inter-supply chain competition, is made. In most cases, competition exists between multiple manufacturers (Jamali and Rasti-Barzoki, 2019; P. Du et al., 2020; Y. J. Chen and Sheu, 2009) or retailers (P. Li et al., 2021; Ghosh et al., 2021; Savaskan and Van Wassenhove, 2006). Usually, only two competing supply chain members are considered. In addition to two competing supply chains (X. Li and Li, 2016; Sheu, 2011; Sheu and Chen, 2012), there is also competition in distribution channels and the production. Jamali and Rasti-Barzoki (2018) considered both competitive dynamics, intra- and inter-supply chain competition. In this case, there is a Nash competition between both retailers as well as between both manufacturers. Additionally, in each supply chain a Stackelberg competition between the manufacturer and the retailer takes place. While for one manufacturer the decision variable is e.g. the price and green degree of the product, for the other manufacturer only the price of the non-green product is the decision variable. The researchers revealed that a centralized scenario leads to a higher supply chain profit and a higher green degree of products. Additionally, the green degree increases with increases in the wholesale price. Jamali and Rasti-Barzoki (2019) showed that competition between supply chain members leads to higher profitability and an acceptable level of sustainability. However, their model achieved the lowest product greenness in a centralized scenario which contradicts the results of a monopolistic scenario.

Types of Contracts

As literature overall agrees that cooperative games generate the optimal results, many studies focused on strategies to yield coordination between supply chain players in a non-cooperative scenario. Generally, there are the following categories of contracts:

1) **Wholesale price contract (WP)**
2) **Cost-sharing contract**
3) **Revenue-sharing contract**
4) **(Linear) Two-part tariff contract (LTT)**
5) **Other: Shapely value, Shared-savings**

In comparison to the other contracts, WP is not a coordination or collaboration contract and does not achieve coordination. However, it is listed here for the sake of completeness, enabling a direct comparison to coordination contracts. The wholesale price contract generally finds great application in the literature (Chauhan and Singh, 2018). It is a simple contract based on a price charged by the manufacturer to the retailer and forms the basic form of pricing contract (Xu et al., 2017).

In the field of SSCM almost all studies include the economic performance in their models aligning with the TBL approach developed by Elkington (2002). Previous studies analyzed different pricing strategies, such as consistent vs. inconsistent wholesale and retail price (P. Li et al., 2021) as well as payment strategies integrating the financial stability/liquidity of the retailer (Ghosh et al., 2021). P. Li et al. (2021) thereby found out that the pricing strategy has an impact on the supply chain member's profit, but not on the green degree of product.

Most models assume that the manufacturer incurs the entire cost of green investments in a product, which can lead to the risk of non-participation, as the retailer often benefits more than the manufacturer or customer. To mitigate this imbalance, a revenue-sharing contract or cost-sharing contract is introduced. A revenue- or cost sharing contract are considered typical coordination contracts in supply chain management (Sheu, 2011). In a cost-sharing contract the costs associated with the green investment are shared between the manufacturer and other supply chain participants, typically the retailer. In a revenue-sharing contract the manufacturer charges a percentage of the retailer's revenue in addition to the wholesale price. The specific percentage is determined by the bargaining power of each supply chain member (S. Du et al., 2015). Studies show that a revenue sharing contract not only improves sustainability of the supply chain but also individual profits of supply chain members and the total profit of the supply chain (Hsueh, 2014; Song and Gao, 2018). Linh and Hong (2009) demonstrate in their model that the introduction of a revenue-sharing contract can achieve channel coordination between the wholesaler and the retailer in a two-period newsboy setting.

Generally, a two-part tariff contract consists of a combination of a fixed and a variable fee that the retailer pays to the manufacturer. The fixed component, often referred to as the franchise fee, is independent of any green investments made by the manufacturer and is always applied. In contrast, the variable component is tied to the manufacturer's green efforts or the resulting level of sustainability of the product. The research findings, derived from the models presented by Sinayi and Rasti-Barzoki (2018), P. Li et al. (2021), and X. Chen et al. (2017), indicate that, in a decentralized supply chain scenario, a two-part tariff contract can achieve supply chain profits equivalent to those in a centralized scenario.

In addition, hybrid model frameworks (e.g. combination of a revenue-sharing contract and two-part tariff contract) are applied.

2.4.3. Integration of ESG Issues

Table 2.1 illustrates which ESG criteria are incorporated into supply chains in existing theoretical models. It is thereby notable, that most models predominantly integrate the environmental dimension. This insight aligns with previous results showing an overall focus on environmental issues in literature. Researchers thereby state the surge of environmental issues in politics and public interest in general as their primary motivation for their studies (Barari et al., 2012). Although the current definition of ESG includes "governance" as the third dimension, which is primarily aimed at corporate management, many researchers refer to three dimensions in terms of environmental, social and economic as defined by Carter and Rogers (2008). The economic dimension thereby refers to the profit of the supply chain members as well as the supply chain itself. It is based on the pricing in the supply chains, i.e. the wholesale price which is charged by the manufacturer to retailer and the retail price which is charged by the retailer to the customer. When reviewing the integration of ESG dimensions, it is crucial to note that most models by far integrate mainly the environmental dimension as a decision variable of the model as well as the economic parameters such as price. The social aspect often only forms a component of the profit function and is not subject to any optimization (Sheu, 2011; Jamali and Rasti-Barzoki, 2018).

Environment	Social	Governance
green vs. brown product	consumer surplus	ESG reporting/disclosure
green degree of product	customer satisfaction	supplier selection
carbon emissions	delivery time	
recycling/remanufacturing		
energy savings		
green transportation		

Table 2.1.: Overview of ESG Integration in Existing Theoretical Models

Environmental Issues

The by far most applied environmental criterion in literature is the consideration of a green product, which is characterized by a high green-degree. Researchers thereby either compare the green product with a traditional non-green, so called brown, product (Jamali and Rasti-Barzoki, 2018) or just consider one product assessing the green-degree determined by a green coefficient. Whereas models that aim for a high green degree of a product determine the green coefficient as decision variable (Jamali and Rasti-Barzoki, 2018; Sinayi and Rasti-Barzoki, 2018), models with two substitutable products analyze the amount of green vs. brown products sold. The degree of greenness of the product can therefore be interpreted as a general greening of a product relating to different environmental factors such as the reduction of carbon emissions or green technology investment (P. Du et al., 2020). However, some studies explicitly investigated the reduction of carbon emissions in combination with cap and trade, where firms can incur costs from purchasing emission permits or carbon credits if their emissions exceed their cap (S. Du et al., 2015). The majority assumes a green-sensitive demand function, meaning customers are willing to pay a price premium for a green product or have a low-carbon preference (S. Du et al., 2015). Most researchers assume a deterministic linear demand function (Agi et al., 2021), such as an increase in demand with an increase in the green degree of a product (Jamali and Rasti-Barzoki, 2018). However, some also consider random versions of demand (L. Zhang et al., 2015) or apply a fuzzy theory to simulate a non-linear demand. Agi and Yan (2020) distinguish between two market segments: one segment with customers who value the lower carbon emissions and the other segment representing customers who do not value the environmental impact of a product and consequently are not willing to pay a higher price for the green product. Analogous to the demand function, most scholars assume a linear cost function for the green degree of a product (Jamali and Rasti-Barzoki, 2018). The green costs for a product therefore do not influence the traditional costs, but a member of the supply chain (often the manufacturer) must make additional investments to achieve the green degree of a product (Sinayi and Rasti-Barzoki, 2018). The green product or green degree of a product is thereby mostly based on a quadratic cost function. The consideration of remanufacturing or recycling of a product as part of the environmental dimension is summarized under the term CLSC. Generally, in CLSC the return rate is considered an environmental variable. The more end-of-use products that have been collected, the better the environmental performance. (De Giovanni and Zaccour, 2014). Sheu and Chen (2012) define green sustainability as a green product composed of both a virgin and a recycled component.

Closed-Loop-Supply Chains

CLSC models address the complete life cycle of a product and often consider a third party who is responsible for collecting the used product from the customer and transferring it back to the manufacturer who is able to remanufacture the product. As shown in Figure 2.2 there are four different models of closed-loop supply chains in the literature. Three are based on a direct collection and one on an indirect collection of the product. In Model C, the retailer collects the end-of-use product from the customer and recycles it. In Model M, the customer returns the end-of-use product directly to the manufacturer, who re-manufactures it. In Model R, the customer returns the product to the retailer, who then forwards it to the manufacturer. Finally, in Model 3P, a third party is involved, collecting the used product from the customer and delivering it directly to the manufacturer. Huang and Wang (2017) also consider hybrid remanufacturing of a product, where two parties,

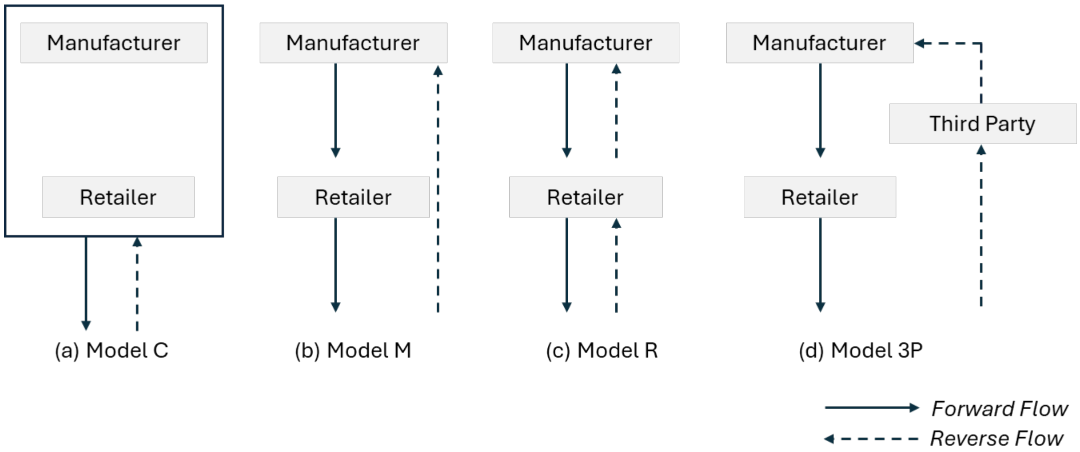


Figure 2.2.: Model Overview of Closed Loop Supply Chains; Source: Own Illustration after Savaskan et al. (2004)

such as the manufacturer and a third party, are involved in the remanufacturing process.

The literature reveals different results on the impact of the selected collector on the economic and environmental performance of CLSC in different scenarios. De Giovanni and Zaccour (2014) found that outsourcing the recycling/product collection should be considered as an option only when the third party performs better operationally and environmentally compared to the manufacturer. When the manufacturer faces higher collection costs or lower effectiveness of the green activity program, an outsourcee should take care of collection. In comparison, Savaskan et al. (2004) revealed that the retailer should always collect the end-of-use product and that the collection through a 3PL is not at all economically advisable. However, in contrast to De Giovanni and Zaccour (2014) they assumed the collection cost to be independent of the chosen collector.

Social Issues

Only a few studies integrate both, social and environmental issues, in supply chains (Sinayi and Rasti-Barzoki, 2018). In most cases the consumer surplus is considered as the social dimension (Sinayi and Rasti-Barzoki, 2018), which is defined as an indicator of social welfare. Consumer surplus is thereby defined as 'the difference between the total amount that customers are willing and able to pay for a good or service and the total amount that they actually pay' (Sinayi and Rasti-Barzoki, 2018, p. 1445). Sheu (2011) incorporated social welfare into their model as the government's utility function. However, unlike the model proposed by Sinayi and Rasti-Barzoki (2018), they do not consider social investment opportunities for supply chain participants. In addition, some researchers also assess the delivery time with respect to customer satisfaction (Jamali and Rasti-Barzoki, 2019).

Governance Issues

Overall, the governance perspective is hardly mentioned in previous studies. Although not explicitly stated by the researchers, a study conducted by Fallahpour et al. (2017) analyzing the process of selecting sustainable suppliers can be classified under the governance dimension, as it relates to corporate management practices. In their study, they provide an extensive criteria catalog for a successful sustainable supplier selection. They decide between three different main areas - economic, environmental and social - which align with the known concept of sustainability TBL. Economics aspects are further subdivided into costs, delivery, service and flexibility. Environmental aspects are broken down into environmental management system, green product, green warehousing, eco-design, green transportation and green technology. Social aspects consist of worker's right, health and safety at work as well as supporting activities (e.g., anti-discrimination, wages, religious/cultural issues at work). This paper is considered one of the first that analyzes the social aspects of supplier selection Fallahpour et al., 2017.

Furthermore, there is a growing body of literature on ESG disclosure and supplier rating. However, theoretical models that examine its impact within supply chains are still relatively rare. For example, Sardanelli et al. (2022) developed an integrated model that rates supply chains based on both financial and sustainability criteria. Their goal is to offer a practical framework for evaluating the performance of upstream and downstream partners of small and medium sized enterprises.

The Role of Governmental Intervention

The government may act as a channel member, and thereby, as a supply chain player, or as an outside player. The integration of governmental policies distinguishes between taxes or subsidies (Sinayi and Rasti-Barzoki, 2018, Sheu, 2011), cap-and-trade policy (L. Zhang et al., 2015), as well as reporting/disclosure regulations. Sinayi and Rasti-Barzoki (2018) highlight the differences between imposing a tax and a subsidy. When the government imposes a tax on the product's price, customer demand decreases, leading to a decline in the overall profit of the supply chain. However, the reduction in profits for supply chain members is greater than the additional revenue earned by the government, resulting in what is known as dead weight loss. Conversely, when the government provides a subsidy on the product's price, the profits of supply chain members exceed the cost of the subsidy provided by the government. Most theoretical models thereby compare scenarios with and without governmental intervention and assess the impact on the objective function. Sinayi and Rasti-Barzoki (2018) show that different governmental policies have significant impacts on the profit of the supply chain member as well on the green degree of a product. Furthermore, they found out incorporating a fraction of consumer surplus into the government's utility function has a more significant impact on the profits of supply chain members and the product's green degree than factoring in environmental concerns. Jamali and Rasti-Barzoki (2018) revealed that if the manufacturer is unable to reduce its cost-coefficient of the green degree, increasing public awareness is necessary to encourage people to buy green products. Therefore, the researchers emphasize the importance of the government, who has the power to influence the buyer's behavior by establishing regulations. S. Zhang et al. (2019) found that under cap-and-trade regulation, social welfare is maximized when the government sets a moderate carbon trading price and encourages manufacturers to adopt green technologies, particularly in supply chains with imbalanced power structures. Additionally, the government should aim to increase consumers' preference for low-carbon products, as this positively influences social welfare.

2.4.4. Limitations and Gaps in Current Models

The limited number of studies addressing the disclosure of non-financial information across entire supply chains, coupled with the significant challenges companies face in integrating ESG principles due to the complexity of supply chain networks, highlights the need for further research in this area. One major limitation of existing studies is the challenge of capturing the complexity of today's global supply chain structures. Most research only considers two or three supply chain participants, even though, in reality, usually numerous players are involved. Another gap is represented by the prevailing integration of environmental aspects compared to the other two dimensions. The social dimension is mostly considered from a customer's perspective, not considering worker's rights, such as wages or discrimination. However, the necessity to integrate the social dimension more often is already emphasized by previous studies (Hsueh, 2015). Furthermore, the governance dimension received little awareness in the current body of literature. There are only a few publications analyzing governance criteria (Fallahpour et al., 2017).

3. Model Framework

3.1. Development of Theoretical Model Framework

The following chapter gives an overview of the theoretical baseline model and applied model adjustments. All calculations were performed with Wolfram Mathematica 13.3 software. As already stated in section 1.4 this thesis adopts the model 'A game-theoretic approach to pricing, greening, and social welfare policies in a supply chain with government intervention' published by Sinayi and Rasti-Barzoki (2018) as the base model for the analysis. In the following part the model of Sinayi and Rasti-Barzoki (2018) will first be described in more detail. Later on in section 3.2 the application of this model in this thesis will be presented.

3.1.1. Model Structure and Characteristics

Sinayi and Rasti-Barzoki (2018) analyzed the integration of the environmental (*green degree of product*) and social (*social welfare as consumer surplus*) dimension in one supply chain. The researchers thereby focused on the impact of a coordination contract, i.e., a two-part tariff contract, between the two supply chain members and the impact of governmental intervention (*tax/subsidies on the green degree of product*) on the sustainable and economic performance of the supply chain. The researchers stated that their model is the first to integrate the three major dimensions of sustainability (economic, environment, social) at both, the supply chain and government level. Furthermore, their approach to define consumer surplus based on price and green level is presented as a novel contribution to the existing literature. The model analyses a two-level supply chain structure with one manufacturer and one retailer. In the scenario with governmental intervention, the model was based on a three-level structure with the government as the third member of the supply chain. Overall, the researchers presented a total of six different scenarios, thereof three with and three without governmental intervention. The six different scenarios are described as follows:

1) Decentralized Scenario
2) Decentralized Scenario with Two-Part Tariff
3) Centralized Scenario
4) Decentralized Scenario with Governmental Intervention
5) Decentralized Scenario with Governmental Intervention and Two-Part Tariff

6) Centralized Scenario with Governmental Intervention

Variable	Description	Type of Variable
α	market potential for the green product	parameter
β	customer price sensitivity	parameter
c	unit production cost of the manufacturer	parameter
η	cost coefficient of the green degree per unit	parameter
$\gamma_1, \gamma_2, \gamma_3$	coefficients of the government utility function for different government policies	parameter
λ	demand expansion effectiveness coefficient of the green degree per unit of green product	parameter
μ_1	fraction of consumer surplus that is the socially responsible manufacturer's concern	parameter
μ_2	fraction of consumer surplus that is the socially responsible government's concern	parameter
p	retail price charged by retailer to customer	decision variable
w	wholesale price charged by manufacturer to retailer	decision variable
θ	green degree of the product	decision variable
F	lump sump fee charged by manufacturer to retailer	decision variable
τ	government tax/subsidy	decision variable
V_M	utility function of manufacturer	dependent variable
π_R	profit function of retailer	dependent variable
π_M	profit function of manufacturer	dependent variable
π_{SC}	profit function of supply chain	dependent variable
V_{SC}	utility function of supply chain	dependent variable
V_G	utility function of government	dependent variable

Table 3.1.: Notations of the Mathematical Model

The model is classified as an equilibrium model using a game-theoretic approach. The main goal was to find the optimal equilibrium between the economic and sustainable performance of the supply chain.

Figure 3.1.: Own Illustration After Sinayi and Rasti-Barzoki (2018)

Figure 3.1 shows the structure of the supply chain. Sinayi and Rasti-Barzoki (2018) distinguish between the centralized and decentralized models. In the centralized model, the members of the supply chain act as a unit and jointly determine the retail price (p) and the green degree of the product (θ), resulting in a single-step game. In the decentralized model, two different contract designs are investigated: the wholesale price contract, where the manufacturer charges the retailer a wholesale price (w), and the two-part tariff contract, where the manufacturer charges the retailer a franchise fee (F) in addition to w. For both models, the impact of governmental intervention is analyzed, with the government imposing a tax/subsidy (τ) on top of the retail price (p). The decentralized non-cooperative scenario is solved using a Stackelberg game, where the manufacturer acts as the leader. Backward induction was used to achieve the equilibrium of this game. This process consists of the following steps:

1) The retailer determines the optimal retail price p by maximizing their profit function.

2) In case of a LTT contract, the retailer determines the optimal franchise fee by maximizing their profit function while considering the optimal retail price as calculated in Step 1.

3) The manufacturer considers the optimal retail price (and franchise fee in case of a LTT contract) determined by the retailer (as calculated in Step 1 and 2) in the manufacturer's utility function and determines the optimal wholesale price and green degree of the product by maximizing w and θ of the manufacturer's utility function simultaneously.

4) In case of governmental intervention, the government determines the optimal amount of taxes / subsidies taking into account p, w, θ (and F in case of a LTT contract) as calculated in Step 1 to 3 by maximizing τ of their profit function.

The model assumes a linear demand function with green customers, who have a preference for a green product and consequently are willing to pay more for a green product. The demand function is linear in the retail price and the green degree of the product. This assumption is aligned with previous models (X. Chen et al., 2017; Huang and Wang, 2017; S. Du et al., 2017; S. Du et al., 2015).

$$\text{Demand}(p, \theta) = \alpha + \theta\lambda - \beta p \tag{3.1}$$

Accordingly, demand is driven by the market potential for the green product (α) and positively influenced by the product's green degree (θ), weighted by the green sensitivity coefficient. Conversely, the retail price (p), in combination with the customer's price sensitivity (β), affects demand negatively. In the governmental scenario, the demand function is adjusted by the tax/subsidy on the green product (τ):

$$\text{Demand}(p, \tau, \theta) = \alpha + \theta\lambda - \beta(p + \tau) \tag{3.2}$$

3.1.2. The Integration of ESG Issues

Integrating Environmental Issues

The environmental dimension is represented by the green degree of a product with a quadratic cost function which is a common assumption in literature (Ghosh et al., 2021; P. Du et al., 2020; Jamali and Rasti-Barzoki, 2018; X. Li and Li, 2016). The costs for the green product are based on the green degree of the product (θ) and the cost coefficient of the green degree per unit (η).

$$\text{Cost}(\theta) := \frac{\eta\theta^2}{2} \tag{3.3}$$

Integrating Social Issues

The social dimension is represented by the consumer surplus, which is the difference between the customer's willingness to pay for the product and its actual price. A smaller difference results in a higher consumer surplus and in a higher social performance. This definition of consumer surplus is commonly used as a measurement of economic benefit in the literature (Biswas et al., 2018; Sheu and Chen, 2012). Mathematically, the consumer surplus is based on the integration of the retail price into the demand function. The lower bound is represented by the market price and the upper bound is represented by the maximum price the customer is willing to pay. As the consumer surplus depends on the applicable demand function, a different consumer surplus is achieved in the scenario with governmental intervention.

Consumer Surplus without Governmental Intervention:

$$\mu \text{CS} = \frac{\mu(\alpha + \theta\lambda - \beta p)^2}{2\beta} \tag{3.4}$$

Consumer Surplus with Governmental Intervention:

$$\mu \text{CS}_G = \frac{\mu(\alpha + \theta\lambda - \beta(p + \tau))^2}{2\beta} \tag{3.5}$$

The consumer surplus differs only with the inclusion of the tax/subsidy combined with the price sensitivity factor which may lead to a reduction in the green market base. The fraction of consumer surplus (μ) is a parameter which varies between 0 and 1. With regards to ESG it can be interpreted as the willingness of a company to invest in social activities, which may include work labor conditions or customer satisfaction.

3.1.3. The Integration of Economic Performance Measures

The economic performance of the whole supply chain is measured by the sum of the utility of each supply chain member. The utility function is based on the pure profit and if applicable, the utility derived from the consumer surplus. The utility that supply chain participants derive from investing in social activities and thereby considering a higher fraction of consumer surplus, can be linked to the motivations for ESG integration outlined in subsection 2.3.1. In particular, these investments can function as strategic marketing efforts to enhance brand reputation and attract greater investor interest. The profit function of manufacturer in the decentralized model is defined as follows:

$$\pi_M = (w - c)\text{Demand}(p, \theta) \tag{3.6}$$

Accordingly, the manufacturer's profit is determined by the product of demand and the wholesale price (w) paid by the retailer, minus the production costs (c) per unit, also multiplied by demand.

The profit function of the retailer in the decentralized model is defined as follows:

$$\pi_R = (p - w)\text{Demand}(p, \theta) \tag{3.7}$$

Accordingly, the retailer's profit function is determined by the product of demand and the retail price (p) paid by the customer, minus the wholesale price (w), also multiplied by demand.

When the manufacturer as supply chain participant is responsible for green investments, the utility function in the decentralized model is adjusted by the costs for the green product:

$$\pi_M = (w - c)\text{Demand}(p, \theta) - \frac{\eta\theta^2}{2} \tag{3.8}$$

When the manufacturer as supply chain participant has social concerns, the utility function in the decentralized model is adjusted by the integration of the utility for consumer surplus (μCS):

$$V_M = (w - c)\text{Demand}(p, \theta) - \frac{\eta\theta^2}{2} + \mu\text{CS} \tag{3.9}$$

As the model considers the economic performance of the supply chain in form of utility, it is possible that a company records a high utility, but low profits. In fact, the more the company has social concerns, the more the company is interested in charging a low price to the customer and thereby sacrifices its profit. The utility value is based on the fraction of consumer surplus μ and can take any value between 0 and 1. If μ is equal to 0, the company acts as a pure profit maximizer. In contrast, if μ is equal to 1, the company acts as a social-welfare maximizer.

3.1.4. The Integration of a Two-Part Tariff Contract

As in this model only the manufacturer bears the costs of green investment, it results in an imbalance between the manufacturer and the retailer. In fact, the retailer benefits more as they are not passing this benefit, in form of a lower retail price, to the consumer. Sinayi and Rasti-Barzoki (2018) introduced a coordination contract to address this imbalance. Under a two-part tariff contract the retailer pays a franchise fee (F) to the manufacturer in addition to the variable wholesale price.

Calculation of Franchise Fee

I had difficulty recalculating the franchise fee (F) as presented in the baseline model of Sinayi and Rasti-Barzoki (2018). The proof provided in the original study did not explain how the final function of the fee was derived. Although the researchers referenced another journal article in their study, the inclusion of additional factors in that model made it challenging to trace the origins of the fee function used. Upon recalculating the model using the mathematical solution of the franchise fee, as presented in subsection 3.1.1, it was observed that the main results (supply chain utility, consumer surplus, green degree of product) were identical to those obtained in the centralized (cooperative) scenario. The only exception is that the retailer's profit is reduced to zero; however, the minimum participation constraint still complies as long as $\pi \geq 0$.

3.1.5. The Integration of Governmental Intervention

The government is included as a third player in the Stackelberg game and acts as the leader of the supply chain. In consequence, the manufacturer becomes the first follower and the retailer the second. The government levies a tax on the product (τ). The utility function of the government is defined as follows:

$$V_G = \gamma_1 \theta + \gamma_2 \left(\tau \text{Demand}[p, \tau, \theta]\right) + \gamma_3 \left(\frac{\mu_2 \left(\text{Demand}[p, \tau, \theta]\right)^2}{2\beta} \right) \tag{3.10}$$

The government's utility is composed of three components, each weighted by a coefficient representing different policy priorities (γ_1, γ_2, γ_3). The first component reflects the green performance of the supply chain, measured by the product's green degree (θ). The second component captures the government's profit from taxation, calculated as the tax rate (τ) multiplied by demand. The third component represents a social interest of the government consisting of the fraction of the consumer surplus, which is the government's concern (μ_2). In the centralized scenario with governmental intervention, the manufacturer and the retailer operate as one entity, effectively functioning as a centralized supply chain. The government, however, retains its role as the leader within this structure. In this setting, the manufacturer and retailer jointly determine the retail price and the green degree of the product, while the government imposes a tax or provides a subsidy based on the governmental policies.

3.2. Analysis and Extension of Framework

3.2.1. Allocation of Responsibility for ESG Integration

Sinayi and Rasti-Barzoki (2018) assumed that the responsibility for integrating ESG issues lies solely with the manufacturer. This thesis analyzes the allocation of responsibilities between the retailer and manufacturer as presented in the study of Biswas et al. (2018). The baseline scenario (SC0) follows the model presented by Sinayi and Rasti-Barzoki (2018). The subsequent three scenarios (SC1, SC2, SC3) explore variations in which the responsibility for green investment and the consideration of social welfare shifts between the retailer and the manufacturer (cf. Table 3.2).

Scenario	Responsibility for Social Investment	Responsibility for Green Investment
SC0	Manufacturer	Manufacturer
SC1	Retailer	Retailer
SC2	Manufacturer	Retailer
SC3	Retailer	Manufacturer

Table 3.2.: Allocation of ESG Responsibilities SC0-SC3

Analogous to the baseline model framework, the integration of a two-part tariff contract and governmental intervention is analyzed resulting in four different models in total.

Model 1: SCi without LTT and without governmental intervention

Model 2: SCi_2 with LTT and without governmental intervention

Model 3: SCi_G without LTT and with governmental intervention

Model 4: SCi_{2G} with LTT and with governmental intervention.

The manufacturer is considered the leader of the Stackelberg game in the decentralized scenario. If the retailer is responsible for the green investment (cf. SC2 and SC3), the process of backward induction changes as follows:

1) The retailer determines the optimal retail price (p) and green degree of product (θ) simultaneously by maximizing their utility function.

2) The retailer determines the optimal franchise fee (F) by maximizing their utility function considering the optimal p and θ.

3) The manufacturer considers the optimal p (and F in case of a LTT contract) and θ determined by retailer in their utility function and determines the optimal wholesale price w by maximizing their utility function.

4) The government determines the optimal tax/subsidy τ in consideration of the optimal p (and F in case of a LTT contract), w and θ by maximizing their utility function.

3.2.2. Extending the Framework for Enhanced ESG Integration

In a further step, the impact of the shared responsibilities between the retailer and the manufacturer on the performance of the supply chain was analyzed. As a result, there are a total of 9 different scenarios. When accounting for the inclusion of the LTT and governmental intervention, this leads to $(9 * 4) = 36$ different decentralized sub-scenarios.

Including the two existing centralized scenarios serving as benchmark scenario, one with governmental intervention and one without, a total of 38 different scenarios are analyzed. A detailed breakdown of all scenarios, along with the corresponding base formulas, can be found in Appendix B.

Scenario	Responsibility for Social Investment	Responsibility for Green Investment
SC0	Manufacturer	Manufacturer
SC1	Retailer	Retailer
SC2	Manufacturer	Retailer
SC3	Retailer	Manufacturer
SC4	Manufacturer, Retailer	Manufacturer
SC5	Manufacturer, Retailer	Retailer
SC6	Manufacturer	Manufacturer, Retailer
SC7	Retailer	Manufacturer, Retailer
SC8	Manufacturer, Retailer	Manufacturer, Retailer

Table 3.3.: Allocation of ESG Responsibilities SC0-SC8

In scenarios where the manufacturer and retailer share responsibility for green and/or social investments, a distinction was made between the green degree and/or consumer surplus under the retailer's responsibility and that under the manufacturer's responsibility. To differentiate in the consumer surplus, a distinction in the fraction of consumer surplus was made.

Differentiation in green investments:

$$\theta_T = \theta_R + \theta_M \tag{3.11}$$

The green degree of the product (θ), which was previously the responsibility of a single supply chain participant, is now determined by the combined green investments of the retailer (θ_R) and the manufacturer (θ_M). The total green investment is denoted by θ_T. Thereby, potential green investments of the manufacturer may range from eco-friendly packaging, green logistics, water and resource efficiency to sustainable sourcing of raw materials. In contrast, potential green investments of the retailer may include the promotion of green products, sustainable store operations (e.g., waste management), or packaging reduction at the point of sale. In general, the manufacturer has a stronger responsibility when it comes to the technical and operational greening of the product, while in the retailer's sphere it is more about enabling sustainability at the point of sale.

Differentiation in social investments:

The consideration of consumer surplus within the utility functions of supply chain participants has also been extended. In the original model, only one participant accounted

Scenario	Social Investment	Green Investment	Two-Part Tariff Contract	Governmental Intervention
SC0	M	M		
SC0-2	M	M	x	
SC0-G	M	M		x
SC0-2G	M	M	x	x
SC1	R	R		
SC1-2	R	R	x	
SC1-G	R	R		x
SC1-2G	R	R	x	x
SC2	M	R		
SC2-2	M	R	x	
SC2-G	M	R		x
SC2-2G	M	R	x	x
SC3	R	M		
SC3-2	R	M	x	
SC3-G	R	M		x
SC3-2G	R	M	x	x
SC4	M, R	M		
SC4-2	M, R	M	x	
SC4-G	M, R	M		x
SC4-2G	M, R	M	x	x
SC5	M, R	R		
SC5-2	M, R	R	x	
SC5-G	M, R	R		x
SC5-2G	M, R	R	x	x
SC6	M	M, R		
SC6-2	M	M, R	x	
SC6-G	M	M, R		x
SC6-2G	M	M, R	x	x
SC7	R	M, R		
SC7-2	R	M, R	x	
SC7-G	R	M, R		x
SC7-2G	R	M, R	x	x
SC8	M, R	M, R		
SC8-2	M, R	M, R	x	
SC8-G	M, R	M, R		x
SC8-2G	M, R	M, R	x	x

Table 3.4.: Allocation of ESG Responsibilities Between (M) Manufacturer and (R) Retailer

for consumer surplus, represented by the parameter μ_1. In the extended model, both the retailer and the manufacturer may have social concerns. As such, μ_1 is replaced by μ_R (the retailer's concern for consumer surplus) and μ_M (the manufacturer's concern). Importantly, while the distribution of responsibility for consumer surplus has changed, the mathematical expression for total consumer surplus remains unchanged. The difference lies in whether and how this value is incorporated into the respective utility functions of the supply chain participants. However, when both, the retailer and the manufacturer, contribute to the greening effort, the consumer surplus formula is updated to account for total green investment:

$$\mathrm{CS} = \frac{(\alpha + \theta_T\lambda - \beta p)^2}{2\beta} \tag{3.12}$$

Here, θ is replaced by θ_T to reflect the aggregate green investments of both supply chain participants. This change also applies to models that include government intervention.

The backward induction process was adjusted accordingly.

1) The retailer determines the optimal retail price p (and green degree of product θ, if they bear green responsibility, or θ_R in case of shared green investments) simultaneously by maximizing their utility function.

2) In the model with a LTT contract, the retailer determines the optimal franchise fee F by maximizing their utility function considering the optimal p and θ/θ_R.

3) The manufacturer considers the optimal p (and F in case of a LTT contract), θ or θ_R in their utility function and determines the optimal wholesale price w (and the optimal θ, if they bear green responsibility, or θ_M in case of shared green investments) by maximizing their utility function.

4) The government determines the optimal tax/subsidy τ considering the optimal p (and F in case of a LTT contract), w, θ or θ_R and θ_M by maximizing their utility function.

In the scenarios where both share social concerns, such as $SC4$, $SC5$, $SC8$, both the manufacturer and the retailer incorporate a fraction of the consumer surplus in their utility function. Accordingly, both utilities increase with increases in consumer surplus. When both share green investments, the manufacturer as the leader of the supply chain determines their green investment first, and the retailer determines their green investment on basis of the manufacturer's decision. The utility function of the supply chain members varies depending on the responsibility of the green investment and the consumer surplus. If the supply chain participant is not responsible for green or social activities, the utility function is equal to the profit function, meaning the supply chain participant acts as a pure profit maximizer.

In Appendix B the model formulations for each scenario are presented, such as the utility function of the manufacturer and the retailer. Appendix D provides the mathematical proof for all scenarios.

4. Results and Discussion

This section presents models results along with related findings and interpretations. Thereby, a sensitivity analysis is conducted for the key decision variables, namely, the wholesale price (w), retail price (p), and green degree of the product (θ). In addition, a numerical example is provided to offer a more illustrative interpretation and discussion of the implications of the model. The section examines key outcomes under different allocations of social and environmental responsibility within the supply chain. The aim is to address the research questions outlined in section 1.2, by analyzing how different allocations of responsibility influence the economic and sustainability performance of the supply chain.

Supply chain performance is evaluated from both an economic and a sustainability perspective. Economic performance is measured by the total supply chain utility (V_{SC}), defined as the sum of the utilities of the retailer (V_R) and the manufacturer (V_M). Sustainability performance is assessed using two indicators: the green degree of the product (θ) as green performance indicator and the consumer surplus (CS) as social performance indicator. In the numerical example, the supply chain utility (*utility*) is further broken down into two components: the monetary profit π_{SC} (interpreted as the book value of the company and hereafter *profit*), and the share of the consumer surplus considered in the utility function of each participant (interpreted as the market premium and hereinafter *share of the consumer surplus*). Consequently, the total utility can be interpreted as the market value of the company. This breakdown allows for a clearer distinction between financial performance and social impact. The centralized scenario serves as the benchmark case, as it reflects a fully coordinated supply chain in which decisions are made to optimize overall supply chain performance.

The solution to the optimization problem for each scenario is provided in Appendix D. In Model 1, the optimization problems for all scenarios are presented to illustrate the impact of responsibility allocation. For Models 2 to 4, only the baseline scenarios, namely $SC0_2$, $SC0_G$, and $SC0_{G2}$, are shown in detail, with the remaining scenarios summarized by highlighting only the changes relative to the respective baseline.

A key contribution of this thesis lies in the examination of the allocation of responsibility for ESG-related investments within the supply chain. The majority of existing theoretical models, typically assumes that the manufacturer is solely responsible for both green and social efforts. This study builds on the framework by Biswas et al. (2018), which compared individual responsibilities between the retailer and the manufacturer. However, it extends the model by introducing scenarios with shared ESG responsibilities, as well as governmental intervention. As the main focus of this thesis is on the implications of shared responsibility ESG, the role of government intervention is treated as a secondary consideration. Only key findings are presented for this aspect.

To aid in understanding, the allocation of responsibilities for green and social investments in all scenarios is summarized once again in Table 4.1.

Scenario	Responsibility for Social Investment	Responsibility for Green Investment
SC0	Manufacturer	Manufacturer
SC1	Retailer	Retailer
SC2	Manufacturer	Retailer
SC3	Retailer	Manufacturer
SC4	Manufacturer, Retailer	Manufacturer
SC5	Manufacturer, Retailer	Retailer
SC6	Manufacturer	Manufacturer, Retailer
SC7	Retailer	Manufacturer, Retailer
SC8	Manufacturer, Retailer	Manufacturer, Retailer

Table 4.1.: Allocation of ESG Responsibilities SC0-SC8

4.1. Analysis of Responsibility Allocation Under a Wholesale Price Contract

The optimal economic performance of the supply chain for each scenario, in terms of utility, is presented in Table 4.2. The underlying optimal pricing decisions, that is, w and p, are shown in Table 4.3. The optimal results of sustainable performance are presented in Table 4.4. The results will be analyzed, discussed and compared with the centralized scenario SCC in the following sections.

Mathematical Analysis of Results

Sustainable Performance of Supply Chain: From a mathematical perspective, it is worth noting that both the optimal consumer surplus and the green degree share a constant numerator in all eight scenarios in Model 1. As a result, the variation in ESG performance in the different scenarios can be entirely attributed to differences in the denominator. This implies that the potential green performance is structurally the same in all cases. However, the extent to which this potential is realized depends on how value is distributed within the supply chain. Specifically, the denominator captures the influence of factors such as the green demand sensitivity (λ), price sensitivity (β), green cost sensitivity (η), and the social investment parameter (μ_1). These parameters determine the degree to which the supply chain participants are incentivized to convert the available ESG potential into actual performance outcomes. The optimal green degree of product and consumer surplus depends on μ_1 in scenarios where only one supply chain participant has social interests and dependent on μ_R and μ_M in scenarios with shared social interests. However, in scenarios with shared social responsibilities, μ_R and μ_M are of different weight. Independent of the responsibility for the green degree of the product,

	V_M	V_R
SCC	$-\frac{\eta(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+\lambda^2)}$	
SC0	$-\frac{\eta(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-4)+\lambda^2)}$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{(\beta\eta(\mu_1-4)+\lambda^2)^2}$
SC1	$-\frac{\eta(\alpha-\beta c)^2}{4(\beta\eta(\mu_1-2)+\lambda^2)}$	$-\frac{\eta(\alpha-\beta c)^2}{8(\beta\eta(\mu_1-2)+\lambda^2)}$
SC2	$-\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_1-4)+4\lambda^2}$	$\frac{\eta\left(2\beta\eta-\lambda^2\right)(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-4)+2\lambda^2)^2}$
SC3	$-\frac{\eta(\alpha-\beta c)^2}{2(2\beta\eta(\mu_1-2)+\lambda^2)}$	$-\frac{\beta\eta^2(\mu_1-2)(\alpha-\beta c)^2}{2(2\beta\eta(\mu_1-2)+\lambda^2)^2}$
SC4	$-\frac{\eta(\alpha-\beta c)^2}{2(\beta\eta(\mu_\mathrm{M}+2\mu_\mathrm{R}-4)+\lambda^2)}$	$-\frac{\beta\eta^2(\mu_\mathrm{R}-2)(\alpha-\beta c)^2}{2(\beta\eta(\mu_\mathrm{M}+2\mu_\mathrm{R}-4)+\lambda^2)^2}$
SC5	$-\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_\mathrm{M}+2\mu_\mathrm{R}-4)+4\lambda^2}$	$-\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_\mathrm{R}-2)+\lambda^2\right)}{2(\beta\eta(\mu_\mathrm{M}+2\mu_\mathrm{R}-4)+2\lambda^2)^2}$
SC6	$-\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_1-4)+6\lambda^2}$	$\frac{\eta\left(2\beta\eta-\lambda^2\right)(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-4)+3\lambda^2)^2}$
SC7	$-\frac{\eta(\alpha-\beta c)^2}{4\beta\eta(\mu_1-2)+6\lambda^2}$	$-\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_1-2)+\lambda^2\right)}{2(2\beta\eta(\mu_1-2)+3\lambda^2)^2}$
SC8	$-\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_\mathrm{M}+2\mu_\mathrm{R}-4)+6\lambda^2}$	$-\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_\mathrm{R}-2)+\lambda^2\right)}{2(\beta\eta(\mu_\mathrm{M}+2\mu_\mathrm{R}-4)+3\lambda^2)^2}$

Table 4.2.: Optimal Economic Results for a Supply Chain with Wholesale-Price Contract

μ_R shows a higher impact compared to μ_M not only on the optimal pricing (p and w), but optimal sustainability results (θ and CS). In addition, in scenarios with shared green investments, both consumer surplus and the product's green degree indicate a greater sensitivity to λ, the green demand coefficient.

Economic Performance of Supply Chain: When comparing the optimal supply chain utilities from a mathematical point of view, analogous to the optimal sustainable performance outcomes, it is notable that the numerator of the optimal utility of the manufacturer is robust in all eight scenarios, while the optimal utility of the retailer shows variations in all scenarios. This variation indicates that the retailer's payoff is more sensitive to the specific contractual and operational conditions in each scenario. Comparing the utility values, it is notable that, analogously to the ESG performance metrics, μ_R has a greater impact on the utility in $SC4$, $SC5$ and $SC8$ for both the retailer's and the manufacturer's utility compared to μ_M. In these scenarios, both supply chain participants share the responsibility for green investments. Similar to the sustainability performance outcomes, utility values as well as the wholesale and retail prices show greater sensitivity to λ in scenarios with shared green investments.

	w	p
SCC		$-\frac{-\alpha\eta\mu_1+\alpha\eta+\beta c\eta-c\lambda^2}{\beta\eta\mu_1-2\beta\eta+\lambda^2}$
SC0	$-\frac{-\alpha\eta\mu_1+2\alpha\eta+2\beta c\eta-c\lambda^2}{\beta\eta\mu_1-4\beta\eta+\lambda^2}$	$\frac{\alpha\eta(\mu_1-3)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-4)+\lambda^2}$
SC1	$\frac{\alpha+\beta c}{2\beta}$	$\frac{\alpha\left(\beta\eta(2\mu_1-3)+\lambda^2\right)+\beta c\left(\lambda^2-\beta\eta\right)}{2\beta(\beta\eta(\mu_1-2)+\lambda^2)}$
SC2	$\frac{\alpha\left(\beta\eta(\mu_1-2)+\lambda^2\right)+\beta c\left(\lambda^2-2\beta\eta\right)}{\beta(\beta\eta(\mu_1-4)+2\lambda^2)}$	$\frac{\alpha\left(\beta\eta(\mu_1-3)+\lambda^2\right)+\beta c\left(\lambda^2-\beta\eta\right)}{\beta(\beta\eta(\mu_1-4)+2\lambda^2)}$
SC3	$-\frac{-\alpha\eta\mu_1+2\alpha\eta-\beta c\eta\mu_1+2\beta c\eta-c\lambda^2}{2\beta\eta\mu_1-4\beta\eta+\lambda^2}$	$\frac{\alpha\eta(2\mu_1-3)+c\left(\lambda^2-\beta\eta\right)}{2\beta\eta(\mu_1-2)+\lambda^2}$
SC4	$\frac{\alpha\eta(\mu_{\mathrm{M}}+\mu_{\mathrm{R}}-2)+c\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)}{\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+\lambda^2}$	$\frac{\alpha\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-3)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+\lambda^2}$
SC5	$\frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+\mu_{\mathrm{R}}-2)+\lambda^2\right)+\beta c\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)}{\beta(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2)}$	$\frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-3)+\lambda^2\right)+\beta c\left(\lambda^2-\beta\eta\right)}{\beta(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2)}$
SC6	$\frac{\alpha\left(\beta\eta(\mu_1-2)+\lambda^2\right)+2\beta c\left(\lambda^2-\beta\eta\right)}{\beta(\beta\eta(\mu_1-4)+3\lambda^2)}$	$\frac{\alpha\left(\beta\eta(\mu_1-3)+\lambda^2\right)+\beta c\left(2\lambda^2-\beta\eta\right)}{\beta(\beta\eta(\mu_1-4)+3\lambda^2)}$
SC7	$\frac{\alpha\left(\beta\eta(\mu_1-2)+\lambda^2\right)+\beta c\left(\beta\eta(\mu_1-2)+2\lambda^2\right)}{\beta(2\beta\eta(\mu_1-2)+3\lambda^2)}$	$\frac{\alpha\left(\beta\eta(2\mu_1-3)+\lambda^2\right)+\beta c\left(2\lambda^2-\beta\eta\right)}{\beta(2\beta\eta(\mu_1-2)+3\lambda^2)}$
SC8	$\frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+\mu_{\mathrm{R}}-2)+\lambda^2\right)+\beta c\left(\beta\eta(\mu_{\mathrm{R}}-2)+2\lambda^2\right)}{\beta(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2)}$	$\frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-3)+\lambda^2\right)+\beta c\left(2\lambda^2-\beta\eta\right)}{\beta(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2)}$

Table 4.3.: Optimal Wholesale and Retail Price in a Supply Chain with Wholesale-Price Contract

	CS_{SC}	θ
SCC	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{\beta\eta(\mu_1-2)+\lambda^2}$
SC0	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-4)+\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{\beta\eta(\mu_1-4)+\lambda^2}$
SC1	$\frac{\beta\eta^2(\alpha-\beta c)^2}{8(\beta\eta(\mu_1-2)+\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{2(\beta\eta(\mu_1-2)+\lambda^2)}$
SC2	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-4)+2\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{\beta\eta(\mu_1-4)+2\lambda^2}$
SC3	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(2\beta\eta(\mu_1-2)+\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{2(\beta\eta(\mu_1-2)+\lambda^2}$
SC4	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(A+\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{A+\lambda^2}$
SC5	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(A+2\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{A+2\lambda^2}$
SC6	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-4)+3\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{\beta\eta(\mu_1-4)+3\lambda^2}$
SC7	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(2\beta\eta(\mu_1-2)+3\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{2\beta\eta(\mu_1-2)+3\lambda^2}$
SC8	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(A+3\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{A+3\lambda^2}$

A$=\beta\eta(\mu_M + 2\mu_R - 4)$

Table 4.4.: Optimal Consumer Surplus and Green Degree of Product of a Supply Chain with Wholesale-Price Contract

4.1.1. Validation of Results with Individual Responsibilities for ESG Investments

Before analyzing the impact of shared responsibilities in detail, this section compares the results of scenarios with individually assigned ESG investment responsibilities with the findings of Biswas et al. (2018). Specifically, the results of the decentralized scenarios with individual responsibility allocation ($SC0$ to $SC3$) are compared to the centralized scenario (SCC) and ranked as established in Propositions 1 and 2. The proofs are provided in Appendix E.

Proposition 1: In a decentralized scenario with WP contract

i. optimal levels of green degree are in the order
   $\theta C > \theta 1 > \theta 2$, $\theta 3 > \theta 0$

ii. optimal levels of consumer surplus are in the order
   $CSC > CS1 > CS2$, $CS3 > CS0$

Proposition 2: In a decentralized scenario with WP contract

i. optimal retail prices are in the order

$p0 > p2,\ p3 > p1 > pC$

ii. optimal wholesale prices are in the order

$w3 > w1,\ w0 > w2\ \forall\ \beta\eta > \lambda^2,\ \mu_1 > 0,\ \alpha > c\beta.$

iii. optimal supply chain utilities are in the order

$VC_{SC} > V1_{SC} > V2_{SC},\ V3_{SC} > V0_{SC}\ \forall \mu_1 > 0, \alpha > c\beta, \beta\eta > \lambda^2$

According to Proposition 1 and 2, the centralized supply chain model (SCC) achieves the highest economic and sustainable performance compared to decentralized scenarios. The results reveal that performance in decentralized scenarios depends strongly on how the responsibility for green and social investment is distributed between the manufacturer and the retailer.

The worst performance is observed in the baseline scenario $SC0$, where the manufacturer is solely responsible for both green and social investments. Here, the retailer does not invest in consumer surplus or green degree and has no incentive to reduce retail price, leading to low demand, low green investment, and ultimately low utility for both supply chain participants.

Performance improves when responsibilities are divided. In $SC2$, the manufacturer covers social investments while the retailer invests in greening. As the manufacturer no longer bears the greening costs, this leads to a lower wholesale price and a higher green degree, as the retailer has a direct incentive to increase demand. In $SC3$, the retailer is responsible for social investment, and the manufacturer handles greening. The lower retail price, driven by the social concern of the retailer, increases demand, encouraging the manufacturer to invest more in greening compared to $SC0$.

The highest decentralized performance is observed in $SC1$, where the retailer has green and social responsibilities. This allocation of responsibilities allows the retailer to directly manage both the price and the greening of the product, resulting in the highest consumer surplus, green degree of product and utility of all decentralized scenarios. In $SC1$, the wholesale price is independent of both η and λ, as the manufacturer is not responsible for green or social investments. As the leader in the supply chain, the manufacturer sets the wholesale price without being influenced by environmental parameters. In contrast, in $SC0$, where the manufacturer is responsible for both green and social investments, the retail price remains sensitive to environmental parameters. This is because the retailer, acting as the follower, responds to a wholesale price that reflects these parameters.

When looking at profits individually, the manufacturer earns the most in scenarios where the retailer is responsible for social efforts, namely $SC1$ and $SC3$, while retailers earn the least in these cases. This outcome aligns with the idea that the participant in the supply chain with social concerns can accept lower profits to maximize overall utility. In contrast, when the manufacturer is responsible for social investments ($SC0$, $SC2$), the manufacturer makes the lowest profit, and the retailer the highest. This result is especially problematic under the WP, where the manufacturer has no way to ensure that the retailer passes on any cost savings to the consumer. If the manufacturer lowers the wholesale price, a profit-maximizing retailer without social concerns will keep prices high, preventing an increase in consumer surplus. When comparing $SC0$ and $SC2$, the latter achieves a better performance score: the retailer controls the degree of greenness and benefits from a lower wholesale price, leading to higher investment in greening, a more attractive retail price and increased demand.

Overall, in a decentralized supply chain with individual responsibilities and a WP, it is most efficient for the retailer to take responsibility for social efforts and ideally also for greening. However, a fully coordinated supply chain remains the best option in all performance indicators, with significantly higher values in utility, green degree, and consumer surplus than in any decentralized scenario.

4.1.2. Impact of Shared Responsibilities for ESG Investments on Supply Chain Performance

Analyzing the results of scenarios with shared responsibilities from a mathematical perspective, under the assumptions outlined in Propositions 3 and 4, presented challenges. The results vary significantly depending on the values of the parameters, particularly the distinction between μ_R and μ_M, which limits the ability to draw general conclusions. However, under the specified assumptions, the results of the shared responsibility scenarios are compared to and ranked against those with individual ESG investment responsibilities, in accordance with Propositions 3 and 4.

Proposition 3: In a decentralized scenario with WP contract

i. optimal levels of green degree are in the order

θC, $\theta 6 > \theta 1 > \theta 2$, $\theta 3 > \theta 0$ and and $\theta_M 6 > \theta 0$, $\theta_R 6 > \theta 2$, $\theta_M 7 > \theta 3$, $\theta_R 7 > \theta 1 \;\forall\; \beta\eta > 2\lambda^2$, $\alpha > c\beta$, $0 < \mu_M = \mu_1 < 1$

ii. optimal levels of consumer surplus are in the order

$CSC > CS1 > CS2$, $CS3 > CS0$, with $CS8$, $CS7$, $CS6$, $CS5$, $CS4 > CS0$

Proposition 4: In a decentralized scenario with WP contract

i. optimal retail prices are in the order

$p6 > p0 > p2$, $p3 > p1 > pC$, with $p4 > pC$

ii. optimal wholesale prices are in the order

$w7 > w3 > w1$, $w0 > w2$ with $w3 > w5$, $w4$ $\forall$ $\beta\eta > \lambda^2$, $\mu_M = \mu_R = \mu_1 > 0$, $\alpha > c\beta$.

iii. optimal supply chain utilities are in the order

$VC_{SC} > V1_{SC} > V2_{SC}$, $V3_{SC} > V0_{SC}$ with $V2_{SC} > V0_{SC}$ and $V6_{SC} > V2_{SC}$ $\forall \mu_1 = \mu_M = \mu_R > 0, \alpha > c\beta, \beta\eta > \lambda^2$

As the propositions yield only limited insights, a general interpretation of the results is not feasible. Therefore, a numerical example is used to enable a more detailed analysis. Before this, a sensitivity analysis of the wholesale price, retail price, and product's green degree is conducted, which also serves as a basis for the interpretation of the results.

4.1.3. Results of Sensitivity Analysis

The sensitivity of the wholesale and retail price is shown in Table 4.5 in all scenarios ($SC0$-$SC8$, SCC), and the sensitivity of the green degree of the product is presented in Table 4.6. The tables show how these decision variables respond to changes in key parameters: α (market potential for green demand), η (cost coefficient of the green degree per unit), λ (demand expansion effectiveness coefficient of the green degree per unit of green product) and c (unit production cost of the manufacturer). The results of the sensitivity analysis are established in Propositions 5 to 7. The proofs are provided in Appendix E.

Scenario	α	η	λ	c
SC0	$+$	$-$	$+$	$+$
SC1	$+$	$-$	$+$	$+$
SC2	$+$	$-$	$+$	$+$
SC3	$+$	$-$	$+$	$+$
SC4	$+$	$-$	$+$	$+$
SC5	$+^A$	$-^A$	$+^A$	$+^A$
SC6	$+$	$-$	$+$	$+^A$
SC7	$+^A$	$-$	$+$	$+^A$
SC8	$+^A$	$-^A$	$+^A$	$+^A$
SCC	$+$	$-$	$+$	$+$

Retail Price

Scenario	α	η	λ	c
SC0	$+$	$-$	$+$	$+$
SC1	$+$	$\perp\!\!\!\perp$	$\perp\!\!\!\perp$	$+$
SC2	$+$	$+$	$-$	$+$
SC3	$+$	$-$	$+$	$+$
SC4	$+$	$-$	$+$	$+$
SC5	$+^A$	$+$	$-$	$+^A$
SC6	$+$	$-$	$+$	$+$
SC7	$+^A$	$-$	$+$	$+^A$
SC8	$+^A$	$-^A$	$+^A$	$+^A$
SCC	N/A	N/A	N/A	N/A

Wholesale Price

Table 4.5.: Sensitivity Analysis of Retail and Wholesale Price in a Decentralized Scenario with Wholesale-Price Contract. In all scenarios the baseline assumptions $\forall\ \beta\eta > \lambda^2$, $\alpha > \beta c$ hold. Cases marked with (A) require $\forall\ \beta\eta > 3\lambda^2$, $\mu M + \mu R < 1$.

Proposition 5: In a decentralized supply chain with WP contract:

i. The retail price is increasing in α, λ, c and decreasing in η in SCC, $SC0$, $SC1$, $SC2$, $SC3$, $SC4$ $\forall\, \beta\eta > \lambda^2, \alpha > \beta c$.

ii. The retail price is increasing in α, λ, c and decreasing in η in $SC5$, $SC6$, $SC7$, $SC8$, $\forall\, \beta\eta > 3\lambda^2, \alpha > \beta c$, $\mu M + \mu R < 1$.

Proposition 6: In a decentralized supply chain with WP contract:

i. The wholesale price is increasing in α, λ, c and decreasing in η in $SC0$, $SC3$, $SC4$, $SC6$.

ii. The wholesale price is increasing in α, λ, c and decreasing in η in $SC7$, $SC8$, $\forall\, \beta\eta > 3\lambda^2, \alpha > \beta c$, $\mu M + \mu R < 1$.

iii. The wholesale price is increasing in α, c and is independent of λ, η in $SC1$ $\forall\, \beta\eta > \lambda^2, \alpha > \beta c$.

iv. The wholesale price is increasing in α, η and c and decreasing in λ in $SC5$ and $SC2$ $\forall\, \beta\eta > \lambda^2, \alpha > \beta c$.

Scenario	α	η	λ	c
SC0	$+$	$-$	$+$	$-$
SC1	$+$	$-$	$+$	$-$
SC2	$+$	$-$	$+$	$-$
SC3	$+$	$-$	$+$	$-$
SC4	$+$	$-$	$+$	$-$
SC5	$+^A$	$-$	$+$	$-^A$
SC6 (M/R)	$+$	$-$	$+$	$-$
SC7 (M/R)	$+^A$	$-$	$+$	$-^A$
SC8 (M/R)	$+^A$	$-$	$+$	$-^A$

Table 4.6.: Sensitivity Analysis of Green Degree in a Decentralized Scenario with Wholesale-Price Contract. In all scenarios the baseline assumptions $\forall\ \beta\eta > \lambda^2$, $\alpha > \beta c$ hold. Cases marked with (A) require $\forall\ \beta\eta > 3\lambda^2$, $\mu_M + \mu_R < 1$.

Proposition 7: In a decentralized supply chain with WP contract:

i. The green degree is increasing in α and λ and decreasing in η, c in $SC0$, $SC1$, $SC2$, $SC3$, $SC4$, $SC6$, SCC $\forall\ \beta\eta > \lambda^2, \alpha > \beta c$.

ii. The green degree is increasing in α and λ and decreasing in η, c in $SC5$, $SC7$, $SC8$ $\forall\ \beta\eta > 3\lambda^2, \alpha > \beta c$, $\mu M + \mu R < 1$.

According to Proposition 5, the retail price increases with the market potential for the green degree (α) and the green demand coefficient (λ). As demand for green products rises, supply chain participants invest more in greening. Consequently, the green degree of the product also increases with α and λ, as confirmed in Proposition 7. The higher greening costs resulting from this increased investment are reflected in higher retail prices.

In contrast, Propositions 5 and 6 show that both retail and wholesale prices typically decrease with an increase in the cost coefficient of the green degree per unit (η). When greening becomes more expensive, investment in it is reduced, which leads to a decline in the green degree, as shown in Proposition 7, and ultimately in the retail and wholesale prices.

Proposition 6 further reveals that, similar to the retail price, the wholesale price increases with α and λ in all scenarios, and decreases with η in most cases. However, scenarios $SC1$, $SC2$, and $SC5$ deviate from this overall pattern and display distinct behaviors. The reasons for this deviation will be further analyzed in the following section subsection 4.1.5.

4.1.4. Results of Numerical Example

To allow a direct comparison between shared and individual responsibility scenarios in terms of supply chain performance, a numerical example is used to illustrate the results. The parameters are defined as shown in Table 4.7, and the resulting outcomes are summarized below.

parameter	value
α	100
β	5
c	3
η	6
λ	3
$\gamma_1, \gamma_2, \gamma_3$	1
μ_1	0.3
μ_2	0.3
μ_R	0.3
μ_M	0.3

Table 4.7.: Notations of Numerical Example

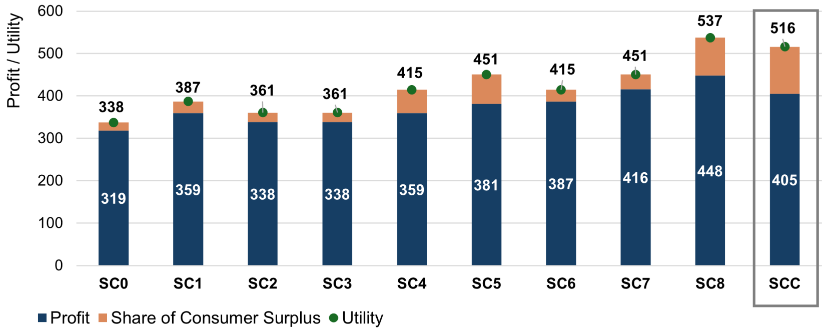


Figure 4.1.: Model 1: Total Utility of Supply Chain

Utility of Supply Chain ($V_{\mathbf{SC}}$)
$SC8 > SCC > SC7 = SC5 > SC6 = SC4 > SC1 > SC3 = SC2 > SC0$

Profit of Supply Chain ($\pi_{\mathbf{SC}}$)
$SC8 > SC7 > SCC > SC6 > SC5 > SC4 = SC1 > SC3 = SC2 > SC0$

Wholesale Price (w)
$SC7 > SC3 > SC8 = SC6 = SC4 = SC1 = SC0 > SC2 > SC5$

Retail Price (p)
$SC6 > SC7 > SC8 > SC0 > SC2 = SC3 = SC1 = SC4 > SC5 > SCC$

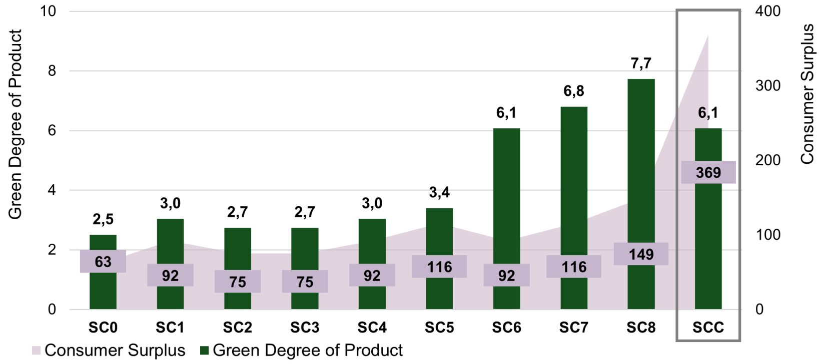


Figure 4.2.: Model 1: Sustainability of Supply Chain

Consumer Surplus (CS)
$SCC > SC8 > SC7 = SC5 > SC6 = SC4 = SC1 > SC3 = SC2 > SC0$

Green Degree (θ)
$SC8 > SC7 > SC6 = SCC > SC5 > SC4 = SC1 > SC3 = SC2 > SC0$

The numerical analysis demonstrates that when both supply chain participants share responsibility for green and social initiatives, the decentralized model yields higher overall utility, increased profits, higher green degree of product and greater consumer surplus in this example. In fact, scenario $SC8$, when both supply chain participants share green and social investments, even outperforms the centralized model in terms of supply chain utility, supply chain profit, and green performance.

Moreover, any combination of shared responsibilities (except from $SC4$, which achieves the same performance as $SC1$ in the green degree, consumer surplus and supply chain profit) improves all performance metrics.

In contrast, the baseline scenario ($SC0$), where the manufacturer is solely responsible for these efforts, consistently records the lowest performance. Among the scenarios with individual responsibility, $SC1$, where the retailer is responsible for green and social efforts, achieves the highest performance.

In the following, a detailed analysis and interpretation of the sustainable and economic performance of the supply chain is presented, building on the insights derived from the preceding mathematical and numerical results.

4.1.5. Analysis of Environmental Performance of Supply Chain

Impact of Green Responsibility Allocation on Green Performance of Supply Chain

Overall, scenarios in which both the retailer and the manufacturer share responsibility for green investments, namely $SC6$, $SC7$, and $SC8$, result in a significantly higher green degree of product compared to the other scenarios. This outcome was expected, as joint contributions lead to a greater total investment in sustainability. Among these scenarios, $SC8$, where both green and social investments are fully shared and the interests of both supply chain participants align, achieves the highest degree of greenness.

Interestingly, in all shared green investment scenarios, the retailer and manufacturer contribute equally to greening, regardless of differences in μ_R or μ_M. This outcome will be further analyzed in subsection 4.1.8. According to Proposition 3, shared green investments incentivize supply chain participants to invest more in greening. In scenarios $SC0$ and $SC6$, the manufacturer is responsible for the social investment. However, in $SC6$, the green investment is shared between the manufacturer and the retailer, whereas in $SC0$ only the manufacturer bears this responsibility. Proposition 3 shows that the green investment of the manufacturer is higher in $SC6$ due to the cost-sharing structure. Moreover, when comparing the green investment of the retailer in $SC6$ with that in $SC2$, where the retailer is solely responsible for the greening, the retailer also contributes more in $SC6$. This shows that shared responsibility leads to higher green investment by both parties.

Proposition 4 further demonstrates that $SC6$ exhibits the highest retail price among all scenarios under the WP. Since the retailer in $SC6$ shares the cost of greening but has no concerns for consumer surplus, the retailer passes on the green costs to the consumers through a higher retail price. In comparison, in $SC0$, the retailer does not invest in greening and therefore can charge a lower retail price. Despite this negative effect on demand, the manufacturer in $SC6$ invests more in greening than in $SC0$, as both parties benefit from the shared green responsibility. Ultimately, this leads to increased demand and higher utilities for both the manufacturer and the retailer. As a result, shared green responsibilities lead to higher total green investments not only because both parties contribute, but also because the sharing of responsibilities incentivizes each supply chain participant to invest more.

In general, as observed in the mathematical analysis of results, scenarios with shared green investments differ from other scenarios primarily in their higher sensitivity to the green demand coefficient λ. As λ increases, the green degree of the product rises significantly more in these scenarios. This increased sensitivity is also reflected in the increased changes in retail and wholesale prices, which are adjusted to compensate for the increased greening costs.

Scenarios $SC2$ and $SC5$ also exhibit increased sensitivity to λ. In both cases, the retailer is solely responsible for green investments and directly benefits from increased demand, motivating a higher green investment. In contrast, $SC0$ (relative to $SC2$) and $SC4$ (relative to $SC5$) show lower sensitivity to λ, and consequently, a lower green degree, as shown in Figure 4.2. Scenarios $SC2$ and $SC5$, thereby reveal the lowest wholesale price in the numerical example. This is also proved by Proposition 4, which presents the lowest wholesale price among all scenarios in $SC2$. In particular, the sensitivity analysis (cf. Proposition 6) revealed that the wholesale price in $SC2$ and $SC5$ increases with the green cost coefficient (η) and decreases with the green demand coefficient (λ). When green demand increases (i.e., higher λ), the manufacturer lowers the wholesale price to encourage a lower retail price and stimulate demand. In contrast, higher green costs (higher η) reduce the retailer's greening efforts, allowing the manufacturer to charge a higher wholesale price without reducing demand. Therefore, under a WP, when only one party is responsible for green investments, assigning this responsibility to the retailer leads to improved green supply chain performance. However, allocating green investment responsibility to both supply chain participants ($SC8$) remains the most effective solution to maximize the green performance.

Impact of Social Responsibility Allocation on Green Performance of Supply Chain

When comparing $SC6$ and $SC7$, the numerical example shows a higher green degree in $SC7$, although in both scenarios the supply chain participants share green investments. Interestingly, both the retail and wholesale prices are also higher in $SC7$. Since the retailer is responsible for consumer surplus in this scenario, they are more willing to invest in greening, even at the expense of their own profits, in order to enhance consumer surplus and, in turn, drive demand. However, in $SC6$, the manufacturer is responsible for the social investments and behaves more conservatively in their investment decisions. Consequently, when both supply chain participants share green investments, green supply chain performance improves if the retailer, rather than the manufacturer, is responsible for social investments.

When analyzing the impact of shared social responsibility allocation, in general a positive impact on green supply chain performance is observed. This conclusion is supported by a comparison of $SC5$ with $SC1$ and of $SC4$ with $SC0$ as well as $SC8$ with $SC7$ and $SC6$. In $SC0$, the manufacturer is solely responsible for sustainable investments, while in $SC1$, this responsibility lies with the retailer. When social responsibilities are shared, as in $SC4$ and $SC5$, the green performance of the supply chain improves. In $SC4$, the integration of social concerns into the retailer's utility function leads to a lower retail price, which incentivizes the manufacturer to increase green investments in the numerical example. In $SC5$, the manufacturer lowers the wholesale price due to the inclusion of social concerns in their utility function, thereby incentivizing the retailer to invest more in greening. Furthermore, $SC8$ shows improved green performance compared to $SC7$ and $SC6$, driven by the shared allocation of social responsibility and the full alignment of the interests of both participants in the supply chain.

The numerical analysis further reveals, when the green cost coefficient (η) decreases, the manufacturer in $SC4$ may make less green investments than the retailer in $SC1$. Despite this, the manufacturer still charges a higher wholesale price, causing higher retail prices and potentially making $SC1$ superior in both economic and sustainable supply chain performance. In contrast, when the retailer is responsible for greening, as in $SC1$, the green degree responds more strongly to variations in green-related parameters, improving sustainable performance. This illustrates that while shared social responsibility can partially mitigate the manufacturer's reduced incentive to invest in greening and consequently increase the green performance of the supply chain, it does not fully resolve the underlying conflict of interest under a WP.

4.1.6. Analysis of Social Performance of Supply Chain

The highest consumer surplus among decentralized scenarios is achieved in $SC8$, where both supply chain participants are fully aligned on green and social goals. However, the centralized scenario (SCC) still results in a higher consumer surplus, primarily due to its significantly lower retail price, as shown in Proposition 2 and 4.

Interestingly, in the numerical example, $SC7$ and $SC5$ yield identical consumer surplus values, both outperforming $SC4$ and $SC6$. Based on their shared social responsibility allocation, a higher consumer surplus in $SC4$ and $SC5$ might have been expected. Along with $SC8$, in these scenarios both participants incorporate social concerns in their utility functions. The strong performance in consumer surplus in $SC7$, despite the absence of shared social concerns, is driven by (a) the shared green investments, which result in a higher green degree, and (b) the retailer's social responsibility. In contrast to $SC6$, where the manufacturer has the social responsibility, the retailer's influence in $SC7$ leads to a lower retail price, thus increasing both consumer surplus and demand. Compared to $SC4$, $SC7$ performs better due to shared green investments, which have a stronger impact on consumer surplus than the sharing of social concerns in the numerical example. This observation highlights the importance of ESG responsibility allocation, as well as the interdependence between green investment responsibility and the social performance of the supply chain, and vice versa, under a WP.

In general, the outcomes in these scenarios are highly sensitive to the level of social concern, represented by μ_1, μ_R, and μ_M. As the level of social concern increases, the social performance of $SC4$ and $SC5$ improves accordingly, eventually surpassing that of $SC1$, $SC6$, and $SC7$. For example, when both the retailer and manufacturer exhibit strong social concerns, $SC4$ can outperform $SC1$, which involves only retailer-led green and social investments. However, if social concern remains low, the disadvantage of the manufacturer bearing the full cost of green investments in $SC4$ outweighs the benefits of shared social responsibility, making $SC1$ the more effective configuration for consumer surplus. In such cases, the positive effect of shared social investments in $SC4$ is offset by lower green investments from the manufacturer, which, in turn, reduces the willingness to pay of the customer.

In conclusion, the results suggest that both parties should share social and green investments to maximize the social performance of the supply chain. However, while shared social responsibilities can mitigate the limitations of the wholesale contract, particularly the manufacturer's reduced incentive to invest in greening, they do not fully resolve the underlying conflict of interest. Even when social concerns are shared, sustainability performance remains constrained if the manufacturer alone bears the cost of green investments. However, as the level of social responsibility increases, this misalignment gradually decreases, leading to improved overall supply chain performance. Thus, the level of social concern of a company is critical in deciding how to allocate sustainable responsibilities.

4.1.7. Analysis of Economic Performance of Supply Chain

When analyzing economic performance, utility serves as the primary economic measure. However, a distinction between profit and the share of consumer surplus is made to allow for a more detailed analysis.

In the numerical example, $SC8$ achieves the highest total utility, even surpassing the centralized benchmark (SCC). When breaking down the total utility of the supply chain into components of pure profit and share of consumer surplus, it becomes clear that $SC8$ achieves the highest total utility, primarily due to its elevated profit levels. However, if we consider only the share of consumer surplus represented by the orange area in the graph Figure 4.1, the centralized scenario scores higher. According to Propositions 2 and 4, SCC achieves the lowest retail price, thereby maximizing consumer surplus, although this comes at the expense of overall supply chain profits. In addition to the centralized scenario, $SC8$, $SC5$, and $SC4$ reveal the highest share of consumer surplus. However, this outcome is not unexpected as in these scenarios both supply chain participants have social concerns and thus gain utility from consumer surplus.

Notably, $SC7$ exceeds the centralized model (SCC) in terms of total profit in the example. High supply chain profits are driven by the manufacturer. This is consistent with Proposition 4 and the observation that $SC7$ features the highest wholesale price in all scenarios, even surpassing $SC3$, where the manufacturer is solely responsible for green investments. In $SC7$, green responsibilities are shared between the manufacturer and the retailer, but only the retailer incorporates social concerns into their utility function. As shown earlier, shared green responsibility incentivizes higher individual investment from both participants. However, since the manufacturer in $SC7$ does not value consumer surplus, they pass on the increased greening costs by setting a high wholesale price resulting in a higher retail price. Although, this pricing strategy leads to a lower consumer surplus compared to $SC8$, $SC5$ and $SC4$, this behavior maximizes the manufacturer's profit. Consequently, the manufacturer records the highest profit in $SC7$ in the example.

Across all scenarios, the manufacturer consistently records higher profits and utility than the retailer. This outcome is a result of the game structure, in which the manufacturer acts as the leader of the supply chain. However, both parties achieve their highest individual utilities in $SC8$, and their lowest in $SC0$. This points out that, despite the imbalance of a WP, both parties benefit from shared ESG investments.

Analogous to the consumer surplus, $SC5$ and $SC7$ yield the same supply chain utility in the numerical example. However, as social concerns (μ_R, μ_M) increase, utility in $SC5$ also increases and eventually exceeds that of $SC7$. This further confirms the value of shared social investments. Again, $SC4$ and $SC6$ show the lowest supply chain utilities in scenarios with shared responsibilities. However, this can be reversed at higher levels of social concern, particularly in $SC4$, which may then outperform $SC6$.

In comparison to scenarios with individual responsibilities, a clear difference in economic performance is observed. In the numerical example, scenarios with shared sustainable investments achieve higher total utility for the supply chain. Importantly, the results indicate not only increased overall utility, but also increased - or at least stable (only in $SC4$) - profits. Furthermore, even when analyzing the economic performance of the manufacturer and retailer separately, both parties record stable or improved utility levels in scenarios with shared responsibilities. Hence, it can be concluded that sharing ESG investments is an economically feasible strategy, not only for the supply chain as a whole, but also for each individual supply chain participant.

4.1.8. Analysis of ESG Investment Parameters

Green and social investment parameters differ depending on the allocation of responsibilities. All applicable parameters are summarized in Table 4.8. In scenarios where a supply chain participant is solely responsible for green or social investments, the model incorporates the parameters θ (green investment) and μ_1 (social concern). When green or social responsibilities are shared between the retailer and the manufacturer, the model distinguishes between θ_R and θ_M for green investments, and μ_R and μ_M for social concerns. Notably, θ_R and θ_M are decision variables and μ_R and μ_M are parameters and accordingly predefined.

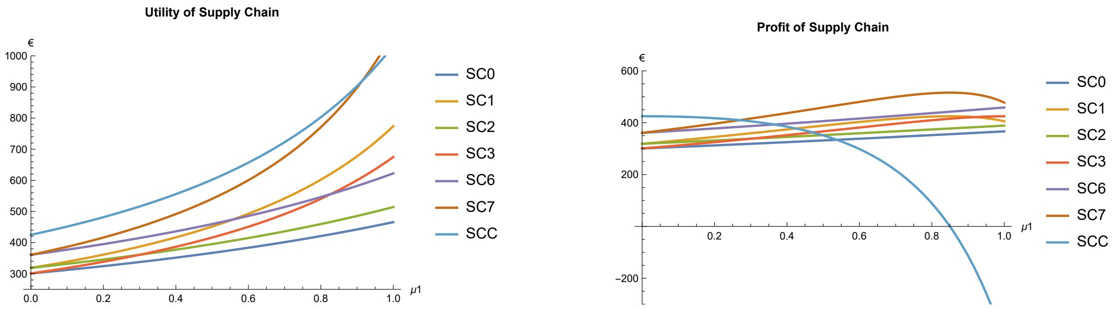
Scenario	Green Investment Variable		Social Investment Parameter	
	θ	θ_R, θ_M	μ_1	μ_R, μ_M
SC0	x		x	
SC1	x		x	
SC2	x		x	
SC3	x		x	
SC4	x			x
SC5	x			x
SC6		x	x	
SC7		x	x	
SC8		x		x
SCC	x		x	

Table 4.8.: Overview of Green and Social Investment Parameters

When further differentiating the economic performance of the supply chain into profits and utility, the results in Figure 4.3 reveal a clear trade-off in the centralized scenario: as the social investment parameter μ_1 increases, the supply chain participants place greater emphasis on consumer surplus, which leads to a steady decline in profits. In the numerical example, the supply chain records losses when $\mu_1 > 0.85$. This reflects a shift from profit-maximization toward utility-maximization. This behavior may resemble real-world strategies in which firms initially accept lower profits or losses, through upfront investment or competitive pricing, to build reputation and secure market share before stabilizing profitability later on. Accordingly, a company's level of social investment may vary over time, reflecting shifts in its economic strategy.

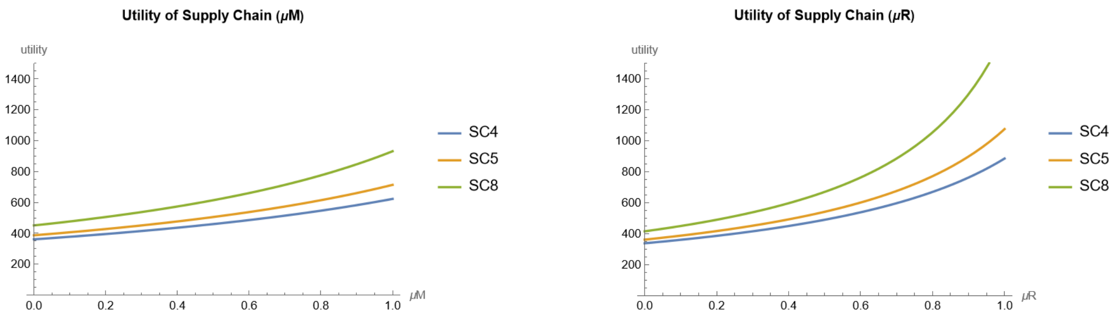
Interestingly, Figure 4.3 shows that in decentralized scenarios, both supply chain profit and utility increase with increasing values of μ_1. In the centralized scenario, the supply chain acts as a single entity aiming to maximize total utility, willingly accepting lower profits to achieve higher consumer surplus and thus greater overall utility. In contrast, in decentralized scenarios, the supply chain members act independently, each seeking to maximize their own utility. Due to the misalignment introduced by the WP, participants adopt more conservative pricing strategies, being less willing to risk profits in pursuit of higher consumer surplus.

However, when comparing SCC with $SC7$, it is noteworthy that the utility in $SC7$ approaches that of SCC as μ_1 increases, while consistently maintaining higher profits. In the centralized scenario, high utility is achieved through a significantly reduced retail price, which results in low supply chain profits or losses. In contrast, in $SC7$, the increase in utility results from the high green investments of both parties, leading to a higher customer's willingness to pay. In addition, the social responsibility of the retailer positively impacts the sustainability of the supply chain.



(a) Utility of Supply Chain (b) Profit of Supply Chain

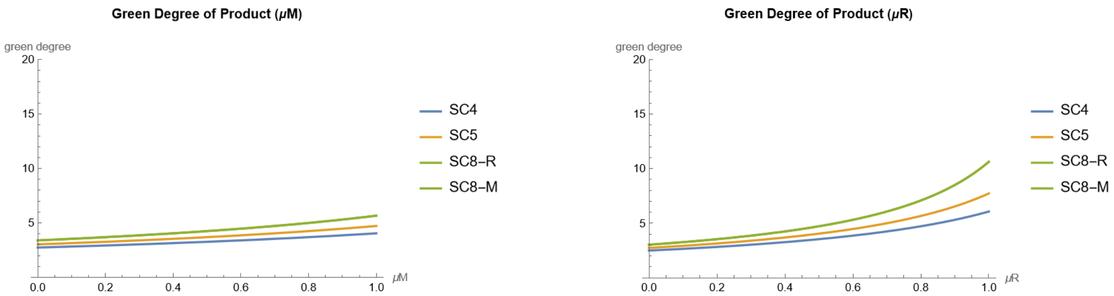
Figure 4.3.: Impact of μ_1 on Supply Chain's Economic Performance in Model 1 with Individual Responsibilities ($\alpha = 100, \beta = 5, c = 3, \eta = 6, \lambda = 3, \mu_1 = \mu_M = \mu_R = 0.3$)



(a) Manufacturer's Social Investment Parameter (μ_M) (b) Retailer's Social Investment Parameter (μ_R)

Figure 4.4.: Impact of Social Investment Parameters on Supply Chain's Utility ($\alpha = 100, \beta = 5, c = 3, \eta = 6, \lambda = 3, \mu_M = \mu_R = 0.3$)

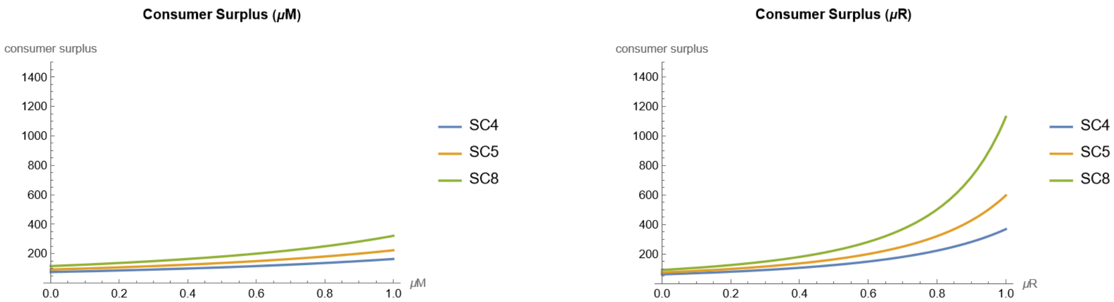
Figure 4.4, Figure 4.5 and Figure 4.6 compare the effects of the retailer's and manufacturer's social investment parameters (μ_R and μ_M) on both economic and sustainability performance in scenarios with shared social investments ($SC4$, $SC5$ and $SC8$). In general, both parameters positively affect the utility of the supply chain, the consumer surplus and the green degree of the product. However, in all scenarios, the overall performance of the supply chain, both economic and sustainable, is more strongly influenced by the social investment parameter of the retailer (μ_R). This higher sensitivity was already evident from the previous mathematical analysis of the results and result from the structure of the WP: although both parties make ESG investments, the retailer ultimately decides whether the benefits are passed on to consumers via the retail price. As such, the retailer's social concern directly affects consumer surplus and demand, amplifying both utility and environmental performance.



(a) Manufacturer's Social Investment Parameter (μ_M)

(b) Retailer's Social Investment Parameter (μ_R)

Figure 4.5.: Impact of Social Investment Parameters on Green Degree of Product ($\alpha = 100, \beta = 5, c = 3, \eta = 6, \lambda = 3, \mu_M = \mu_R = 0.3$)



(a) Manufacturer's Social Investment Parameter (μ_M)

(b) Retailer's Social investment Parameter (μ_R)

Figure 4.6.: Impact of Social Investment Parameters on Consumer Surplus ($\alpha = 100, \beta = 5, c = 3, \eta = 6, \lambda = 3, \mu_M = \mu_R = 0.3$)

When comparing green investments in scenarios with shared responsibilities, such as $SC6$, $SC7$, and $SC8$, it is also notable that both the retailer and the manufacturer consistently invest the same amount in greening, regardless of any variation in μ_1, μ_R, or μ_M. This is because both parties benefit equally from the overall green degree ($\theta_T = \theta_M + \theta_R$), face the same marginal costs and returns on their investment, and cannot gain a strategic advantage by deviating. Consequently, the model yields a symmetric equilibrium in which environmental efforts are evenly distributed between the supply chain participants.

In summary, the impact of social investment on both economic and sustainable performance is more strongly impacted by the retailer under a WP. It is thereby irrelevant who is responsible for greening. This result confirms that social responsibilities should be assigned to the retailer to maximize supply chain performance.

4.2. Impact of a Two-Part Tariff Contract on Supply Chain Performance

In the following section, the impact of a LTT on supply chain performance is analyzed. Under this contract structure, the manufacturer charges the retailer a fixed franchise fee in addition to the wholesale price. This franchise fee serves as a cost-sharing mechanism and enables a more flexible distribution of (green) costs between the two supply chain participants.

In general, when comparing the results of the LTT to those of the centralized benchmark model, several scenarios under the two-part tariff structure match or even surpass the centralized scenario in terms of overall supply chain performance. This improvement is evident in economic and sustainability results, demonstrating the effectiveness of the coordination mechanism in aligning incentives and enabling a more efficient distribution of value across the supply chain.

Table 4.10 shows the optimal wholesale price, retail price and franchise fee in all scenarios and Table 4.9 presents the resulting supply chain utility of the manufacturer and the retailer. Table 4.11 reports the optimal values for consumer surplus and the green degree of the product in all scenarios. The results of all scenarios have been compared and ranked as established in Propositions 6 and 7.

4.2.1. Analysis of ESG Responsibility Allocation

Proposition 8: In a decentralized scenario with LTT

i. optimal green degree levels are in the following order:

$\theta 8_2 = \theta 6_2 > \theta 5_2 = \theta 4_2 = \theta C = \theta 2_2 = \theta 0_2 > \theta 3_2 = \theta 1_2$ and $\theta_M 6_2 > \theta 0_2$, $\theta_R 6_2 > \theta 2_2$, $\theta_M 7_2 > \theta 3_2$, $\theta_R 7_2 > \theta 1_2$ $\forall$ $\beta\eta > 2\lambda^2$, $\alpha > c\beta$, $0 < \mu_M = \mu_1 < 1$

ii. optimal levels of consumer surplus are in the following order:

$CS8_2 = CS6_2 > CS5_2 = CS4_2 = CSC = CS2_2 = CS0_2 > CS3_2 = CS1_2$ with $CS7_2 > CS3_2$ $\forall$ $\beta\eta > \lambda^2$, $\alpha > c\beta$ and $0 < \mu_M = \mu_1 < 1$

	V_M	V_R
$SC0_2$	$-\frac{\eta(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+\lambda^2)}$	0
$SC1_2$	$\frac{\eta(\alpha-\beta c)^2}{4\beta\eta-2\lambda^2}$	$\frac{\beta\eta^2\mu_1(\alpha-\beta c)^2}{2(\lambda^2-2\beta\eta)^2}$
$SC2_2$	$-\frac{\eta(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+\lambda^2)}$	0
$SC3_2$	$\frac{\eta(\alpha-\beta c)^2}{4\beta\eta-2\lambda^2}$	$\frac{\beta\eta^2\mu_1(\alpha-\beta c)^2}{2(\lambda^2-2\beta\eta)^2}$
$SC4_2$	$-\frac{\eta(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2)}$	$\frac{\beta\eta^2\mu\mathrm{R}(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2)^2}$
$SC5_2$	$-\frac{\eta(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2)}$	$\frac{\beta\eta^2\mu\mathrm{R}(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2)^2}$
$SC6_2$	$-\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_1-2)+4\lambda^2}$	0
$SC7_2$	$\frac{\eta(\alpha-\beta c)^2}{4\beta\eta-4\lambda^2}$	$\frac{\beta\eta^2\mu_1(\alpha-\beta c)^2}{8(\lambda^2-\beta\eta)^2}$
$SC8_2$	$-\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_{\mathrm{M}}-2)+4\lambda^2}$	$\frac{\beta\eta^2\mu\mathrm{R}(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+2\lambda^2)^2}$

Table 4.9.: Optimal Manufacturer's and Retailer's Utility for a Supply Chain with Two-Part Tariff Contract

Proposition 9: In a decentralized scenario with LTT

i. the optimal retail prices are in the following order:

   $p7_2 > p3_2 = p1_2 > p5_2 = p4_2 = pC = p2_2 = p0_2$ with $p8_2 = p6_2$ $\forall$ $\beta\eta > 2\lambda^2$, $\alpha > c\beta$ and $0 < \mu_1 = \mu_M = \mu_R < 1$

ii. the optimal wholesale prices are in the following order:

   $w7_2 > w3_2 = w1_2 > w8_2 = w5_2 = w4_2 > w2_2 = w0_2 > w6_2$ $\forall$ $\beta\eta > 2\lambda^2$, $\alpha > c\beta$ and $0 < \mu_1 = \mu_M = \mu_R < 1$

iii. the optimal franchise fees are in the following order:

   $F6_2 > F0_2 > F4_2$,$F3_2$, $F2_2 > F1_2$ $\forall$ $\beta\eta > 2\lambda^2$, $\alpha > c\beta$ and $0 < \mu_1 = \mu_M = \mu_R < 1$

iv. the optimal supply chain utilities are in the following order:

   $V8_{SC2} > V5_{SC2} = V4_{SC2} > VC_{SC} = V2_{SC2} = V0_{SC2} > V3_{SC2} = V1_{SC2}$ with $V6_{SC2} > VC_{SC}$ and $V7_{SC2} > V3_{SC2}$ $\forall$ $\beta\eta > 2\lambda^2$, $\alpha > c\beta$ and $0 < \mu_1 = \mu_M = \mu_R < 1$

	w	p	F
$SC0_2$	$\frac{\alpha\eta\mu_1+c\left(\lambda^2-2\beta\eta\right)}{\beta\eta(\mu_1-2)+\lambda^2}$	$\frac{\alpha\eta(\mu_1-1)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-2)+\lambda^2}$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{(\beta\eta(\mu_1-2)+\lambda^2)^2}$
$SC1_2$	$\frac{\eta\mu_1(\alpha-\beta c)}{2\beta\eta-\lambda^2}+c$	$\frac{\alpha\eta+\beta c\eta-c\lambda^2}{2\beta\eta-\lambda^2}$	$-\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_1-1)+\lambda^2\right)}{2(\lambda^2-2\beta\eta)^2}$
$SC2_2$	$\frac{\alpha\eta\mu_1+c\left(\lambda^2-2\beta\eta\right)}{\beta\eta(\mu_1-2)+\lambda^2}$	$\frac{\alpha\eta(\mu_1-1)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-2)+\lambda^2}$	$\frac{\eta\left(2\beta\eta-\lambda^2\right)(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+\lambda^2)^2}$
$SC3_2$	$\frac{\eta\mu_1(\alpha-\beta c)}{2\beta\eta-\lambda^2}+c$	$\frac{\alpha\eta+\beta c\eta-c\lambda^2}{2\beta\eta-\lambda^2}$	$-\frac{\beta\eta^2(\mu_1-1)(\alpha-\beta c)^2}{(\lambda^2-2\beta\eta)^2}$
SCC		$-\frac{-\alpha\eta\mu_1+\alpha\eta+\beta c\eta-c\lambda^2}{\beta\eta\mu_1-2\beta\eta+\lambda^2}$	
$SC4_2$	$\frac{\alpha\eta(\mu_\mathrm{M}-\mu_\mathrm{R})+c\left(\beta\eta(\mu_\mathrm{R}-2)+\lambda^2\right)}{\beta\eta(\mu_\mathrm{M}-2)+\lambda^2}$	$\frac{\alpha\eta(\mu_\mathrm{M}-1)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_\mathrm{M}-2)+\lambda^2}$	$-\frac{\beta\eta^2(\mu_\mathrm{R}-1)(\alpha-\beta c)^2}{(\beta\eta(\mu_\mathrm{M}-2)+\lambda^2)^2}$
$SC5_2$	$\frac{\alpha\eta(\mu_\mathrm{M}-\mu_\mathrm{R})+c\left(\beta\eta(\mu_\mathrm{R}-2)+\lambda^2\right)}{\beta\eta(\mu_\mathrm{M}-2)+\lambda^2}$	$\frac{\alpha\eta(\mu_\mathrm{M}-1)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_\mathrm{M}-2)+\lambda^2}$	$-\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_\mathrm{R}-1)+\lambda^2\right)}{2(\beta\eta(\mu_\mathrm{M}-2)+\lambda^2)^2}$
$SC6_2$	$\frac{\alpha\eta\mu_1+2c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-2)+2\lambda^2}$	$\frac{\alpha\eta(\mu_1-1)+c\left(2\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-2)+2\lambda^2}$	$\frac{\eta\left(2\beta\eta-\lambda^2\right)(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+2\lambda^2)^2}$
$SC7_2$	$\frac{\eta\mu_1(\alpha-\beta c)}{2\beta\eta-2\lambda^2}+c$	$\frac{\eta(\alpha-\beta c)}{2\beta\eta-2\lambda^2}+c$	$\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_1-1)+\lambda^2\right)}{8(\lambda^2-\beta\eta)^2}$
$SC8_2$	$\frac{\alpha\eta(\mu_\mathrm{M}-\mu_\mathrm{R})+\beta c\eta(\mu_\mathrm{R}-2)+2c\lambda^2}{\beta\eta(\mu_\mathrm{M}-2)+2\lambda^2}$	$\frac{\alpha\eta(\mu_\mathrm{M}-1)+c\left(2\lambda^2-\beta\eta\right)}{\beta\eta(\mu_\mathrm{M}-2)+2\lambda^2}$	$-\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_\mathrm{R}-1)+\lambda^2\right)}{2(\beta\eta(\mu_\mathrm{M}-2)+2\lambda^2)^2}$

Table 4.10.: Optimal Wholesale Price, Retail Price and Franchise Fee for a Supply Chain with Two-Part Tariff Contract

Propositions 8 and 9 show that under a LTT, several scenarios result in identical supply chain performance in terms of the green degree of the product, consumer surplus, and total utility. These equivalences are summarized in Table 4.12 for clarity. In addition, Figure 4.12, Figure 4.13 and Figure 4.14 provide a numerical illustration of these findings.

Scenario	SR	GR	Same Utility	Same Consumer Surplus	Same Green Degree
$SC0_2$	M	M	$SC2_2$	$SC2_2$, $SC4_2$, $SC5_2$	$SC2_2$, $SC4_2$, $SC5_2$
$SC1_2$	R	R	$SC3_2$	$SC3_2$	$SC3_2$
$SC2_2$	M	R	$SC0_2$	$SC0_2$, $SC4_2$, $SC5_2$	$SC0_2$, $SC4_2$, $SC5_2$
$SC3_2$	R	M	$SC1_2$	$SC1_2$	$SC1_2$
$SC4_2$	M, R	M	$SC5_2$	$SC0_2$, $SC2_2$, $SC5_2$	$SC0_2$, $SC2_2$, $SC5_2$
$SC5_2$	M, R	R	$SC4_2$	$SC0_2$, $SC2_2$, $SC4_2$	$SC0_2$, $SC2_2$, $SC4_2$
$SC6_2$	M	M, R	–	$SC8_2$	$SC8_2$
$SC7_2$	R	M, R	–	–	–
$SC8_2$	M, R	M, R	–	$SC6_2$	$SC6_2$

Table 4.12.: Performance Equivalence of Scenarios under LTT; SR=Social Responsibility and GR=Green Responsibility

	CS_{SC}	θ
$SC0_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+\lambda^2)^2}$	$\frac{\lambda(\beta c-\alpha)}{\beta\eta(\mu_1-2)+\lambda^2}$
$SC1_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\lambda^2-2\beta\eta)^2}$	$\frac{\lambda(\alpha-\beta c)}{2\beta\eta-\lambda^2}$
$SC2_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+\lambda^2)^2}$	$\frac{\lambda(c\beta-\alpha)}{\beta\eta(\mu_1-2)+\lambda^2}$
$SC3_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\lambda^2-2\beta\eta)^2}$	$\frac{\lambda(\alpha-\beta c)}{2\beta\eta-\lambda^2}$
$SC4_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2)^2}$	$\frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2}$
$SC5_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2)^2}$	$\frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2}$
$SC6_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_1-2)+2\lambda^2)^2}$	$-\frac{2\lambda(\alpha-\beta c)}{\beta\eta(\mu_1-2)+2\lambda^2}$
$SC7_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{8(\lambda^2-\beta\eta)^2}$	$\frac{\lambda(\alpha-\beta c)}{\beta\eta-\lambda^2}$
$SC8_2$	$\frac{\beta\eta^2(\alpha-\beta c)^2}{2(\beta\eta(\mu_{\mathrm{M}}-2)+2\lambda^2)^2}$	$-\frac{2\lambda(\alpha-\beta c)}{\beta\eta(\mu_{\mathrm{M}}-2)+2\lambda^2}$

Table 4.11.: Optimal Consumer Surplus and Green Degree of Product for a Supply Chain with Two-Part Tariff Contract

Table 4.12 shows that under the LTT, scenarios with the same allocation of social responsibility show identical supply chain performance in terms of utility, consumer surplus, and green degree, provided that only one party is responsible for greening. For example, $SC0_2$ and $SC2_2$ yield the same outcomes, while $SC6_2$ differs in all three metrics due to the effect of shared green responsibility. A similar pattern is observed in $SC4_2$, $SC5_2$, and $SC8_2$: although all three scenarios involve shared social responsibility, only $SC4_2$ and $SC5_2$ show the same results. In contrast, $SC8_2$ matches $SC6_2$ in terms of consumer surplus and green degree.

In general, scenarios with shared social responsibility ($SC4_2$, $SC5_2$) and those where only the manufacturer is socially responsible ($SC0_2$, $SC2_2$) achieve the same performance in consumer surplus and green degree. This also applies to $SC6_2$ and $SC8_2$. These results suggest that, under a LTT, green responsibility does not affect the supply chain's performance if social responsibility allocation is the same.

This outcome highlights that the introduction of a franchise fee effectively addresses the limitations of the WP, especially the uneven distribution of greening costs. By allowing the manufacturer to recover costs through the franchise fee, the burden of green investment can be more evenly shared between the two supply chain participants, regardless of which party has the responsibility. As a result, the specific assignment of green responsibility becomes less relevant for the overall performance, as long as the social responsibility structure remains unchanged.

Indeed, the impact of social responsibility differs significantly depending on whether it lies with the manufacturer or the retailer. In scenarios where the manufacturer has social concerns (e.g., $SC0_2$, $SC2_2$, $SC4_2$, $SC5_2$, $SC6_2$, and $SC8_2$), there is a clear incentive to lower the wholesale price, potentially even below marginal cost, because profits can be recovered via the franchise fee. This cost-sharing mechanism enables the retailer to lower the retail price, resulting in higher demand, improved consumer surplus, and a higher green degree of the product. By contrast, in scenarios where only the retailer is responsible for consumer surplus (e.g., $SC1_2$, $SC3_2$, $SC7_2$), the manufacturer lacks the incentive to adjust the wholesale price. Consequently, the retail price remains higher, reducing demand and limiting the scope for sustainability improvements. These dynamics are are also reflected in Proposition 9, which identifies the highest wholesale and retail prices in $SC7_2$, followed by $SC3_2$ and $SC1_2$.

Consequently, in a supply chain with a LTT, where the manufacturer acts as the leader, assigning social responsibility to the manufacturer is essential to improve overall supply chain performance.

4.2.2. Results of Sensitivity Analysis

Sensitivities of the retail and wholesale prices are examined in Table 4.14, and the sensitivity of the green degree of the product is illustrated inTable 4.13. The results of the sensitivity analysis are summarized in Propositions 10 to 13.

Scenario	α	η	γ	c
$SC0_2$	$+$	$-$	$+$	$+$
$SC1_2$	$+$	$-$	$+$	$+$
$SC2_2$	$+$	$-$	$+$	$+$
$SC3_2$	$+$	$-$	$+$	$+$
$SC4_2$	$+$	$-$	$+$	$+$
$SC5_2$	$+^B$	$-^B$	$+^B$	$+$
$SC6_2$	$+^B$	$-^B$	$+^B$	$+^B$
$SC7_2$	$+$	$-$	$+$	$+^B$
$SC8_2$	$+^B$	$-^B$	$+^B$	$+^B$
SCC	$+$	$-$	$+$	$+$

Retail Price

Scenario	α	η	λ	c
$SC0_2$	$+$	$-$	$+$	$-$
$SC1_2$	$+$	$-$	$+$	$-$
$SC2_2$	$+$	$-$	$+$	$-$
$SC3_2$	$+$	$-$	$+$	$-$
$SC4_2$	$+$	$-$	$+$	$-$
$SC5_2$	$+$	$-$	$+$	$-$
$SC6_2$ (M/R	$+^B$	$-$	$+$	$-^B$
$SC7_2$ (M/R)	$+$	$-$	$+$	$-$
$SC8_2$ (M/R)	$+^B$	$-$	$+$	$-^B$
SCC	$+$	$-$	$+$	$-$

Green Degree

Table 4.13.: Sensitivity Analysis of Retail Price and Green Degree in a Decentralized Scenario with Two-Part Tariff Contract. In all scenarios the baseline assumptions $\forall\ \beta\eta > \lambda^2$, $\alpha > \beta c$ hold. Cases marked with (B) require $\forall\ 0 < \mu_M, \mu_1 < 1$, $\beta\eta > 2\lambda^2$.

Proposition 10: In a decentralized supply chain with a LTT:

i. the retail price is increasing in α, λ, c and decreasing in η in SCC, $SC0_2$, $SC1_2$, $SC2_2$, $SC3_2$, $SC4_2$ $\forall\, \beta\eta > \lambda^2, \alpha > \beta c$

ii. the retail price is increasing in α, λ, c and decreasing in η in $SC5_2$, $SC6_2$, $SC7_2$, $SC8_2$ $\forall\, \beta\eta > 2\lambda^2, 0 < \mu M + \mu R < 1$

Proposition 11: In a decentralized supply chain with LTT:

i. the wholesale price is increasing in α, λ, c and decreasing in η in $SC1_2$, $SC3_2$, $SC7_2$ $\forall\, \beta\eta > 2\lambda^2$

ii. the wholesale price is increasing in η, c and decreasing in α, λ in $SC0_2$, $SC2_2$, $SC6_2$ $\forall\, \beta\eta > 2\lambda^2$

iii. the wholesale price is increasing in c in $SC4_2$, $SC5_2$, $SC8_2$ and increasing or decreasing in α, η, λ depending on the relative magnitudes of μ_R and μ_M $\forall\, \beta\eta > 2\lambda^2, \alpha > \beta c, \mu_1 > 0$

Scenario	α	η	λ	c
$SC0_2$	$-$	$+$	$-$	$+$
$SC1_2$	$+$	$-$	$+$	$+$
$SC2_2$	$-$	$+$	$-$	$+$
$SC3_2$	$+$	$-$	$+$	$+$
$SC4_2$	$\pm^D$	$\pm^D$	$\pm^D$	$+$
$SC5_2$	$\pm^D$	$\pm^D$	$\pm^D$	$+$
$SC6_2$	$-^C$	$+$	$-$	$+^C$
$SC7_2$	$+$	$-$	$+$	$+^C$
$SC8_2$	$\pm^D$	$\pm^D$	$\pm^D$	$+^C$

Wholesale Price

Scenario	α	η	λ	c
$SC0_2$	$+$	$-$	$+$	$-$
$SC1_2$	$\pm^E$	$\pm^E$	$\pm^E$	$\pm^E$
$SC2_2$	$+$	$-$	$+$	$-$
$SC3_2$	$+$	$-$	$+$	$-$
$SC4_2$	$\pm^D$	$-^B$	$+^B$	$-^B$
$SC5_2$	$\pm^E$	$\pm^E$	$\pm^E$	$\pm^E$
$SC6_2$	$+^C$	$-^C$	$+^C$	$-^C$
$SC7_2$	$\pm^E$	$\pm^E$	$\pm^E$	$\pm^E$
$SC8_2$	$\pm^E$	$\pm^E$	$\pm^E$	$\pm^E$

Franchise Fee

Table 4.14.: Sensitivity Analysis of Wholesale Price and Franchise Fee in a Decentralized Scenario with Two-Part Tariff Contract. In all scenarios the baseline assumptions $\forall\, \beta\eta > \lambda^2$, $\alpha > \beta c$ hold. Cases marked with (B) require $\forall\, 0 < \mu_M, \mu_1 < 1$. Cases marked with (C) require $\forall\, \beta\eta > 2\lambda^2$. Cases marked with (D) depend on the relative magnitudes of μ_R and μ_M, increasing or decreasing depending on $\mu_R > \mu_M$ or vice versa. Cases marked with (E) are sensitive to the values of μ_R or μ_M, increasing or decreasing depending on these values.

Proposition 12: In a decentralized supply chain with LTT:

i. the franchise fee is increasing in α, λ and decreasing in η, c in $SC0_2$, $SC2_2$, $SC3_2$, $SC6_2$ $\forall\, \beta\eta > 2\lambda^2$

ii. the franchise fee is increasing in λ, decreasing in η, c and increasing or decreasing in α depending on the value of μ_R and μ_M in $SC4_2$

iii. the franchise fee is increasing or decreasing in α, η, λ, c depending on the value of μ_1, μ_R, μ_M in $SC1_2$, $SC5_2$, $SC7_2$, $SC8_2$

Proposition 13: In a decentralized supply chain with LTT:

i. The green degree is increasing in α and λ and decreasing in η, c in $SC0_2$, $SC1_2$, $SC2_2$, $SC3_2$, $SC4_2$, $SC5_2$, $SC7_2$ $\forall\, \beta\eta > \lambda^2, \alpha > \beta c$.

ii. The green degree increasing in α and λ and decreasing in η, c in $SC6_2$, $SC8_2$ $\forall\, \beta\eta > 2\lambda^2, 0 < \mu_M, \mu_1 < 1$

From Propositions 10 and 13, we know that the retail price and the green degree of product show the same parametric sensitivities as in Model 1. Therefore, we can conclude that the introduction of a LTT does not lead to changes in sensitivities in these two decision variables.

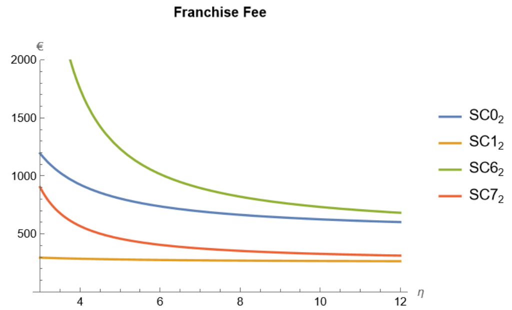
However, Proposition 11 reveals changes in the sensitivity of the wholesale price. With the introduction of the LTT, the manufacturer manages its pricing via both, the wholesale price and franchise fee. From Propositions 11 and 12 we observe that in scenarios where the manufacturer has individual social responsibility ($SC0_2$, $SC2_2$ and $SC6_2$), the manufacturer decreases the wholesale price in response to increases in α and λ, while increasing the franchise fee. As green demand becomes stronger (higher α and λ), the manufacturer faces higher total green investment costs, but shifts these costs to the fixed fee, ensuring a competitive wholesale price to stimulate demand. In contrast, with an increase in green investment costs (η), the manufacturer lowers the franchise fee in response to fewer green investments and increases the wholesale price. This highlights the flexibility in price adjustment for the manufacturer under the LTT.

On the other hand, scenarios $SC1_2$, $SC3_2$, and $SC7_2$, where the retailer has individual social responsibility, show different sensitivity trends: The wholesale price increases with α and λ because the retailer's ESG investments lead to a higher customer's willingness to pay, allowing the manufacturer to raise the wholesale price without affecting demand. In contrast, as η increases and the degree of green of the product decreases (cf. Proposition 13), the manufacturer responds by reducing the wholesale price to maintain consumer surplus and demand.

In Figure 4.7 and Figure 4.8, the sensitivity of the wholesale price and franchise fee to the green demand coefficient (λ) and the green cost coefficient (η) is illustrated in the numerical example. It should be noted that $SC0_2$ represents $SC2_2$ and $SC1_2$ represents $SC3_2$ in the wholesale price, as the results in these scenarios are identical.

In certain scenarios, such as $SC0_2$, $SC2_2$, and $SC6_2$, where the manufacturer is socially responsible, the model yields a negative wholesale price. While this outcome is not economically realistic, since it implies the manufacturer is effectively paying the retailer, it highlights a theoretical mechanism in which the manufacturer lowers the wholesale price to incentivize lower retail pricing and increased consumer surplus. In these cases,

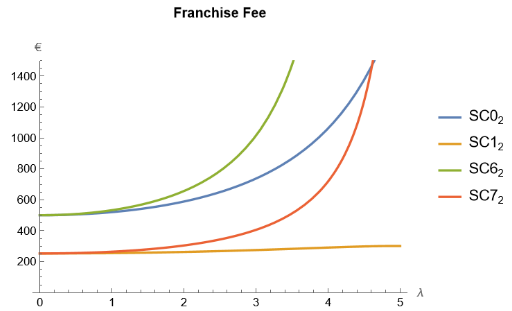
(a) Wholesale Price



(b) Franchise Fee

Figure 4.7.: Impact of Green Cost Coefficient on Wholesale Price and Franchise Fee

(a) Wholesale Price



(b) Franchise Fee

Figure 4.8.: Impact of Green Demand Coefficient on Wholesale Price and Franchise Fee

the manufacturer primarily captures their profit through the franchise fee. However, this does not apply universally: in other scenarios, especially those where the manufacturer is not socially responsible (e.g., $SC1_2$, $SC3_2$, $SC7_2$), profit is extracted through both, wholesale price and franchise fee.

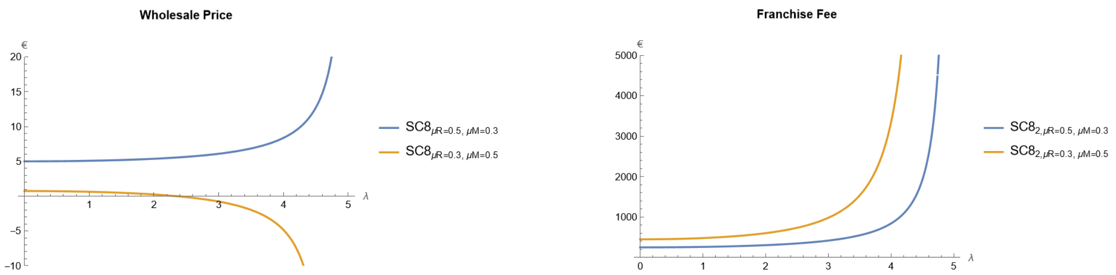
In scenarios where the manufacturer has social responsibility, an increase in the green cost coefficient leads to a higher wholesale price and a lower franchise fee, as the manufacturer passes on the higher marginal costs to the retailer. The franchise fee is reduced accordingly to keep the retailer willing to participate. In contrast, when green demand increases, the wholesaler reduces the wholesale price to stimulate demand and allow a competitive retail price. The loss in margin is compensated for by increasing the franchise fee.

In scenarios where the retailer has social concerns, namely $SC1_2$ and $SC3_2$, a higher green cost coefficient leads to a slight decrease in the wholesale price and a slight increase in the franchise fee. Interestingly, in $SC7_2$, where the retailer is solely responsible for social concerns and both parties share the green responsibility, the wholesale price and the franchise fee are both decreasing with increases in μ in the example. The opposite effect is observed when analyzing the impact of the green demand coefficient, where an increase in green demand leads to higher wholesale prices and franchise fees. In $SC7_2$, the manufacturer acts as a pure profit maximizer, and as green demand increases, the consumer's willingness to pay increases. The manufacturer can capture this increased willingness to pay by charging a higher wholesale price. Similarly, as green investments increase, the manufacturer attempts to pass on the higher costs to the retailer through a higher franchise fee.

Notably, scenarios with shared responsibilities, i.e. $SC8_2$, indicate that sensitivities change with increases in μ. Depending on the relative magnitude of $\mu_R > \mu_M$, the wholesale price increases or decreases in α, η and λ, highlighting the effect of individual social investment parameters of the supply chain participants on the manufacturer's pricing strategy.

Proposition 11a: In a decentralized supply chain with LTT:

i. The wholesale price is increasing in c in $SC8_2$. When $\mu_M > \mu_R$, the wholesale price increasing in η and decreasing in α, λ. When $\mu_R > \mu_M$, the wholesale price is decreasing in η and increasing in α, λ $\forall\, \beta\eta > 2\lambda^2$



(a) Wholesale Price

(b) Franchise Fee

Figure 4.9.: Impact of Green Demand Coefficient on Wholesale Price and Franchise Fee depending on the relative magnitude of μ_R and μ_M

When the level of social concern of the manufacturer is higher, the wholesale price increases in η and decreases in α and λ. The opposite is the case, when the retailer's social investment is higher than that of the manufacturer. Interestingly, Proposition 10 reveals that the retail price always increases in α, λ, c and decreases in η. Figure 4.9 shows that in the numerical example, when $\mu_R > \mu_M$, the wholesale price and the franchise fee increase in λ. However, when $\mu_M > \mu_R$, the wholesale price decreases while the franchise fee increases. When the manufacturer has greater social concerns, the manufacturer lowers the wholesale price and compensates for their higher ESG investment costs through the franchise fee. In contrast, when the retailer is more socially concerned ($\mu_R > \mu_M$), the wholesale price increases as the manufacturer knows that the retailer derives increased utility from consumer surplus and is willing to accept a higher wholesale price. Simultaneously, the franchise fee also increases, reflecting the manufacturer's strategic behavior to capture the retailer's higher willingness to invest in ESG activities.

In general, the sensitivity analysis shows that the manufacturer's pricing strategy under a LTT is strongly affected by the allocation of social responsibilities and the level of social investment preferences of the supply chain members. In contrast, the allocation of green responsibilities does not show any notable impact.

4.2.3. Results of Numerical Example

Analogous to Model 1, to illustrate the results of the Model 2, this thesis presents a numerical example. Based on the parameters as defined in Table 4.7, the following results are obtained:

Utility of Supply Chain ($V_{\mathbf{SC}}$)
$SC8_2 > SC6_2 > SC7_2 > SC5_2 = SC2_2 > SCC = SC2_2 = SC0_2 > SC3_2 = SC1_2$

Profit of Supply Chain ($\pi_{\mathbf{SC}}$)
$SC7_2 > SC8_2 = SC6_2 > SC3_2 = SC1_2 > SCC = SC5_2 = SC4_2 = SC2_2 = SC0_2$

Wholesale Price (w)
$SC7_2 > SC3_2 = SC1_2 > SC8_2 = SC5_2 > SC4_2 > SC2_2 = SC0_2 > SC6_2$

Franchise Fee(F)
$SC6_2 > SC0_2 > SC8_2 > SC2_2 > SC4_2 > SC7_2 = SC5_2 > SC3_2 > SC1_2$

Retail Price (p)
$SC7_2 > SC8_2 = SC6_2 > SC3_2 = SC1_2 > SCC = SC5_2 = SC4_2 = SC2_2 = SC0_2$

Consumer Surplus (CS)
$SC8_2 = SC6_2 > SCC = SC7_2 = SC5_2 = SC4_2 = SC2_2 = SC0_2 > SC3_2 = SC1_2$

Green Degree (θ)
$SC8_2 = SC6_2 > SC7_2 > SCC = SC5_2 = SC4_2 = SC2_2 = SC0_2 > SC3_2 = SC1_2$

In the second model with a two-part tariff contract, the highest overall supply chain performance in the example is achieved when both supply chain participants share social and green responsibilities. Specifically, $SC8_2$ yields the highest values for supply chain utility, consumer surplus, and green degree, clearly outperforming the centralized scenario. Notably, only $SC7_2$ generates a higher supply chain profit than $SC8_2$. In general, all scenarios demonstrate equal or superior economic and sustainable performance compared to the coordinated scenario, with the exception of $SC1_2$ and $SC3_2$, where only the retailer invests in social efforts.

Comparing the economic performance of the supply chain under a two-part tariff contract as presented in Figure 4.10, it is evident that, with the exception of $SC1_2$ and $SC3_2$, every scenario achieves the same or a higher total supply chain utility than the coordinated benchmark scenario. As shown in Table 4.12 scenarios $SC0_2$ and $SC2_2$, $SC1_2$ and $SC3_2$, as well as $SC4_2$ and $SC5_2$, yield identical performance results. The

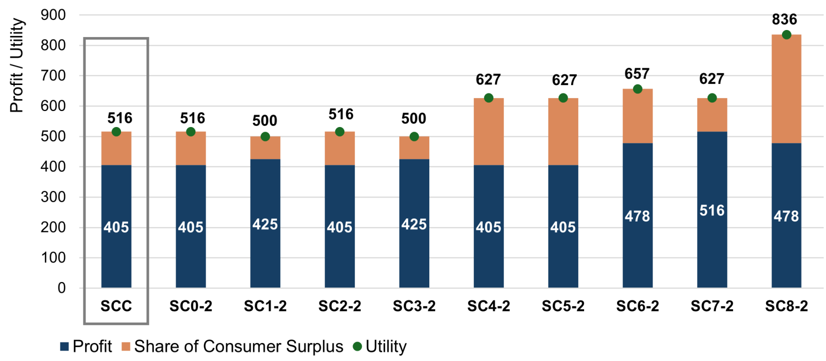


Figure 4.10.: Model 2: Total Utility of Supply Chain

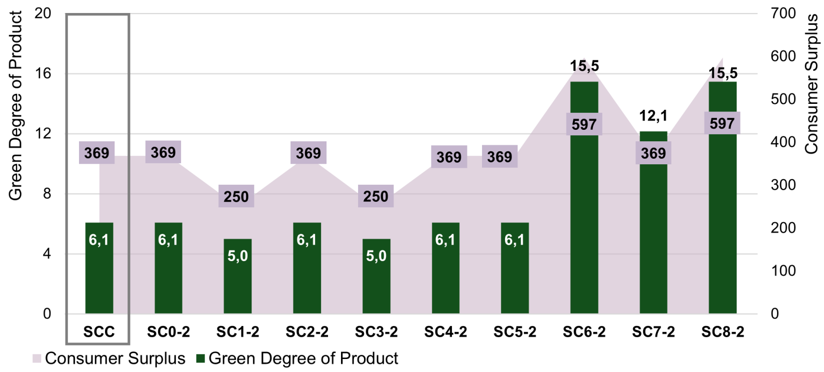


Figure 4.11.: Model 2: Sustainability of Supply Chain

highest supply chain utility is observed in $SC8_2$, $SC6_2$ ranks second, followed by $SC7_2$, $SC5_2$, and $SC4_2$. Consequently, shared responsibility leads to improved supply chain utility under a two-part tariff contract in the numerical example.

When comparing the profits across the scenarios, $SC7_2$ yields the highest profit, followed by $SC8_2$ and $SC6_2$. Moreover, the profits in $SC3_2$ (which are identical to those in $SC1_2$) exceed those in $SC5_2$ and $SC4_2$, which are, in turn, equal to the profits in $SC2_2$ and $SC0_2$. Finally, when evaluating share of consumer surplus as part of utility, $SC4_2$, $SC5_2$, and $SC8_2$ record clearly higher performance values, followed by $SC6_2$.

Comparing the sustainability performance of the supply chain as illustrated in Figure 4.11, scenarios $SC8_2$ and $SC6_2$ exhibit the highest values for both green degree and consumer surplus. They are followed by $SC7_2$, $SC5_2$, $SC4_2$ in the example, again demonstrating the positive impact of shared responsibilities. Notably, $SC1_2$ and $SC3_2$ stand out with the lowest performance in both sustainable metrics. Furthermore, in $SC8_2$, $SC6_2$, and $SC7_2$ the green degree shows a significantly improved performance compared to the other scenarios. This is primarily driven by the higher total amount of green investments resulting from shared green responsibilities.

4.2.4. Analysis of Sustainable Performance of Supply Chain

When comparing the sustainable performance of the supply chain under a LTT with a WP in the numerical example, all scenarios reveal improved sustainability scores, as shown in Figure 4.12 and Figure 4.13. As also shown in Proposition 8, the highest social and green performance of supply chain is achieved in $SC8_2$ and $SC6_2$.

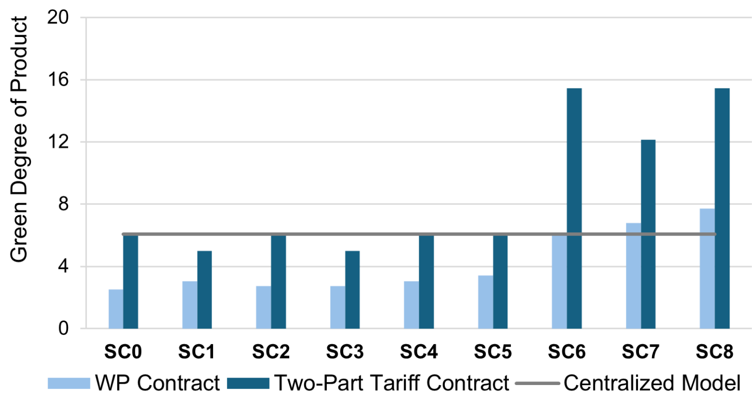


Figure 4.12.: Impact of Contract Type on Green Degree of Product

With further analyzing the sustainability of supply chain with regards to the responsibility allocation, the following conclusions are made: According to Proposition 8, $SC0_2$ and $SC2_2$ with individual responsibility allocation and $SC4_2$ and $SC5_2$ with shared responsibilities achieve the benchmark case. Furthermore, $SC8_2$ and $SC6_2$ surpass the benchmark case. Although no general conclusion can be drawn for $SC7_2$, the numerical example shows that the sustainability metrics in $SC7_2$ also exceed the benchmark case. Hence, only in scenarios where the retailer has social responsibility and green investments are not shared, $SC1_2$ and $SC3_2$, the performance of the supply chain does not meet the benchmark case under a LTT.

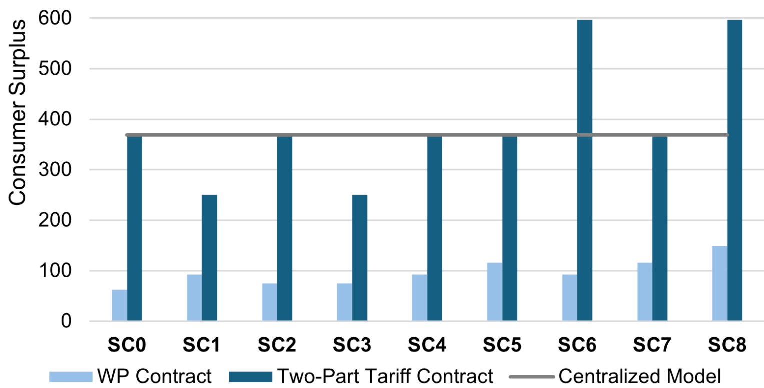


Figure 4.13.: Impact of Contract Type on Consumer Surplus

Interestingly, while $SC4_2$, $SC5_2$, and $SC8_2$ all involve shared social responsibility, the retailer's contribution (represented by μ_R) has no impact on sustainability outcomes. In each of these cases, the optimal results of green degree and consumer surplus depend solely on the social concern of the manufacturer (μ_M). Moreover, in scenarios where the retailer alone is socially responsible ($SC1_2$, $SC3_2$, $SC7_2$), sustainability performance is not dependent on μ at all. This leads to the following conclusion: Under a LTT, the social investment parameter of the retailer has no influence on the sustainability outcomes, regardless of the responsibility structure. Only the social concern of the manufacturer impacts the environmental and social performance of the supply chain. This finding explains why $SC6_2$ and $SC8_2$ reveal the same sustainable supply chain performance as well as $SC0_2$, $SC2_2$, $SC4_2$ and $SC5_2$. Consequently, shared social responsibilities do not lead to improved ESG performance under a LTT. In addition, the findings indicate that assigning social responsibility to the manufacturer results in higher supply chain sustainability under this contract type.

The higher impact of the manufacturer can be attributed to the underlying game-theoretic structure in which the manufacturer acts as the leader. Under the LTT, this leadership allows the manufacturer to fully exercise their decision-making power. As a result, their level of social concern directly shapes the environmental and social performance of the supply chain. If the power dynamics were reversed, placing the retailer as the leader of the supply chain, different results would likely emerge.

Overall, Proposition 8 reveals a positive impact of shared green investments. Although, $SC8_2$, $SC4_2$ and $SC5_2$ all share the social responsibility allocation, $SC8_2$ indicates higher sustainable performance of supply chain due to the shared responsibility for green investments. In addition, $SC7_2$ shows a higher sustainable performance than $SC1_2$ and $SC3_2$. Consequently, shared green investments of the two supply chain participants lead to a higher green degree of product. The optimal levels of green degree across scenarios follow the same order as the optimal levels of consumer surplus.

As already observed in Model 1, when supply chain participants share green investments, they always invest the same amount in greening. In addition, similar to Model 1 (cf. Proposition 3), Proposition 8 shows that also under a LTT, shared green responsibility not only increases the total green degree of product, but incentivizes each participant to invest more than they would independently. This mutual reinforcement highlights a key strength of collaborative ESG efforts.

4.2.5. Analysis of Economic Performance of Supply Chain

As noted in Table 4.12 the introduction of the franchise fee leads to identical supply chain utility outcomes in several scenarios. However, a closer differentiation between the utilities of the manufacturer and the retailer reveals further structural patterns.

The manufacturer's utility function is identical in $SC0_2$, $SC2_2$, $SC4_2$, and $SC5_2$ as well as in $SC6_2$ and $SC8_2$. The only formal difference lies in the use of μ_1 versus μ_M; however, in $SC0_2$ and $SC2_2$, the manufacturer is solely responsible for social investment, allowing μ_1 to be equated with μ_M. Furthermore, the manufacturer's utility in $SC6_2$ and $SC8_2$ differs from $SC0_2$, $SC2_2$, $SC4_2$, and $SC5_2$ only in the higher weighting of

λ, the green demand coefficient. Similarly, the manufacturer's utility function in $SC7_2$ deviates from $SC1_2$ and $SC3_2$ solely due to a stronger weighting of λ. These results show that the manufacturer's utility is independent of the allocation of green responsibilities between the retailer and manufacturer. However, shared green investments impact the manufacturer's utility positively. The retailer's utility functions mirror this structure: they are identical in $SC1_2$ and $SC3_2$, as well as in $SC4_2$ and $SC5_2$. Additionally, the retailer's utility function in $SC8_2$ only differs from $SC4_2$ and $SC5_2$ in the increased weighting of λ, reflecting the impact of shared green investments.

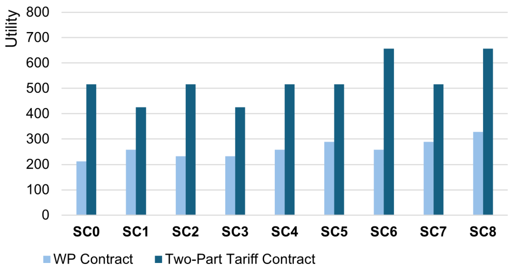
These findings further confirm that, under a LTT, the utilities of supply chain participants are solely impacted by the allocation of social responsibilities and shared green investments. Accordingly, the total supply chain utility in $SC4_2$ and $SC5_2$ differs from that in $SC0_2$ and $SC2_2$ only because the retailer benefits from consumer surplus due to shared social responsibility. In contrast, the manufacturer's utility remains unchanged across all these scenarios. Additionally, shared green investments in $SC6_2$ and $SC8_2$ result in a higher weighting of the green demand coefficient in the utility functions of both the manufacturer and the retailer. This represents the only distinction between these two scenarios and $SC4_2$ and $SC5_2$.

While in Model 1, the utility function of both the manufacturer and the retailer depends on μ in all scenarios, in Model 2, the utility of the manufacturer is independent of μ in scenarios where only the retailer is responsible for social investments ($SC1_2$, $SC3_2$ and $SC7_2$). In addition, the utility of the retailer is independent of μ in scenarios where only the manufacturer has social responsibility ($SC0_2$, $SC2_2$, $SC6_2$). This indicates that the LTT structurally decouples the utility of each participant in the supply chain from the social preferences of the other.

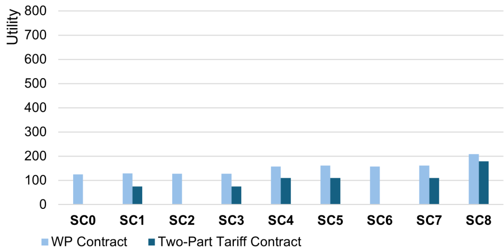
Furthermore, when the retailer and the manufacturer share social responsibilities, the utility function of the manufacturer depends only on μ_M, whereas the utility function of the retailer depends on μ_M and μ_R. Consequently, when social responsibilities are shared, the manufacturer does not benefit from a higher social interest of the retailer, whereas the retailer's utility is directly impacted by the social investments of the manufacturer.

When analyzing the retail and wholesale price, it is notable that, under a LTT, the wholesale price is dependent on μ_1 or μ_M and μ_R. However, the retail price depends only on μ_1 in scenarios where the manufacturer is socially responsible. In scenarios where the retailer has the sole responsibility for the consumer surplus, the retail price is not dependent on a social investment parameter. In scenarios with shared social responsibilities, the retail price is only dependent on μ_M. These results confirm, that with a LTT the manufacturer exercises the complete power over the retailer making the retailer's social investment irrelevant to overall supply chain performance.

This power structure becomes evident, when comparing the economic performance of the participants in the supply chain in the numerical example. Under both types of contracts (wholesale price and two-part tariff), the manufacturer consistently achieves higher utility than the retailer, regardless of the allocation of responsibility as shown in Figure 4.14. However, this disparity becomes more pronounced with the introduction of a LTT. Specifically, the inclusion of a franchise fee in conjunction with the wholesale



(a) Utility of Manufacturer



(b) Utility of Retailer

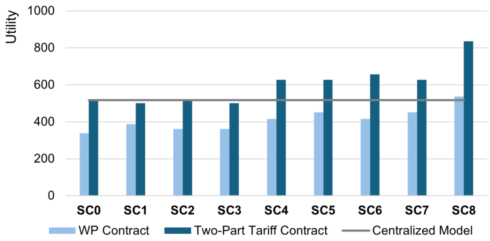
Figure 4.14.: Impact of Contract Type on Supply Chain's Participant's Utility

price significantly increases the utility of the manufacturer, while the utility of the retailer declines, even reaching zero in scenarios $SC0_2$, $SC2_2$ and $SC6_2$. In fact, under a LTT, the retailer's profit remains zero in all scenarios, as shown in section A.2. Only in cases where the retailer incorporates social welfare, thus obtaining additional utility from consumer surplus (cf. $SC1_2$, $SC3_2$, $SC4_2$, $SC5_2$, $SC7_2$ and $SC8_2$), the total utility of the retailer exceeds zero, while the manufacturer earns profits in all scenarios. This shift illustrates a clear redistribution of economic benefit toward the manufacturer under the two-part tariff mechanism.

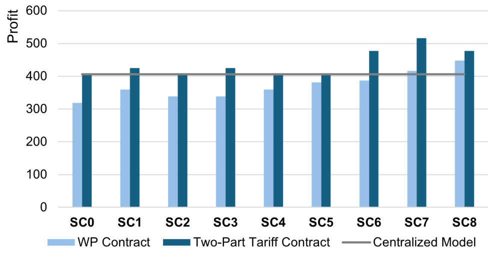
Overall, it is evident that in scenarios where the manufacturer holds social responsibility, the manufacturer generates profits primarily through the franchise fee, while charging a lower wholesale price. In contrast, in scenarios where the retailer has social concerns, the manufacturer charges a higher wholesale price and a lower franchise fee. When the manufacturer is responsible for social concerns, their goal is to encourage the retailer to lower the retail price by charging a lower wholesale price, thereby reducing the retailer's marginal costs. However, to compensate for the reduced margin from the wholesale price, the manufacturer collects profits via the franchise fee, which does not affect the retailer's pricing or green investment decisions. On the other hand, when the retailer cares about consumer surplus, they voluntarily set a lower retail price to stimulate demand. In this case, the manufacturer, who does not have social concerns, acts as a profit-maximizer and increases the wholesale price to extract more profit. Since the manufacturer already ensures a high profit from the wholesale price, the franchise fee is reduced. The findings indicate that the retailer's profits always remain equal to zero in these scenarios.

Although the manufacturer gains higher profits in scenarios where the retailer has social concerns, the total utility of the manufacturer (profit + utility) is higher in scenarios where the manufacturer holds the social responsibility. This behavior reflects the leader-follower dynamic of the supply chain and illustrates the flexibility of the LTT. The manufacturer, as the leader, adjusts pricing strategically based on the retailer's social investment. As a result, the allocation of social responsibilities influences how profits are extracted.

In general, all scenarios, regardless of whether they have individual or shared responsibilities, demonstrate improved performance under a LTT compared to the WP in the numerical example. $SC0_2$, $SC2_2$ thereby achieve the same sustainable and economic



(a) Total Utility of Supply Chain

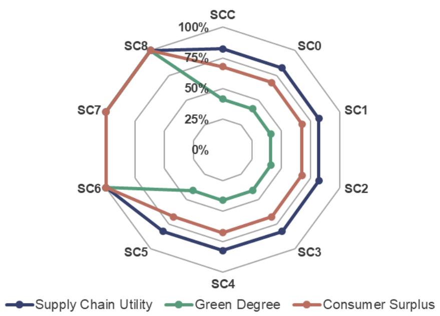


(b) Total Profit of Supply Chain

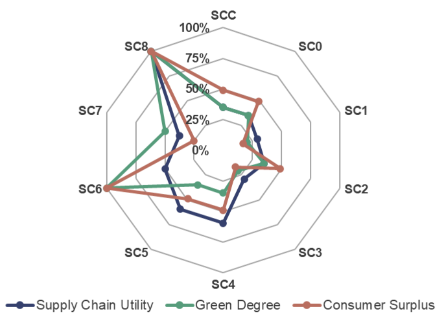
Figure 4.15.: Impact of Contract Type on Supply Chain's Economic Performance

performance as the centralized scenario, highlighting the value of giving the manufacturer responsibility for social investment while coordinating green investment through pricing mechanisms. The franchise fee allows the manufacturer to retain greater control over the profit distribution, enabling better alignment of incentives within the supply chain. As a result, coordination improves even without full centralization. This outcome aligns with existing literature in that a cooperation contract leads to better supply chain performance (Sinayi and Rasti-Barzoki, 2018, Jamali and Rasti-Barzoki, 2018).

4.2.6. Analysis of ESG Investment Parameters



(a) $\forall\ \mu_1 = \mu_M = \mu_R = 0$



(b) $\forall\ \mu_1 = \mu_M = \mu_R = 0.7$

Figure 4.16.: Relative Performance of Supply Chain with LTT in All Scenarios as Percentage of Maximum Value Across All Scenarios ($\forall\alpha = 100, \beta = 5, c = 3, \eta = 6, \lambda = 3$)

Figure 4.16 illustrates the economic and sustainability performance of the supply chain in all scenarios by comparing two cases in the numerical example. The first case represents the results of a purely profit-oriented supply chain ($\mu_1 = \mu_M = \mu_R = 0$), and in the second case, the participants of the supply chain have a high level of social concern ($\mu_1 = \mu_M = \mu_R = 0.7$). Performances are measured relative to the maximum performance achieved in all scenarios to highlight variations.

In the profit-maximizing case, two distinct performance groups can be observed. The scenarios SC_C, $SC0_2$, $SC1_2$, $SC2_2$, $SC3_2$, $SC4_2$, and $SC5_2$ show similar and relatively lower performance. In contrast, $SC6_2$, $SC7_2$, and $SC8_2$ achieve noticeably higher results. Since social concerns are excluded in this case, the differences in performance are solely driven by how green investment responsibilities are allocated.

Overall, results confirm the earlier findings: Under a LTT, the specific assignment of individual green responsibilities has no impact, as additional costs are compensated by the franchise fee. Only shared green investments lead to measurable improvements in supply chain performance. Scenarios with shared green responsibilities, namely $SC6_2$, $SC7_2$, and $SC8_2$, not only achieve a significantly higher green degree but also perform better in terms of consumer surplus and overall utility. The increase in consumer surplus is driven by a higher willingness to pay due to the higher green degree of product. In addition, supply chain utility (= supply chain profit), is positively influenced by the higher green demand. The results show that in a pure profit-driven supply chain under a LTT, the supply chain performs significantly better with shared green responsibilities, not only in the green degree, but also in social and economic performance.

When the supply chain exhibits a high level of social concern, scenarios $SC6_2$ and $SC8_2$ show a significantly improved performance, clearly outperforming the centralized scenario. In both scenarios, the manufacturer and retailer share responsibility for green investments. However, what distinguishes them from $SC7_2$, where green responsibilities are also shared, is the inclusion of social concern from the manufacturer or both parties. In contrast, in $SC7_2$, only the retailer considers consumer surplus in their decision-making.

In general, the outcomes suggest that the strongest economic and sustainability outcomes under a LTT are achieved when the responsibilities for green investments are shared, regardless of the level of social concern. However, when social concerns are present, sharing social responsibility or assigning social responsibility solely to the manufacturer leads to improved sustainable and economic supply chain performance.

To provide a clearer perspective, consider a real-world example from the hotel real estate industry. In this context, the building owner (lessor) and the hotel operator (lessee) generally share similar ESG interests, but green investments, such as energy-efficient infrastructure or sustainable materials, are often cost-intensive and yield returns only in the long term. If the owner attempts to recover these investments solely through increased rent (=wholesale price), the hotel operator may, in turn, raise room rates (retail price), ultimately transferring the cost burden to the consumer. This approach risks lowering the long-term value of the investment, as investments remain low. Instead, both parties must coordinate and agree on a fixed, jointly financed investment strategy (=franchise fee) to ensure that sustainability initiatives are both economically viable and effectively implemented.

4.2.7. Role of Governmental Intervention in Supply Chain Performance

This part discusses the impact of introducing the government as a third participant and leader in the supply chain. In this structure, the manufacturer becomes the first follower and the retailer the second. In distinction from Models 1 and 2, in Models 3 and 4 with governmental intervention, the consumer pays a tax in addition to the retail price $(p+\tau)$. Due to the limited scope of this thesis and the relatively modest additional insights from the results, the analysis focuses only on the most significant observations. For future research, a more detailed investigation, particularly into the influence of individual parameters and differentiated policy mechanisms, is recommended to gain deeper insights.

The optimal outcomes of the supply chain under a WP with governmental intervention are summarized in Appendix C. Table C.1 and Table C.4 present the optimal utility levels for the manufacturer and retailer in Models 3 and 4. Table C.2 and Table C.5 show the government's utility along with the corresponding tax rates. Finally, Table C.3 and Table C.6 illustrate the optimal consumer surplus and green degree of the product in each model.

In general, governmental intervention does not lead to a coordination of the supply chain. Only Model 4 achieves a coordinated supply chain, due to the introduction of a LTT, similar to Model 2. The results on optimal responsibility allocation with regard to the type of contract remain largely unchanged with the introduction of the government as an additional actor. The pattern of identical performance outcomes across certain scenarios in terms of utility and sustainability remains consistent with the introduction of the LTT.

Results of Numerical Example

The results of the numerical example are based on the parameters defined as shown in Table 4.7 and illustrated in Appendix C. Figure C.1 and Figure C.3 present the supply chain utilities in Model 3 and Model 4. Figure C.2 and Figure C.4 present the supply chain sustainability for both models.

In general, when comparing models with governmental intervention to those without, sustainable supply chain performance as well as utility of supply chain participants is lower under governmental intervention. This performance decline is primarily due to the introduction of a tax, which leads to lower wholesale and retail prices.

In Model 3, the centralized scenario (SCC_G) yields the highest supply chain utility and consumer surplus in the numerical example under a WP. These results differ from those of Model 1, where the scenario $SC8$ outperforms SCC_G in terms of supply chain utility. The difference is due to reduced supply chain profits in $SC8_G$, caused by the additional tax burden, which makes SCC_G the optimal scenario in Model 3. A comparison between Model 4 and Model 2, both based on a LTT, shows that the highest overall performance in terms of both economic and sustainability metrics is achieved in scenarios with shared green and social responsibilities ($SC8_2$ and $SC8_{G2}$). The results reveal that sharing ESG responsibilities also maximizes both economic and sustainable supply chain performance under governmental intervention.

In addition, the power distribution between the retailer and the manufacturer remains unchanged. The retailer does not earn any profits in any scenario in Model 4; they only derive utility when they hold social concerns, gaining from consumer surplus. The introduction of a LTT improves both economic and sustainability performance, resulting in coordinated supply chain outcomes in scenarios such as $SC0_{G2}$ and $SC2_{G2}$, and even

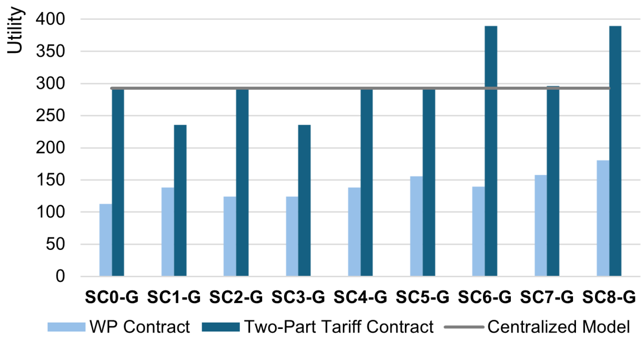


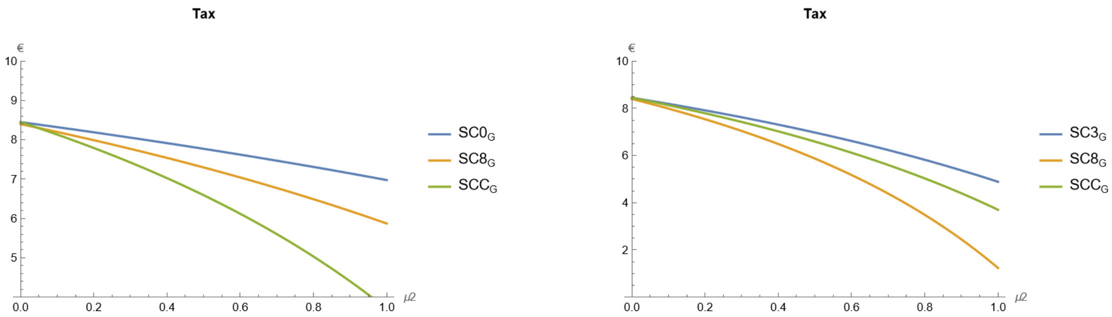
Figure 4.17.: Impact of Contract Type on Utility of Government

greater performance in scenarios with shared responsibilities. Consequently, the impact of the LTT on supply chain performance remains consistent regardless of the presence of governmental intervention.
The government's utility functions consist of three different parts: profit derived from tax, green degree of product, and consumer surplus each weighted by a corresponding governmental policy. For simplicity, in this study all government policies were weighted equally. To explore the role of government policies in greater detail, it is recommended that future research introduce differentiated governmental policy weights. The numerical example as shown in Figure 4.17 reveals that the highest government utility is achieved in $SC6_{G2} = SC8_{G2}$. Consequently, sharing ESG responsibilities and in particular assigning social responsibilities to the manufacturer, not only improves the sustainable and economic performance of the supply chain, but also leads to higher governmental utility.

With the introduction of the government, besides the tax rate (τ), μ_2, the government's social investment parameter is incorporated in the model. All scenarios in Model 3 and 4 depend on μ_2, the social concern of the government. In general, μ_2 has a positive impact on the utility of the supply chain, consumer surplus, and the green degree of the product. However, results show, that μ_1 or μ_M and μ_R haver a greater impact on supply chain performance than μ_2. This outcome shows that the social concerns of the manufacturer and retailer are more relevant to the sustainable performance of the supply chain than the government's social concern.

Analysis of Governmental Tax

By incorporating the government, a tax/subsidy is charged which has to be paid by the consumer in addition to the retail price.



(a) WP with Governmental Intervention (b) LTT with Governmental Intervention

Figure 4.18.: Impact of Contract Types on Government's Utility ($\alpha = 100, \beta = 5, c = 3, \eta = 6, \lambda = 3, \mu_1 = \mu_M = \mu_R = 0.3$)

The numerical example reveals that a higher level of governmental social concern (μ_2) leads to lower tax rates, as shown in Figure 4.18. This can be attributed to the government's higher social interest. The reduction of tax incentivizes the supply chain participants to make ESG investments.

Furthermore, results show that the introduction of a governmental tax leads to a lower wholesale- and retail price as the costs are shared between wholesaler, retailer and consumer. In fact, when comparing the utility of the retailer, manufacturer, and consumer (consumer surplus), it is notable that the costs of tax are split equally between the three participants in all scenarios. The supply chain (manufacturer and retailer) records the smallest losses in $SC8_{G2}$ and $SC6_{G2}$ and the largest losses in $SC0_G$ compared to the model without governmental intervention. This variation is explained by the applied tax rates: $SC8_{G2}$ and $SC6_{G2}$ are associated with the lowest tax rates, whereas the highest tax is applied in $SC1_G$. The tax rate is negatively correlated with λ, the green demand expansion coefficient; scenarios with higher levels of green investment are subject to lower tax rates.

In general, the introduction of a LTT leads to a lower tax rate, which is further strengthened by shared ESG investments. Consequently, shared responsibilities limit losses in consumer surplus and supply chain utility due to tax.

5. Conclusion

5.1. Summary of Key Findings

This thesis examined how the allocation of environmental and social investment responsibilities between a manufacturer and a retailer in a supply chain affects the supply chain's performance in terms of both economic and sustainable performance. A game-theoretic model was developed to compare two different types of contract, a simple WP and a LTT, under different responsibility allocations. The role of governmental intervention was only briefly analyzed and therefore, offers scope for future studies.

Several key findings were identified from the analysis. First, shared responsibility for ESG investments between the manufacturer and retailer clearly leads to better supply chain performance. Accordingly, under both contract types, sustainable and economic supply chain performance is maximized when manufacturer and retailer share responsibility for both green and social investments. It highlights the importance of cooperation in supply chains to increase both economic and sustainable performance.

When both participants share responsibility for green investments, the green degree of the product increases significantly under both contract types, as shown in the numerical example. Thereby, the manufacturer and retailer always invest the same amount in greening under both contract types. This happens because they both benefit equally from the resulting total green degree of product and both face the same green investment costs.

Furthermore, the optimal allocation of social and green responsibility with respect to sustainable and economic supply chain performance depends on the type of contract. Under a WP, it is more effective if the retailer, rather than the manufacturer, is responsible for green and social investments, as this leads to a higher sustainable and economic supply chain performance. Under this type of contract, the retailer controls the final retail price and decides whether the benefit of social investments is passed on to the customer. When the manufacturer alone bears responsibility for ESG investments, the retailer has little incentive to pass on the benefits to customers by lowering the retail price, even if the wholesale price is reduced. In contrast, under a LTT, a higher sustainable and economic supply chain performance is achieved, when the manufacturer is socially responsible. The allocation of green responsibilities becomes irrelevant, as costs are compensated by the franchise fee. Interestingly, shared social responsibilities do not lead to an increase in supply chain utility, as the retailer's social concern does not impact the results. However, if the retailer shares social concerns, this leads to increased supply chain utility.

Moreover, introducing a LTT resolves the coordination problem present under a WP. Under this contract, the manufacturer can compensate ESG investment costs through a franchise fee rather than increasing the wholesale price. This contract mechanism improves coordination by enabling the retailer to maintain competitive pricing and stimulate demand.

When comparing the individual economic performance of the retailer and manufacturer, the manufacturer consistently outperforms the retailer. This inequality is particularly present under the LTT, where the manufacturer captures all profits via the franchise fee, regardless of how responsibilities are allocated. As a result, the retailer only achieves positive utility in scenarios where they have social interest and gain utility from consumer surplus.

However, in both types of contract, the highest individual utilities are observed for both the retailer and the manufacturer when ESG investments are shared. When shared social and green responsibilities are combined with a LTT, the supply chain outperforms the centralized benchmark model in both sustainability and utility. Notably, sharing green investments not only results in higher total green investment but also incentivizes both participants to invest more individually.

In addition, when both supply chain participants show social concern under a WP, they adjust their pricing strategies to drive consumer surplus. It is important to note that higher supply chain utility in scenarios where both parties have social concern is expected, as both incorporate consumer surplus into their utility functions in addition to profit. In contrast, in the base model, only one participant accounts for consumer surplus, so higher utility in the extended model is partly driven by the presence of an additional actor valuing social welfare.

This thesis also found a trade-off between profit and utility. In the centralized scenario in particular, as the level of social concern increases, supply chain profits decrease and can even turn negative at high values, while utility increases. This reflects a common practice, in which companies may accept lower short-term profits to invest in sustainability and build their reputation, potentially leading to higher returns in the long term. To explore this further, future models should adopt a time-based (dynamic) perspective.

Governmental intervention was only analyzed briefly. Governmental intervention does not solve the coordination problem under the WP. Supply chain coordination is only achieved with a LTT. This supports the idea that the introduction of a policy alone is not enough; effective contract design between supply chain partners is still necessary. The study revealed that the tax burden is always shared equally between the manufacturer, retailer and consumer irrespective of the allocation of ESG responsibilities.

Overall, the findings show that shared responsibilities and proper contract design can significantly improve the sustainable and economic performance of supply chains. The results also highlight the importance of cooperation across the supply chain. They show that companies can maintain or improve economic performance while investing in sustainability, if the responsibilities between supply chain participants are allocated correctly.

5.2. Limitations and Future Research

This study has several limitations that offer possibilities for future studies. First, the game-theoretic approach assumes that all players act rationally and have perfect information, which does not reflect a real-word situation.

Second, the model includes only one manufacturer and one retailer, which does not reflect the complexity of real supply chains. Future models should consider multi-tier networks and competitive supply chains, including scenarios where multiple companies compete or cooperate while sharing ESG responsibilities.

Third, while this study looked at environmental and social investments, the governance dimension of ESG was not explicitly modeled. Thereby, the impact of governmental intervention was simplified by assuming equal weights for all three objectives. In reality, the government can focus more on environmental, social, or economic outcomes. Future research should explore differentiated policy weights to better reflect real-world priorities. In addition, social performance was simplified as a consumer surplus, although in practice it includes a variety of different aspects such as worker rights, fair wages, safety, and ethical treatment. Future work should expand the incorporation of social responsibility to cover these aspects in a more comprehensive way.

Fourth, one major limitation of the model is the equal sustainable investment capacity of the manufacturer and the retailer. In practice, the manufacturer often has more opportunities and more control over ESG-related investments, especially in areas such as production, packaging, and supply chain emissions. The model could be improved by introducing asymmetric investment capabilities or cost structures, for example by modeling different green cost coefficients ($\eta_R \neq \eta_M$).

Fifth, an important point not analyzed in detail is sustainable supplier selection, such as the decision model provided by Fallahpour et al. (2017). In reality, choosing the right suppliers is a critical part of ESG strategy, especially when firms rely on external partners for manufacturing. Models that combine sustainability criteria and supplier choice (such as in multi-criteria decision-making frameworks) should be integrated into ESG responsibility models.

Finally, the results highlight the positive impact of shared ESG responsibilities and proper contract design. Future research should explore more deeply how the scope and effectiveness of ESG investments by individual supply chain participants influence overall supply chain performance.

In summary, this thesis contributes to understanding how ESG investment responsibilities can be effectively allocated in a supply chain. It shows that shared responsibility and cooperation, supported by well-designed contracts, improve both economic and sustainable performance in supply chains. Although the models are simplified, the findings provide practical information for companies looking to balance profit and sustainability in supply chains.

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A. Model Results

A.1. Model 1: Wholesale-Price Contract

SCC: centralized scenario

$$p^{\mathrm{DC}} = -\frac{-\alpha\eta\mu_1 + \alpha\eta + \beta c\eta - c\lambda^2}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2} \tag{A.1}$$

$$\theta^{\mathrm{DC}} = -\frac{\alpha\lambda - \beta c\lambda}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2} \tag{A.2}$$

$$V_{SC}^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)} \tag{A.3}$$

$$\pi_{SC}^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.4}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.5}$$

SC0: manufacturer invests in social and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1 - 3) + c\left(\lambda^2 - \beta\eta\right)}{\beta\eta(\mu_1 - 4) + \lambda^2} \tag{A.6}$$

$$w^{\mathrm{DC}} = -\frac{-\alpha\eta\mu_1 + 2\alpha\eta + 2\beta c\eta - c\lambda^2}{\beta\eta\mu_1 - 4\beta\eta + \lambda^2} \tag{A.7}$$

$$\theta^{\mathrm{DC}} = -\frac{\alpha\lambda - \beta c\lambda}{\beta\eta\mu_1 - 4\beta\eta + \lambda^2} \tag{A.8}$$

$$V_{M}^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)} \tag{A.9}$$

$$\pi_{M}^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)}{2\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)^2} \tag{A.10}$$

$$\pi_{R}^{\mathrm{DC}} = -\frac{\beta\eta^2(\alpha - \beta c)^2}{\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)^2} \tag{A.11}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)^2} \tag{A.12}$$

SC1: retailer invests in social and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(2\mu_1 - 3) + \lambda^2\right) + \beta c\left(\lambda^2 - \beta\eta\right)}{2\beta\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)} \tag{A.13}$$

$$w^{\mathrm{DC}} = \frac{\alpha + \beta c}{2\beta} \tag{A.14}$$

$$\theta^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)} \tag{A.15}$$

$$V_R^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{8\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)} \tag{A.16}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)}{8\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.17}$$

$$\pi_M^{\mathrm{DC}} = \frac{\eta(\alpha - \beta c)^2}{4\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)} \tag{A.18}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)^2} \tag{A.19}$$

SC2: manufacturer invests in social efforts, retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_1 - 3) + \lambda^2\right) + \beta c\left(\lambda^2 - \beta\eta\right)}{\beta\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)} \tag{A.20}$$

$$w^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_1 - 2) + \lambda^2\right) + \beta c\left(\lambda^2 - 2\beta\eta\right)}{\beta\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)} \tag{A.21}$$

$$\theta^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_1 - 4) + 2\lambda^2} \tag{A.22}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\beta\eta(\mu_1 - 4) + 4\lambda^2} \tag{A.23}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)}{\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)^2} \tag{A.24}$$

$$\pi_R^{\mathrm{DC}} = \frac{\eta\left(2\beta\eta - \lambda^2\right)(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)^2} \tag{A.25}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)^2} \tag{A.26}$$

SC3: retailer invests in social efforts, manufacturer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(2\mu_1 - 3) + c\left(\lambda^2 - \beta\eta\right)}{2\beta\eta(\mu_1 - 2) + \lambda^2} \tag{A.27}$$

$$w^{\mathrm{DC}} = -\frac{-\alpha\eta\mu_1 + 2\alpha\eta - \beta c\eta\mu_1 + 2\beta c\eta - c\lambda^2}{2\beta\eta\mu_1 - 4\beta\eta + \lambda^2} \tag{A.28}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha - \beta c)}{2\beta\eta\mu_1 - 4\beta\eta + \lambda^2} \tag{A.29}$$

$$V_R^{\mathrm{DC}} = -\frac{\beta\eta^2(\mu_1 - 2)(\alpha - \beta c)^2}{2\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.30}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\beta\eta^2(\mu_1 - 1)(\alpha - \beta c)^2}{\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.31}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)} \tag{A.32}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.33}$$

SC4: manufacturer and retailer invest in social efforts, and manufacturer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 3) + c\left(\lambda^2 - \beta\eta\right)}{\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2} \tag{A.34}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + c\left(\beta\eta(\mu_{\mathrm{R}} - 2) + \lambda^2\right)}{\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2} \tag{A.35}$$

$$\theta^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2} \tag{A.36}$$

$$V_R^{\mathrm{DC}} = -\frac{\beta\eta^2(\mu_{\mathrm{R}} - 2)(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2\right)^2} \tag{A.37}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\beta\eta^2(\mu_{\mathrm{R}} - 1)(\alpha - \beta c)^2}{\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2\right)^2} \tag{A.38}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2\right)} \tag{A.39}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(2\beta\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + \lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2\right)^2} \tag{A.40}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2\right)^2} \tag{A.41}$$

SC5: manufacturer and retailer invest in social efforts, and retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-3)+\lambda^2\right)+\beta c\left(\lambda^2-\beta\eta\right)}{\beta\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2\right)} \tag{A.42}$$

$$w^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+\mu_{\mathrm{R}}-2)+\lambda^2\right)+\beta c\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)}{\beta\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2\right)} \tag{A.43}$$

$$\theta^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2} \tag{A.44}$$

$$V_R^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2\right)^2} \tag{A.45}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_{\mathrm{R}}-1)+\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2\right)^2} \tag{A.46}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+4\lambda^2} \tag{A.47}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_{\mathrm{M}}+\mu_{\mathrm{R}}-2)+\lambda^2\right)}{\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2\right)^2} \tag{A.48}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2\right)^2} \tag{A.49}$$

SC6: manufacturer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_1-3)+\lambda^2\right)+\beta c\left(2\lambda^2-\beta\eta\right)}{\beta\left(\beta\eta(\mu_1-4)+3\lambda^2\right)} \tag{A.50}$$

$$w^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_1-2)+\lambda^2\right)+2\beta c\left(\lambda^2-\beta\eta\right)}{\beta\left(\beta\eta(\mu_1-4)+3\lambda^2\right)} \tag{A.51}$$

$$\theta_R^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_1-4)+3\lambda^2} \tag{A.52}$$

$$\theta_M^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_1-4)+3\lambda^2} \tag{A.53}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_1-4)+6\lambda^2} \tag{A.54}$$

$$\pi_R^{\mathrm{DC}} = \frac{\eta\left(2\beta\eta-\lambda^2\right)(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_1-4)+3\lambda^2\right)^2} \tag{A.55}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_1-2)+3\lambda^2\right)}{2\left(\beta\eta(\mu_1-4)+3\lambda^2\right)^2} \tag{A.56}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_1-4)+3\lambda^2\right)^2} \tag{A.57}$$

SC7: retailer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(2\mu_1-3)+\lambda^2\right)+\beta c\left(2\lambda^2-\beta\eta\right)}{\beta\left(2\beta\eta(\mu_1-2)+3\lambda^2\right)} \tag{A.58}$$

$$w^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_1-2)+\lambda^2\right)+\beta c\left(\beta\eta(\mu_1-2)+2\lambda^2\right)}{\beta\left(2\beta\eta(\mu_1-2)+3\lambda^2\right)} \tag{A.59}$$

$$\theta_R^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{2\beta\eta(\mu_1-2)+3\lambda^2} \tag{A.60}$$

$$\theta_M^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{2\beta\eta(\mu_1-2)+3\lambda^2} \tag{A.61}$$

$$V_R^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_1-2)+\lambda^2\right)}{2\left(2\beta\eta(\mu_1-2)+3\lambda^2\right)^2} \tag{A.62}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_1-1)+\lambda^2\right)}{2\left(2\beta\eta(\mu_1-2)+3\lambda^2\right)^2} \tag{A.63}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2}{4\beta\eta(\mu_1-2)+6\lambda^2} \tag{A.64}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_1-4)+3\lambda^2\right)^2} \tag{A.65}$$

SC8: manufacturer and retailer invest in social´and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-3)+\lambda^2\right)+\beta c\left(2\lambda^2-\beta\eta\right)}{\beta\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2\right)} \tag{A.66}$$

$$w^{\mathrm{DC}} = \frac{\alpha\left(\beta\eta(\mu_{\mathrm{M}}+\mu_{\mathrm{R}}-2)+\lambda^2\right)+\beta c\left(\beta\eta(\mu_{\mathrm{R}}-2)+2\lambda^2\right)}{\beta\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2\right)} \tag{A.67}$$

$$\theta_R^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2} \tag{A.68}$$

$$\theta_M^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2} \tag{A.69}$$

$$V_R^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2\right)^2} \tag{A.70}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+6\lambda^2} \tag{A.71}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_{\mathrm{R}}-1)+\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2\right)^2} \tag{A.72}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_{\mathrm{M}}+\mu_{\mathrm{R}}-2)+3\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2\right)^2} \tag{A.73}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2\right)^2} \tag{A.74}$$

A.2. Model 2: Two-Part Tariff Contract

SC0$_2$: manufacturer invests in social and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1-1)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-2)+\lambda^2} \tag{A.75}$$

$$w^{\mathrm{DC}} = -\frac{-\alpha\eta\mu_1+2\beta c\eta-c\lambda^2}{\beta\eta\mu_1-2\beta\eta+\lambda^2} \tag{A.76}$$

$$F^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{\left(\beta\eta(\mu_1-2)+\lambda^2\right)^2} \tag{A.77}$$

$$\theta^{\mathrm{DC}} = \frac{\lambda(\beta c-\alpha)}{\beta\eta\mu_1-2\beta\eta+\lambda^2} \tag{A.78}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_1-2)+\lambda^2\right)} \tag{A.79}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.80}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_1-1)+\lambda^2\right)}{2\left(\beta\eta(\mu_1-2)+\lambda^2\right)^2} \tag{A.81}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_1-2)+\lambda^2\right)^2} \tag{A.82}$$

SC1$_2$: retailer invests in social and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta + \beta c\eta - c\lambda^2}{2\beta\eta - \lambda^2} \tag{A.83}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta\mu_1 - c\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)}{2\beta\eta - \lambda^2} \tag{A.84}$$

$$F^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)}{2\left(\lambda^2 - 2\beta\eta\right)^2} \tag{A.85}$$

$$\theta^{\mathrm{DC}} = \frac{\lambda(\alpha - \beta c)}{2\beta\eta - \lambda^2} \tag{A.86}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\eta^2\mu_1(\alpha - \beta c)^2}{2\left(\lambda^2 - 2\beta\eta\right)^2} \tag{A.87}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.88}$$

$$\pi_M^{\mathrm{DC}} = \frac{\eta(\alpha - \beta c)^2}{4\beta\eta - 2\lambda^2} \tag{A.89}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\lambda^2 - 2\beta\eta\right)^2} \tag{A.90}$$

SC2$_2$: manufacturer invests in social efforts, retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1 - 1) + c\left(\lambda^2 - \beta\eta\right)}{\beta\eta(\mu_1 - 2) + \lambda^2} \tag{A.91}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta\mu_1 + c\left(\lambda^2 - 2\beta\eta\right)}{\beta\eta(\mu_1 - 2) + \lambda^2} \tag{A.92}$$

$$F^{\mathrm{DC}} = \frac{\eta\left(2\beta\eta - \lambda^2\right)(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.93}$$

$$\theta^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_1 - 2) + \lambda^2} \tag{A.94}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)} \tag{A.95}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.96}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.97}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{A.98}$$

SC3$_2$: retailer invests in social efforts, manufacturer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta + \beta c\eta - c\lambda^2}{2\beta\eta - \lambda^2} \tag{A.99}$$

$$w^{\mathrm{DC}} = \frac{\eta\mu_1(\alpha - \beta c)}{2\beta\eta - \lambda^2} + c \tag{A.100}$$

$$F^{\mathrm{DC}} = -\frac{\beta\eta^2(\mu_1 - 1)(\alpha - \beta c)^2}{\left(\lambda^2 - 2\beta\eta\right)^2} \tag{A.101}$$

$$\theta^{\mathrm{DC}} = \frac{\lambda(\alpha - \beta c)}{2\beta\eta - \lambda^2} \tag{A.102}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\eta^2\mu_1(\alpha - \beta c)^2}{2\left(\lambda^2 - 2\beta\eta\right)^2} \tag{A.103}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.104}$$

$$\pi_M^{\mathrm{DC}} = \frac{\eta(\alpha - \beta c)^2}{4\beta\eta - 2\lambda^2} \tag{A.105}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\lambda^2 - 2\beta\eta\right)^2} \tag{A.106}$$

SC4$_2$: manufacturer and retailer invest in social efforts, and manufacturer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} - 1) + c\left(\lambda^2 - \beta\eta\right)}{\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2} \tag{A.107}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} - \mu_{\mathrm{R}}) + c\left(\beta\eta(\mu_{\mathrm{R}} - 2) + \lambda^2\right)}{\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2} \tag{A.108}$$

$$F^{\mathrm{DC}} = -\frac{\beta\eta^2(\mu_{\mathrm{R}} - 1)(\alpha - \beta c)^2}{\left(\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2\right)^2} \tag{A.109}$$

$$\theta^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2} \tag{A.110}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\eta^2\mu_{\mathrm{R}}(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2\right)^2} \tag{A.111}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.112}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2\right)} \tag{A.113}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_{\mathrm{M}}-1)+\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2\right)^2} \tag{A.114}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2\right)^2} \tag{A.115}$$

SC5$_2$: manufacturer and retailer invest in social efforts, and retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}}-1)+c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2} \tag{A.116}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}}-\mu_{\mathrm{R}})+c\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)}{\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2} \tag{A.117}$$

$$F^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_{\mathrm{R}}-1)+\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2\right)^2} \tag{A.118}$$

$$\theta^{\mathrm{DC}} = \frac{\beta c\lambda-\alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2} \tag{A.119}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\eta^2\mu_{\mathrm{R}}(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2\right)^2} \tag{A.120}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.121}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2\right)} \tag{A.122}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_{\mathrm{M}}-1)+\lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2\right)^2} \tag{A.123}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}-2)+\lambda^2\right)^2} \tag{A.124}$$

SC6$_2$: manufacturer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1-1)+c\left(2\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-2)+2\lambda^2} \tag{A.125}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta\mu_1+2c\left(\lambda^2-\beta\eta\right)}{\beta\eta(\mu_1-2)+2\lambda^2} \tag{A.126}$$

$$F^{\mathrm{DC}} = \frac{\eta\left(2\beta\eta-\lambda^2\right)(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_1-2)+2\lambda^2\right)^2} \tag{A.127}$$

$$\theta_R^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_1 - 2) + 2\lambda^2} \tag{A.128}$$

$$\theta_M^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_1 - 2) + 2\lambda^2} \tag{A.129}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.130}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2}{2\beta\eta(\mu_1 - 2) + 4\lambda^2} \tag{A.131}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(\beta\eta(\mu_1 - 1) + \lambda^2\right)}{\left(\beta\eta(\mu_1 - 2) + 2\lambda^2\right)^2} \tag{A.132}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{2\left(\beta\eta(\mu_1 - 2) + 2\lambda^2\right)^2} \tag{A.133}$$

SC7$_2$: retailer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{\eta(\alpha - \beta c)}{2\beta\eta - 2\lambda^2} + c \tag{A.134}$$

$$w^{\mathrm{DC}} = \frac{\eta\mu_1(\alpha - \beta c)}{2\beta\eta - 2\lambda^2} + c \tag{A.135}$$

$$F^{\mathrm{DC}} = -\frac{\eta(\alpha - \beta c)^2\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)}{8\left(\lambda^2 - \beta\eta\right)^2} \tag{A.136}$$

$$\theta_R^{\mathrm{DC}} = \frac{\lambda(\alpha - \beta c)}{2\beta\eta - 2\lambda^2} \tag{A.137}$$

$$\theta_M^{\mathrm{DC}} = \frac{\lambda(\alpha - \beta c)}{2\beta\eta - 2\lambda^2} \tag{A.138}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\eta^2\mu_1(\alpha - \beta c)^2}{8\left(\lambda^2 - \beta\eta\right)^2} \tag{A.139}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.140}$$

$$\pi_M^{\mathrm{DC}} = \frac{\eta(\alpha - \beta c)^2}{4\beta\eta - 4\lambda^2} \tag{A.141}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha - \beta c)^2}{8\left(\lambda^2 - \beta\eta\right)^2} \tag{A.142}$$

SC8$_2$: manufacturer and retailer invest in social´and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}}-1) + c\left(2\lambda^2 - \beta\eta\right)}{\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2} \tag{A.143}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}}-\mu_{\mathrm{R}}) + \beta c\eta(\mu_{\mathrm{R}}-2) + 2c\lambda^2}{\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2} \tag{A.144}$$

$$F^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(2\beta\eta(\mu_{\mathrm{R}}-1) + \lambda^2\right)}{2\left(\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2\right)^2} \tag{A.145}$$

$$\theta_R^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2} \tag{A.146}$$

$$\theta_M^{\mathrm{DC}} = \frac{\beta c\lambda - \alpha\lambda}{\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2} \tag{A.147}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\eta^2\mu_{\mathrm{R}}(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2\right)^2} \tag{A.148}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.149}$$

$$V_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2}{2\beta\eta(\mu_{\mathrm{M}}-2) + 4\lambda^2} \tag{A.150}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\eta(\alpha-\beta c)^2\left(\beta\eta(\mu_{\mathrm{M}}-1) + \lambda^2\right)}{\left(\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2\right)^2} \tag{A.151}$$

$$CS^{\mathrm{DC}} = \frac{\beta\eta^2(\alpha-\beta c)^2}{2\left(\beta\eta(\mu_{\mathrm{M}}-2) + 2\lambda^2\right)^2} \tag{A.152}$$

A.3. Model 3: Wholesale Price Contract with Governmental Intervention

SCC$_G$: centralized supply chain

$$p^{\mathrm{C}} = \frac{\alpha\eta(\mu_1-1) + \beta c\eta(\mu_1+\mu_2-3) + 2c\lambda^2 + \lambda(\mu_1-1)}{\beta\eta(2\mu_1+\mu_2-4) + 2\lambda^2} \tag{A.153}$$

$$\tau^{\mathrm{C}} = \frac{\beta\eta^2\mu_2(\alpha-\beta c) + \left(\beta\eta(\mu_1-2) + \lambda^2\right)(\alpha\eta - \beta c\eta - \lambda)}{\beta\eta\left(\beta\eta(2\mu_1+\mu_2-4) + 2\lambda^2\right)} \tag{A.154}$$

$$\theta^{\mathrm{C}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(2\mu_1+\mu_2-4) + 2\lambda^2\right)} \tag{A.155}$$

$$\pi_{SC}^{\mathrm{C}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)} \tag{A.156}$$

$$V_{SC}^{\mathrm{C}} = -\frac{\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.157}$$

$$V_{G}^{\mathrm{C}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)} \tag{A.158}$$

$$CS^{\mathrm{C}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.159}$$

SC0$_G$: manufacturer invests in social and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1 - 3) + \beta c\eta(\mu_1 + \mu_2 - 5) + 2c\lambda^2 + \lambda(\mu_1 - 3)}{\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2} \tag{A.160}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1 - 2) + \beta c\eta(\mu_1 + \mu_2 - 6) + 2c\lambda^2 + \lambda(\mu_1 - 2)}{\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2} \tag{A.161}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) + \left(\beta\eta(\mu_1 - 4) + \lambda^2\right)(\alpha\eta - \beta c\eta - \lambda)}{\beta\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2\right)} \tag{A.162}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2\right)} \tag{A.163}$$

$$\pi_{R}^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.164}$$

$$V_{M}^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.165}$$

$$\pi_{M}^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.166}$$

$$V_{G}^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2\right)} \tag{A.167}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.168}$$

SC1$_G$: retailer invests in social and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta\left(\beta\eta(2\mu_1-3)+\lambda^2\right)+\beta\eta\lambda(2\mu_1-3)+\beta c\eta\left(\beta\eta(2\mu_1+\mu_2-5)+3\lambda^2\right)+\lambda^3}{\beta\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.169}$$

$$w^{\mathrm{DC}} = \frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)(\alpha\eta+3\beta c\eta+\lambda)+\beta^2 c\eta^2\mu_2}{\beta\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.170}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha-\beta c)+2\left(\beta\eta(\mu_1-2)+\lambda^2\right)(\alpha\eta-\beta c\eta-\lambda)}{\beta\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.171}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.172}$$

$$V_R^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)^2} \tag{A.173}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)^2} \tag{A.174}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)^2} \tag{A.175}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.176}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2\left(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2\right)^2} \tag{A.177}$$

SC2$_G$: manufacturer invests in social efforts, retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta\left(\beta\eta(\mu_1-3)+\lambda^2\right)+\beta\eta\lambda(\mu_1-3)+\beta c\eta\left(\beta\eta(\mu_1+\mu_2-5)+3\lambda^2\right)+\lambda^3}{\beta\eta\left(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.178}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta\left(\beta\eta(\mu_1-2)+\lambda^2\right)+\beta\eta\lambda(\mu_1-2)+\beta c\eta\left(\beta\eta(\mu_1+\mu_2-6)+3\lambda^2\right)+\lambda^3}{\beta\eta\left(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.179}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-4)+2\lambda^2\right)(\alpha\eta-\beta c\eta-\lambda)}{\beta\eta\left(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.180}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta\left(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2\right)} \tag{A.181}$$

$$\pi_R^{\mathrm{DC}} = \frac{\left(2\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 4\lambda^2\right)^2} \tag{A.182}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 4\lambda^2\right)^2} \tag{A.183}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 4\lambda^2\right)^2} \tag{A.184}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 4\lambda^2\right)} \tag{A.185}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 4\lambda^2\right)^2} \tag{A.186}$$

SC3$_G$: retailer invests in social efforts, manufacturer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(2\mu_1 - 3) + \beta c\eta(2\mu_1 + \mu_2 - 5) + 2c\lambda^2 + \lambda(2\mu_1 - 3)}{\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2} \tag{A.187}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1 - 2) + \beta c\eta(3\mu_1 + \mu_2 - 6) + 2c\lambda^2 + \lambda(\mu_1 - 2)}{\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2} \tag{A.188}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) + \left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta - \lambda)}{\beta\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2\right)} \tag{A.189}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2\right)} \tag{A.190}$$

$$V_R^{\mathrm{DC}} = -\frac{\beta(\mu_1 - 2)(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.191}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\beta(\mu_1 - 1)(\alpha\eta - \beta c\eta + \lambda)^2}{\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.192}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.193}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2\right)} \tag{A.194}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 2\lambda^2\right)^2} \tag{A.195}$$

SC4$_G$: manufacturer and retailer invest in social efforts, and manufacturer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 3) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 5) + 2c\lambda^2 + \lambda(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 3)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2} \tag{A.196}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} + 3\mu_{\mathrm{R}} - 6) + 2c\lambda^2 + \lambda(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2} \tag{A.197}$$

$$\tau^{\mathrm{DC}} = \frac{1}{2}\left(\frac{\mu_2(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2} - \frac{-\alpha\eta + \beta c\eta + \lambda}{\beta\eta}\right) \tag{A.198}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2\right)} \tag{A.199}$$

$$V_R^{\mathrm{DC}} = -\frac{\beta(\mu_{\mathrm{R}} - 2)(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2\right)^2} \tag{A.200}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\beta(\mu_{\mathrm{R}} - 1)(\alpha\eta - \beta c\eta + \lambda)^2}{\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2\right)^2} \tag{A.201}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2\right)^2} \tag{A.202}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2\right)^2} \tag{A.203}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2\right)} \tag{A.204}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 2\lambda^2\right)^2} \tag{A.205}$$

SC5$_G$: manufacturer and retailer invest in social efforts, and retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\begin{array}{c}\alpha\eta\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 3) + \lambda^2\right)\\ +\beta\eta\lambda(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 3) + \beta c\eta\left(\beta\eta(\mu_2 + \mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 5) + 3\lambda^2\right) + \lambda^3\end{array}}{\beta\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)} \tag{A.206}$$

$$w^{\mathrm{DC}} = \frac{\begin{array}{c}\alpha\eta\left(\beta\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + \lambda^2\right) + \beta\eta\lambda(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2)\\ +\beta c\eta\left(\beta\eta(\mu_2 + \mu_{\mathrm{M}} + 3\mu_{\mathrm{R}} - 6) + 3\lambda^2\right) + \lambda^3\end{array}}{\beta\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)} \tag{A.207}$$

$$\tau^{\mathrm{DC}} = \frac{1}{2}\left(\frac{\mu_2(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2} - \frac{-\alpha\eta + \beta c\eta + \lambda}{\beta\eta}\right) \tag{A.208}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)} \tag{A.209}$$

$$V_R^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{R}} - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)^2} \tag{A.210}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{R}} - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)^2} \tag{A.211}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + 2\lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)^2} \tag{A.212}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)^2} \tag{A.213}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)} \tag{A.214}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 4\lambda^2\right)^2} \tag{A.215}$$

SC6$_G$: manufacturer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta\left(\beta\eta(\mu_1 - 3) + \lambda^2\right) + 2\left(\beta\eta\lambda(\mu_1 - 3) + \lambda^3\right) + \beta c\eta\left(\beta\eta(\mu_1 + \mu_2 - 5) + 5\lambda^2\right)}{\beta\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.216}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta\left(\beta\eta(\mu_1 - 2) + \lambda^2\right) + 2\left(\beta\eta\lambda(\mu_1 - 2) + \lambda^3\right) + \beta c\eta\left(\beta\eta(\mu_1 + \mu_2 - 6) + 5\lambda^2\right)}{\beta\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.217}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) + \left(\beta\eta(\mu_1 - 4) + 3\lambda^2\right)(\alpha\eta - \beta c\eta - 2\lambda)}{\beta\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.218}$$

$$\theta_M^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.219}$$

$$\theta_R^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.220}$$

$$\pi_R^{\mathrm{DC}} = \frac{\left(2\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.221}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 4) + 3\lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.222}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 2) + 3\lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.223}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.224}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\left(\beta\eta(2\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.225}$$

SC7$_G$: retailer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta\left(\beta\eta(2\mu_1 - 3) + \lambda^2\right) + 2\lambda\left(\beta\eta(2\mu_1 - 3) + \lambda^2\right) + \beta c\eta\left(\beta\eta(2\mu_1 + \mu_2 - 5) + 5\lambda^2\right)}{\beta\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.226}$$

$$w^{\mathrm{DC}} = \frac{\alpha\eta\left(\beta\eta(\mu_1 - 2) + \lambda^2\right) + 2\lambda\left(\beta\eta(\mu_1 - 2) + \lambda^2\right) + \beta c\eta\left(\beta\eta(3\mu_1 + \mu_2 - 6) + 5\lambda^2\right)}{\beta\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.227}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) + \left(2\beta\eta(\mu_1 - 2) + 3\lambda^2\right)(\alpha\eta - \beta c\eta - 2\lambda)}{\beta\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.228}$$

$$\theta_M^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.229}$$

$$\theta_R^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.230}$$

$$V_R^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.231}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.232}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 2) + 3\lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.233}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)} \tag{A.234}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\left(\beta\eta(4\mu_1 + \mu_2 - 8) + 6\lambda^2\right)^2} \tag{A.235}$$

SC8$_G$: manufacturer and retailer invest in social´and green efforts

$$p^{\mathrm{DC}} = \frac{\begin{array}{c}\alpha\eta\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 3) + \lambda^2\right) + 2\left(\beta\eta\lambda(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 3) + \lambda^3\right)\\ +\beta c\eta\left(\beta\eta(\mu_2 + \mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 5) + 5\lambda^2\right)\end{array}}{\beta\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)} \tag{A.236}$$

$$w^{\mathrm{DC}} = \frac{\begin{array}{c}\alpha\eta\left(\beta\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + \lambda^2\right) + 2\left(\beta\eta\lambda(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + \lambda^3\right)\\ +\beta c\eta\left(\beta\eta(\mu_2 + \mu_{\mathrm{M}} + 3\mu_{\mathrm{R}} - 6) + 5\lambda^2\right)\end{array}}{\beta\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)} \tag{A.237}$$

$$\tau^{\mathrm{DC}} = \frac{1}{2}\left(\frac{\mu_2(\alpha\eta - \beta c\eta + 2\lambda)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2} + \frac{\alpha\eta - \beta c\eta - 2\lambda}{\beta\eta}\right) \tag{A.238}$$

$$\theta_M^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)} \tag{A.239}$$

$$\theta_R^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)} \tag{A.240}$$

$$V_R^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{R}} - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)^2} \tag{A.241}$$

$$\pi_R^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{R}} - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)^2} \tag{A.242}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + 3\lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)^2} \tag{A.243}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2) + 3\lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)^2} \tag{A.244}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)} \tag{A.245}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} + 4\mu_{\mathrm{R}} - 8) + 6\lambda^2\right)^2} \tag{A.246}$$

A.4. Model 4: Two-Part Tariff Contract with Governmental Intervention

SC0$_{G2}$:: manufacturer invests in social and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1 - 1) + \beta c\eta(\mu_1 + \mu_2 - 3) + 2c\lambda^2 + \lambda(\mu_1 - 1)}{\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2} \tag{A.247}$$

$$w^{\mathrm{DC}} = \frac{\mu_1(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2} + c \tag{A.248}$$

$$F^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.249}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) + \left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta - \lambda)}{\beta\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)} \tag{A.250}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)} \tag{A.251}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.252}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.253}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.254}$$

$$V_G^{\mathrm{DC}} = \tag{A.255}$$

$$CS^{\mathrm{DC}} = \tag{A.256}$$

SC1$_{G2}$: retailer invests in social and green efforts

$$p^{\mathrm{DC}} = c - \frac{\alpha\eta - \beta c\eta + \lambda}{\beta\eta(\mu_2 - 4) + 2\lambda^2} \tag{A.257}$$

$$w^{\mathrm{DC}} = c - \frac{\mu_1(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(\mu_2 - 4) + 2\lambda^2} \tag{A.258}$$

$$F^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.259}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) - \left(2\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta - \lambda)}{\beta\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)} \tag{A.260}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)} \tag{A.261}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\mu_1(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.262}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.263}$$

$$\pi_M^{\mathrm{DC}} = \frac{\left(2\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.264}$$

$$V_G^{\mathrm{DC}} = \frac{\beta\mu_1(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.265}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.266}$$

SC2$_{G2}$: manufacturer invests in social efforts, retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1 - 1) + \beta c\eta(\mu_1 + \mu_2 - 3) + 2c\lambda^2 + \lambda(\mu_1 - 1)}{\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2} \tag{A.267}$$

$$w^{\mathrm{DC}} = \frac{\mu_1(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2} + c \tag{A.268}$$

$$F^{\mathrm{DC}} = \frac{\left(2\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.269}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) + \left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta - \lambda)}{\beta\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)} \tag{A.270}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)} \tag{A.271}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.272}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.273}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.274}$$

$$V_G^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.275}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(2\mu_1 + \mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.276}$$

SC3$_{G2}$: retailer invests in social efforts, manufacturer invests in green efforts

$$p^{\mathrm{DC}} = c - \frac{\alpha\eta - \beta c\eta + \lambda}{\beta\eta(\mu_2 - 4) + 2\lambda^2} \tag{A.277}$$

$$w^{\mathrm{DC}} = c - \frac{\mu_1(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(\mu_2 - 4) + 2\lambda^2} \tag{A.278}$$

$$F^{\mathrm{DC}} = -\frac{\beta(\mu_1 - 1)(\alpha\eta - \beta c\eta + \lambda)^2}{\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.279}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) - \left(2\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta - \lambda)}{\beta\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)} \tag{A.280}$$

$$\theta^{\mathrm{DC}} - \frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)} \tag{A.281}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\mu_1(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.282}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.283}$$

$$\pi_M^{\mathrm{DC}} = \frac{\left(2\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.284}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)} \tag{A.285}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 - 4) + 2\lambda^2\right)^2} \tag{A.286}$$

SC4$_{G2}$: manufacturer and retailer invest in social efforts, and manufacturer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} - 1) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} - 3) + 2c\lambda^2 + \lambda(\mu_{\mathrm{M}} - 1)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2} \tag{A.287}$$

$$w^{\mathrm{DC}} = \frac{(\mu_{\mathrm{M}} - \mu_{\mathrm{R}})(\alpha\eta + \lambda) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 4) + 2c\lambda^2}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2} \tag{A.288}$$

$$F^{\mathrm{DC}} = -\frac{\beta(\mu_{\mathrm{R}} - 1)(\alpha\eta - \beta c\eta + \lambda)^2}{\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.289}$$

$$\tau^{\mathrm{DC}} = \frac{1}{2}\left(\frac{\mu_2(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2} - \frac{-\alpha\eta + \beta c\eta + \lambda}{\beta\eta}\right) \tag{A.290}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)} \tag{A.291}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\mu_{\mathrm{R}}(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.292}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.293}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.294}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{M}} - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.295}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)} \tag{A.296}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.297}$$

SC5$_{G2}$: manufacturer and retailer invest in social efforts, and retailer invests in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} - 1) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} - 3) + 2c\lambda^2 + \lambda(\mu_{\mathrm{M}} - 1)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2} \tag{A.298}$$

$$w^{\mathrm{DC}} = \frac{(\mu_{\mathrm{M}} - \mu_{\mathrm{R}})(\alpha\eta + \lambda) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 4) + 2c\lambda^2}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2} \tag{A.299}$$

$$F^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{R}} - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.300}$$

$$\tau^{\mathrm{DC}} = \frac{1}{2}\left(\frac{\mu_2(\alpha\eta - \beta c\eta + \lambda)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2} - \frac{-\alpha\eta + \beta c\eta + \lambda}{\beta\eta}\right) \tag{A.301}$$

$$\theta^{\mathrm{DC}} = -\frac{\lambda(\alpha\eta - \beta c\eta + \lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)} \tag{A.302}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\mu_{\mathrm{R}}(\alpha\eta - \beta c\eta + \lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.303}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.304}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} - 2) + \lambda^2\right)(\alpha\eta - \beta c\eta + \lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 2\lambda^2\right)^2} \tag{A.305}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{M}}-1)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta\left(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2\right)^2} \tag{A.306}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta\left(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2\right)} \tag{A.307}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2\left(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2\right)^2} \tag{A.308}$$

SC6$_{G2}$: manufacturer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_1-1)+\beta c\eta(\mu_1+\mu_2-3)+4c\lambda^2+2\lambda(\mu_1-1)}{\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2} \tag{A.309}$$

$$w^{\mathrm{DC}} = \frac{\mu_1(\alpha\eta-\beta c\eta+2\lambda)}{\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2}+c \tag{A.310}$$

$$F^{\mathrm{DC}} = \frac{\left(2\beta\eta-\lambda^2\right)(\alpha\eta-\beta c\eta+2\lambda)^2}{2\eta\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)^2} \tag{A.311}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-2)+2\lambda^2\right)(\alpha\eta-\beta c\eta-2\lambda)}{\beta\eta\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)} \tag{A.312}$$

$$\theta_M^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)} \tag{A.313}$$

$$\theta_R^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)} \tag{A.314}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1-2)+2\lambda^2\right)(\alpha\eta-\beta c\eta+2\lambda)^2}{2\eta\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)^2} \tag{A.315}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.316}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_1-1)+\lambda^2\right)(\alpha\eta-\beta c\eta+2\lambda)^2}{\eta\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)^2} \tag{A.317}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta-\beta c\eta+2\lambda)^2}{2\eta\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)} \tag{A.318}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta-\beta c\eta+2\lambda)^2}{2\left(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2\right)^2} \tag{A.319}$$

SC7$_{G2}$: retailer invests in social efforts, and manufacturer and retailer invest in green efforts

$$p^{\mathrm{DC}} = \frac{-\alpha\eta + \beta c\eta - 2\lambda}{\beta\eta(\mu_2 - 4) + 4\lambda^2} + c \tag{A.320}$$

$$w^{\mathrm{DC}} = \frac{\mu_1(-\alpha\eta + \beta c\eta - 2\lambda)}{\beta\eta(\mu_2 - 4) + 4\lambda^2} + c \tag{A.321}$$

$$F^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_1 - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)^2} \tag{A.322}$$

$$\tau^{\mathrm{DC}} = \frac{\beta\eta^2\mu_2(\alpha - \beta c) - 2\left(\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta - 2\lambda)}{\beta\eta\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)} \tag{A.323}$$

$$\theta_M^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)} \tag{A.324}$$

$$\theta_R^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)} \tag{A.325}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\mu_1(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)^2} \tag{A.326}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.327}$$

$$\pi_M^{\mathrm{DC}} = \frac{\left(\beta\eta - \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{\eta\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)^2} \tag{A.328}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)} \tag{A.329}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\left(\beta\eta(\mu_2 - 4) + 4\lambda^2\right)^2} \tag{A.330}$$

SC8$_{G2}$: manufacturer and retailer invest in social´and green efforts

$$p^{\mathrm{DC}} = \frac{\alpha\eta(\mu_{\mathrm{M}} - 1) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} - 3) + 4c\lambda^2 + 2\lambda(\mu_{\mathrm{M}} - 1)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2} \tag{A.331}$$

$$w^{\mathrm{DC}} = \frac{(\mu_{\mathrm{M}} - \mu_{\mathrm{R}})(\alpha\eta + 2\lambda) + \beta c\eta(\mu_2 + \mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 4) + 4c\lambda^2}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2} \tag{A.332}$$

$$F^{\mathrm{DC}} = -\frac{\left(2\beta\eta(\mu_{\mathrm{R}} - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)^2} \tag{A.333}$$

$$\tau^{\mathrm{DC}} = \frac{1}{2}\left(\frac{\mu_2(\alpha\eta - \beta c\eta + 2\lambda)}{\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2} + \frac{\alpha\eta - \beta c\eta - 2\lambda}{\beta\eta}\right) \tag{A.334}$$

$$\theta_M^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)} \tag{A.335}$$

$$\theta_R^{\mathrm{DC}} = \frac{\lambda(-\alpha\eta + \beta c\eta - 2\lambda)}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)} \tag{A.336}$$

$$V_R^{\mathrm{DC}} = \frac{\beta\mu_{\mathrm{R}}(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)^2} \tag{A.337}$$

$$\pi_R^{\mathrm{DC}} = 0 \tag{A.338}$$

$$V_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} - 2) + 2\lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)^2} \tag{A.339}$$

$$\pi_M^{\mathrm{DC}} = -\frac{\left(\beta\eta(\mu_{\mathrm{M}} - 1) + \lambda^2\right)(\alpha\eta - \beta c\eta + 2\lambda)^2}{\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)^2} \tag{A.340}$$

$$V_G^{\mathrm{DC}} = -\frac{(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\eta\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)} \tag{A.341}$$

$$CS^{\mathrm{DC}} = \frac{\beta(\alpha\eta - \beta c\eta + 2\lambda)^2}{2\left(\beta\eta(\mu_2 + 2\mu_{\mathrm{M}} - 4) + 4\lambda^2\right)^2} \tag{A.342}$$

B. Model Formulations

B.1. Allocation of Green Responsibilities

Individual Green Responsibility

$$\text{Demand}[\text{p}, \theta] = \alpha + \theta\lambda - \beta p \tag{B.1}$$

$$\text{Cost}(\theta) = \frac{\eta\theta^2}{2} \tag{B.2}$$

$$\text{CS} = \frac{(\alpha + \theta\lambda - \beta p)^2}{2\beta} \tag{B.3}$$

Individual Green Responsibility with Governmental Intervention

$$\text{Demand}[\text{p}, \tau, \theta] = \alpha + \theta\lambda - \beta(p + \tau) \tag{B.4}$$

$$\text{CS} = \frac{(\alpha + \theta\lambda - \beta(p + \tau))^2}{2\beta} \tag{B.5}$$

Shared Green Responsibility

$$\theta_T = \theta_M + \theta_R \tag{B.6}$$

$$\text{Cost}(\theta_R) = \frac{\eta\theta_R^2}{2} \tag{B.7}$$

$$\text{Cost}(\theta_M) = \frac{\eta\theta_M^2}{2} \tag{B.8}$$

$$\text{Demand}[\text{p}, \theta_T] = \alpha + \theta_T\lambda - \beta p \tag{B.9}$$

$$CS\theta = \frac{(\alpha + \theta_T\lambda - \beta p)^2}{2\beta} \tag{B.10}$$

Shared Green Responsibility with Governmental Intervention

$$\text{Demand}[\text{p}, \theta_T] = \alpha + \theta_T\lambda - \beta(p+\tau) \tag{B.11}$$

$$CS\theta = \frac{(\alpha + \theta_T\lambda - \beta(p+\tau))^2}{2\beta} \tag{B.12}$$

B.2. Model 1: Wholesale-Price Contract

SC0

$$\pi_R = (p-w) * \text{Demand}[p, \theta] \tag{B.13}$$

$$\pi_M = (w-c) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} \tag{B.14}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.15}$$

SC1

$$\pi_R = (p-w) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} \tag{B.16}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.17}$$

$$\pi_M = (w-c) * \text{Demand}[p, \theta] \tag{B.18}$$

SC2

$$\pi_R = (p-w) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} \tag{B.19}$$

$$\pi_M = (w-c) * \text{Demand}[p, \theta] \tag{B.20}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.21}$$

SC3

$$\pi_R = (p-w) * \text{Demand}[p, \theta] \tag{B.22}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.23}$$

$$\pi_M = (w-c) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} \tag{B.24}$$

SC4

$$\pi_R = (p - w) * \text{Demand}[p, \theta] \tag{B.25}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.26}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} \tag{B.27}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.28}$$

SC5

$$\pi_R = (p - w) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} \tag{B.29}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.30}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] \tag{B.31}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.32}$$

SC6

$$\pi_R = (p - w) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_R^2}{2} \tag{B.33}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_M^2}{2} \tag{B.34}$$

$$V_M = \pi_M + \mu_1 * CS\theta \tag{B.35}$$

SC7

$$\pi_R = (p - w) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_R^2}{2} \tag{B.36}$$

$$V_R = \pi_R + \mu_1 * CS\theta \tag{B.37}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_M^2}{2} \tag{B.38}$$

SC8

$$\pi_R = (p - w) * \text{Demand}[p, \theta_T] \frac{\eta \theta_R^2}{2} \tag{B.39}$$

$$V_R = \pi_R + \mu_R * CS\theta \tag{B.40}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta_T] - \frac{\eta \theta_M^2}{2} \tag{B.41}$$

$$V_M = \pi_M + \mu_M * CS\theta \tag{B.42}$$

B.3. Model 2: Two-part Tariff Contract

SC0

$$\pi_R = (p - w) * \text{Demand}[p, \theta] - F \tag{B.43}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] - \frac{\eta \theta^2}{2} + F \tag{B.44}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.45}$$

SC1

$$\pi_R = (p - w) * \text{Demand}[p, \theta] - \frac{\eta \theta^2}{2} - F \tag{B.46}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.47}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] + F \tag{B.48}$$

SC2

$$\pi_R = (p - w) * \text{Demand}[p, \theta] - \frac{\eta \theta^2}{2} - F \tag{B.49}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] + F \tag{B.50}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.51}$$

SC3

$$\pi_R = (p - w) * \text{Demand}[p, \theta] - F \tag{B.52}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.53}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] - \frac{\eta \theta^2}{2} + F \tag{B.54}$$

SC4

$$\pi_R = (p - w) * \text{Demand}[p, \theta] - F \tag{B.55}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.56}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} + F \tag{B.57}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.58}$$

SC5

$$\pi_R = (p - w) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} - F \tag{B.59}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.60}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] + F \tag{B.61}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.62}$$

SC6

$$\pi_R = (p - w) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_R^2}{2} - F \tag{B.63}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_M^2}{2} + F \tag{B.64}$$

$$V_M = \pi_M + \mu_1 * CS\theta \tag{B.65}$$

SC7

$$\pi_R = (p - w) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_R^2}{2} - F \tag{B.66}$$

$$V_R = \pi_R + \mu_1 * CS\theta \tag{B.67}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_M^2}{2} + F \tag{B.68}$$

SC8

$$\pi_R = (p - w) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_R^2}{2} - F \tag{B.69}$$

$$V_R = \pi_R + \mu_R * CS\theta \tag{B.70}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta_T] - \frac{\eta\theta_M^2}{2} + F \tag{B.71}$$

$$V_M = \pi_M + \mu_M * CS\theta \tag{B.72}$$

B.4. Model 3: Wholesale-Price Contract with Governmental Intervention

SC0

$$\pi_R = (p - w) * \text{Demand}[p, \theta] \tag{B.73}$$

$$\pi_M = (w - c) * \text{Demand}[p, \theta] - \frac{\eta\theta^2}{2} \tag{B.74}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.75}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.76}$$

SC1

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} \tag{B.77}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.78}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta])(p, \theta) \tag{B.79}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.80}$$

SC2

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} \tag{B.81}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) \tag{B.82}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.83}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.84}$$

SC3

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) \tag{B.85}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.86}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} \tag{B.87}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.88}$$

SC4

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) \tag{B.89}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.90}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} \tag{B.91}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.92}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.93}$$

SC5

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} \tag{B.94}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.95}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) \tag{B.96}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.97}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.98}$$

SC6

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_R^2}{2} \tag{B.99}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_M^2}{2} \tag{B.100}$$

$$V_M = \pi_M + \mu_1 * CS\theta \tag{B.101}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta_T]) + \lambda_3 * (\mu_2 * CS) \tag{B.102}$$

SC7

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_R^2}{2} \tag{B.103}$$

$$V_R = \pi_R + \mu_1 * CS\theta \tag{B.104}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_M^2}{2} \tag{B.105}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta_T]) + \lambda_3 * (\mu_2 * CS) \tag{B.106}$$

SC8

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_R^2}{2} \tag{B.107}$$

$$V_R = \pi_R + \mu_R * CS\theta \tag{B.108}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_M^2}{2} \tag{B.109}$$

$$V_M = \pi_M + \mu_M * CS\theta \tag{B.110}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta_T]) + \lambda_3 * (\mu_2 * CS) \tag{B.111}$$

B.5. Model 4: Two-Part Tariff Contract with Governmental Intervention

SC0

$$\pi_R = (p - w) * \text{Demand}(p, \theta) - F \tag{B.112}$$

$$\pi_M = (w - c) * \text{Demand}(p, \theta) - \frac{\eta\theta^2}{2} + F \tag{B.113}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.114}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.115}$$

SC1

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} - F \tag{B.116}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.117}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta])(p, \theta) + F \tag{B.118}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.119}$$

SC2

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} - F \tag{B.120}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) + F \tag{B.121}$$

$$V_M = \pi_M + \mu_1 * CS \tag{B.122}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.123}$$

SC3

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - F \tag{B.124}$$

$$V_R = \pi_R + \mu_1 * CS \tag{B.125}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} + F \tag{B.126}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.127}$$

SC4

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - F \tag{B.128}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.129}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} + F \tag{B.130}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.131}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.132}$$

SC5

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta]) - \frac{\eta\theta^2}{2} - F \tag{B.133}$$

$$V_R = \pi_R + \mu_R * CS \tag{B.134}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta]) + F \tag{B.135}$$

$$V_M = \pi_M + \mu_M * CS \tag{B.136}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta]) + \lambda_3 * (\mu_2 * CS) \tag{B.137}$$

SC6

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_R^2}{2} - F \tag{B.138}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_M^2}{2} + F \tag{B.139}$$

$$V_M = \pi_M + \mu_1 * CS\theta \tag{B.140}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta_T]) + \lambda_3 * (\mu_2 * CS) \tag{B.141}$$

SC7

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_R^2}{2} - F \tag{B.142}$$

$$V_R = \pi_R + \mu_1 * CS\theta \tag{B.143}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_M^2}{2} + F \tag{B.144}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta_T]) + \lambda_3 * (\mu_2 * CS) \tag{B.145}$$

SC8

$$\pi_R = (p - w) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_R^2}{2} - F \tag{B.146}$$

$$V_R = \pi_R + \mu_R * CS\theta \tag{B.147}$$

$$\pi_M = (w - c) * \text{Demand}[p, \tau, \theta_T]) - \frac{\eta\theta_M^2}{2} + F \tag{B.148}$$

$$V_M = \pi_M + \mu_M * CS\theta \tag{B.149}$$

$$V_G = \lambda_1 * \theta + \lambda_2 * (\tau * \text{Demand}[p, \tau, \theta_T]) + \lambda_3 * (\mu_2 * CS) \tag{B.150}$$

C. Governmental Intervention: Results of Model 3 and 4

C.0.1. Mathematical and Numerical Results of Models

Results of Model 3: Wholesale-Price Contract with Governmental Intervention

	V_M	V_R
$SC0_G$	$-\frac{\left(\beta\eta(\mu_1-4)+\lambda^2\right)A}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+2\lambda^2)^2}$	$\frac{\beta A}{(\beta\eta(2\mu_1+\mu_2-8)+2\lambda^2)^2}$
$SC1_G$	$-\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)A}{\eta(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2)^2}$	$-\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)A}{2\eta(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2)^2}$
$SC2_G$	$-\frac{\left(\beta\eta(\mu_1-4)+2\lambda^2\right)A}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2)^2}$	$\frac{\left(2\beta\eta-\lambda^2\right)A}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2)^2}$
$SC3_G$	$-\frac{\left(2\beta\eta(\mu_1-2)+\lambda^2\right)A}{2\eta(\beta\eta(4\mu_1+\mu_2-8)+2\lambda^2)^2}$	$-\frac{\beta(\mu_1-2)A}{2(\beta\eta(4\mu_1+\mu_2-8)+2\lambda^2)^2}$
SCC_G	$-\frac{A}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$	
$SC4_G$	$-\frac{\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+\lambda^2\right)A}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+2\lambda^2)^2}$	$-\frac{\beta(\mu_{\mathrm{R}}-2)A}{2(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+2\lambda^2)^2}$
$SC5_G$	$-\frac{\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+2\lambda^2\right)A}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+4\lambda^2)^2}$	$-\frac{\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)A}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+4\lambda^2)^2}$
$SC6_G$	$-\frac{\left(\beta\eta(\mu_1-4)+3\lambda^2\right)A}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+6\lambda^2)^2}$	$\frac{\left(2\beta\eta-\lambda^2\right)A}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+6\lambda^2)^2}$
$SC7_G$	$-\frac{\left(2\beta\eta(\mu_1-2)+3\lambda^2\right)A}{2\eta(\beta\eta(4\mu_1+\mu_2-8)+6\lambda^2)^2}$	$-\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)A}{2\eta(\beta\eta(4\mu_1+\mu_2-8)+6\lambda^2)^2}$
$SC8_G$	$-\frac{\left(\beta\eta(\mu_{\mathrm{M}}+2\mu_{\mathrm{R}}-4)+3\lambda^2\right)A}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+6\lambda^2)^2}$	$-\frac{\left(\beta\eta(\mu_{\mathrm{R}}-2)+\lambda^2\right)A}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+6\lambda^2)^2}$

Table C.1.: Optimal Economic Results for a Supply Chain with Wholesale-Price Contract and Governmental Intervention with A=$(\alpha\eta - \beta c\eta + \lambda)^2$

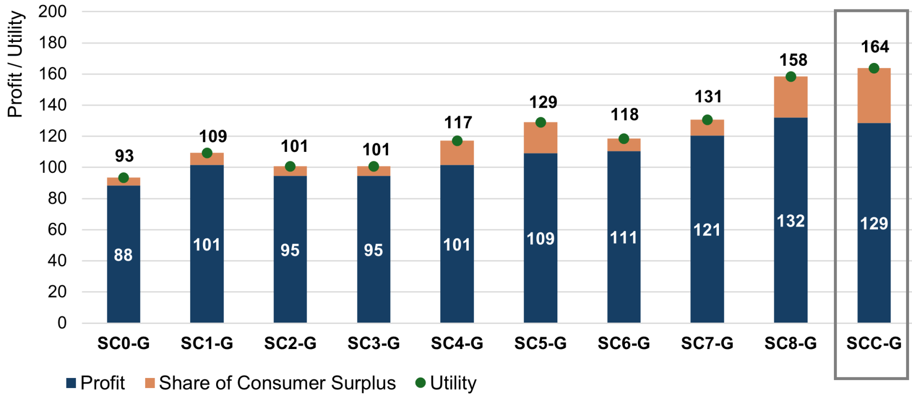

Figure C.1.: Model 3: Total Utility of Supply Chain

	V_G	τ
$SC0_G$	$-\frac{A^2}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+2\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-4)+\lambda^2\right)A}{\beta\eta(\beta\eta(2\mu_1+\mu_2-8)+2\lambda^2)}$
$SC1_G$	$-\frac{A^2}{2\eta(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+2\left(\beta\eta(\mu_1-2)+\lambda^2\right)A}{\beta\eta(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2)}$
$SC2_G$	$-\frac{A^2}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-4)+2\lambda^2\right)A}{\beta\eta(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2)}$
$SC3_G$	$-\frac{A^2}{2\eta(\beta\eta(4\mu_1+\mu_2-8)+2\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(2\beta\eta(\mu_1-2)+\lambda^2\right)A}{\beta\eta(\beta\eta(4\mu_1+\mu_2-8)+2\lambda^2)}$
SCC_G	$-\frac{A^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-2)+\lambda^2\right)A}{\beta\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC4_G$	$-\frac{A^2}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+2\lambda^2)}$	$\frac{1}{2}\left(\frac{\mu_2 A}{\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+2\lambda^2}-\frac{-\alpha\eta+\beta c\eta+\lambda}{\beta\eta}\right)$
$SC5_G$	$-\frac{A^2}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+4\lambda^2)}$	$\frac{1}{2}\left(\frac{\mu_2 A}{\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+4\lambda^2}-\frac{-\alpha\eta+\beta c\eta+\lambda}{\beta\eta}\right)$
$SC6_G$	$-\frac{B^2}{2\eta(\beta\eta(2\mu_1+\mu_2-8)+6\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-4)+3\lambda^2\right)(\alpha\eta-\beta c\eta-2\lambda)}{\beta\eta(\beta\eta(2\mu_1+\mu_2-8)+6\lambda^2)}$
$SC7_G$	$-\frac{B^2}{2\eta(\beta\eta(4\mu_1+\mu_2-8)+6\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(2\beta\eta(\mu_1-2)+3\lambda^2\right)(\alpha\eta-\beta c\eta-2\lambda)}{\beta\eta(\beta\eta(4\mu_1+\mu_2-8)+6\lambda^2)}$
$SC8_G$	$-\frac{B^2}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+6\lambda^2)}$	$\frac{1}{2}\left(\frac{\mu_2 B}{\beta\eta(\mu_2+2\mu_{\mathrm{M}}+4\mu_{\mathrm{R}}-8)+6\lambda^2}+\frac{\alpha\eta-\beta c\eta-2\lambda}{\beta\eta}\right)$

Table C.2.: Optimal Utility of Government and Tax for a Supply Chain with Wholesale-Price Contract and Governmental Intervention with A=$(\alpha\eta-\beta c\eta+\lambda)$ and B=$(\alpha\eta-\beta c\eta+2\lambda)$

	CS_{SC}	θ
$SC0_G$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-8)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-8)+2\lambda^2)}$
$SC1_G$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(4\mu_1+\mu_2-8)+4\lambda^2)}$
$SC2_G$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-8)+4\lambda^2)}$
$SC3_G$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(4\mu_1+\mu_2-8)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(4\mu_1+\mu_2-8)+2\lambda^2)}$
SCC_G	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC4_G$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2+2\mu_M+4\mu_R-8)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(\mu_2+2\mu_M+4\mu_R-8)+2\lambda^2)}$
$SC5_G$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2+2\mu_M+4\mu_R-8)+4\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(\mu_2+2\mu_M+4\mu_R-8)+4\lambda^2)}$
$SC6_G$	$\frac{\beta(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-8)+6\lambda^2)^2}$	$\frac{2\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-8)+6\lambda^2)}$
$SC7_G$	$\frac{\beta(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(4\mu_1+\mu_2-8)+6\lambda^2)^2}$	$\frac{2\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta(\beta\eta(4\mu_1+\mu_2-8)+6\lambda^2)}$
$SC8_G$	$\frac{\beta(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(\mu_2+2\mu_M+4\mu_R-8)+6\lambda^2)^2}$	$\frac{2\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta(\beta\eta(\mu_2+2\mu_M+4\mu_R-8)+6\lambda^2)}$

Table C.3.: Optimal Consumer Surplus and Green Degree of Product for a Supply Chain with Two-Part Tariff Contract and Governmental Intervention

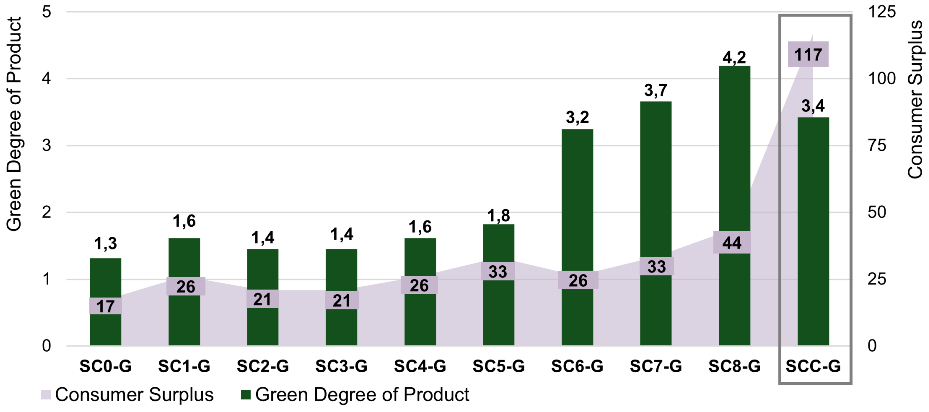

Figure C.2.: Model 3: Sustainability of Supply Chain

Results of Model 4: Two-Part Tariff Contract with Governmental Intervention

	V_M	V_R
$SC0_{G2}$	$-\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)^2}$	0
$SC1_{G2}$	$\frac{\left(2\beta\eta-\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta(\beta\eta(\mu_2-4)+2\lambda^2)^2}$	$\frac{\beta\mu_1(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2-4)+2\lambda^2)^2}$
$SC2_{G2}$	$-\frac{\left(\beta\eta(\mu_1-2)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)^2}$	0
$SC3_{G2}$	$\frac{\left(2\beta\eta-\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta(\beta\eta(\mu_2-4)+2\lambda^2)^2}$	$\frac{\beta\mu_1(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2-4)+2\lambda^2)^2}$
SCC_G	$-\frac{(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$	
$SC4_{G2}$	$-\frac{\left(\beta\eta(\mu_M-2)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta(\beta\eta(\mu_2+2\mu_M-4)+2\lambda^2)^2}$	$\frac{\beta\mu_R(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2+2\mu_M-4)+2\lambda^2)^2}$
$SC5_{G2}$	$-\frac{\left(\beta\eta(\mu_M-2)+\lambda^2\right)(\alpha\eta-\beta c\eta+\lambda)^2}{2\eta(\beta\eta(\mu_2+2\mu_M-4)+2\lambda^2)^2}$	$\frac{\beta\mu_R(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2+2\mu_M-4)+2\lambda^2)^2}$
$SC6_{G2}$	$-\frac{\left(\beta\eta(\mu_1-2)+2\lambda^2\right)(\alpha\eta-\beta c\eta+2\lambda)^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2)^2}$	0
$SC7_{G2}$	$\frac{\left(\beta\eta-\lambda^2\right)(\alpha\eta-\beta c\eta+2\lambda)^2}{\eta(\beta\eta(\mu_2-4)+4\lambda^2)^2}$	$\frac{\beta\mu_1(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(\mu_2-4)+4\lambda^2)^2}$
$SC8_{G2}$	$-\frac{\left(\beta\eta(\mu_M-2)+2\lambda^2\right)(\alpha\eta-\beta c\eta+2\lambda)^2}{2\eta(\beta\eta(\mu_2+2\mu_M-4)+4\lambda^2)^2}$	$\frac{\beta\mu_R(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(\mu_2+2\mu_M-4)+4\lambda^2)^2}$

Table C.4.: Optimal Economic Results for a Supply Chain with Two-Part Tariff Contract and Governmental Intervention with A=$(\alpha\eta-\beta c\eta+\lambda)^2$

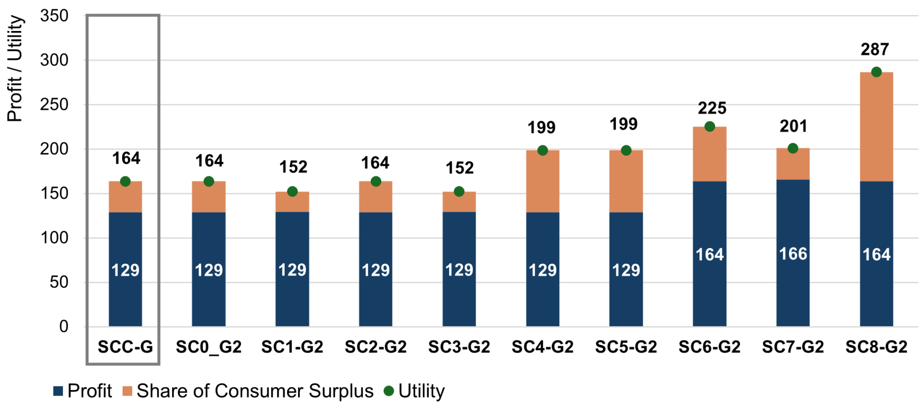

Figure C.3.: Model 4: Total Utility of Supply Chain

	V_G	τ
$SC0_{G2}$	$-\frac{A^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$	$\frac{\beta\eta^2 mu_2(\alpha-\beta c)+\left(\beta\eta(mu_1-2)+\lambda^2\right)A}{\beta\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC1_{G2}$	$-\frac{A^2}{2\eta(\beta\eta(\mu_2-4)+2\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)-\left(2\beta\eta-\lambda^2\right)A}{\beta\eta(\beta\eta(\mu_2-4)+2\lambda^2)}$
$SC2_{G2}$	$-\frac{A^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-2)+\lambda^2\right)A}{\beta\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC3_{G2}$	$-\frac{A^2}{2\eta(\beta\eta(\mu_2-4)+2\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)-\left(2\beta\eta-\lambda^2\right)A}{\beta\eta(\beta\eta(\mu_2-4)+2\lambda^2)}$
SCC_G	$-\frac{A^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-2)+\lambda^2\right)A}{\beta\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC4_{G2}$	$-\frac{A^2}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2)}$	$\frac{1}{2}\left(\frac{\mu_2 A}{\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2}-\frac{-\alpha\eta+\beta c\eta+\lambda}{\beta\eta}\right)$
$SC5_{G2}$	$-\frac{A^2}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2)}$	$\frac{1}{2}\left(\frac{\mu_2 A}{\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2}-\frac{-\alpha\eta+\beta c\eta+\lambda}{\beta\eta}\right)$
$SC6_{G2}$	$-\frac{B^2}{2\eta(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)+\left(\beta\eta(\mu_1-2)+2\lambda^2\right)(\alpha\eta-\beta c\eta-2\lambda)}{\beta\eta(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2)}$
$SC7_{G2}$	$-\frac{B^2}{2\eta(\beta\eta(\mu_2-4)+4\lambda^2)}$	$\frac{\beta\eta^2\mu_2(\alpha-\beta c)-2\left(\beta\eta-\lambda^2\right)(\alpha\eta-\beta c\eta-2\lambda)}{\beta\eta(\beta\eta(\mu_2-4)+4\lambda^2)}$
$SC8_{G2}$	$-\frac{B^2}{2\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+4\lambda^2)}$	$\frac{1}{2}\left(\frac{\mu_2 B}{\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+4\lambda^2}+\frac{\alpha\eta-\beta c\eta-2\lambda}{\beta\eta}\right)$

Table C.5.: Optimal Utility of Government and Tax for a Supply Chain with Two-Part Tariff Contract and Governmental Intervention with A=$(\alpha\eta-\beta c\eta+\lambda)$ and B=$(\alpha\eta-\beta c\eta+2\lambda)$

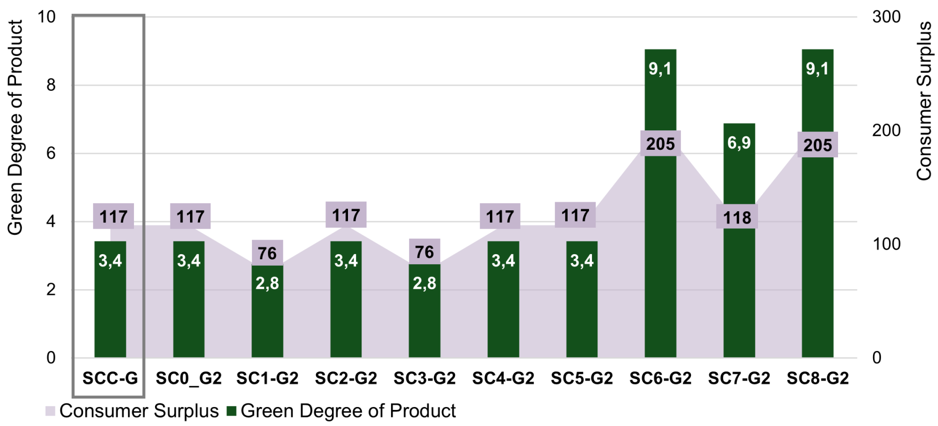

Figure C.4.: Model 4: Sustainability of Supply Chain

	CS_{SC}	θ
$SC0_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC1_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2-4)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(\mu_2-4)+2\lambda^2)}$
$SC2_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC3_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2-4)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(\mu_2-4)+2\lambda^2)}$
SCC_{G2}	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-4)+2\lambda^2)}$
$SC4_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2+2\mu\mathrm{M}-4)+2\lambda^2)^2}$	$-\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(\mu_2+2\mu\mathrm{M}-4)+2\lambda^2)}$
$SC5_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+\lambda)^2}{2(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2)^2}$	$\frac{\lambda(\alpha\eta-\beta c\eta+\lambda)}{\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+2\lambda^2)}$
$SC6_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2)^2}$	$\frac{2\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta(\beta\eta(2\mu_1+\mu_2-4)+4\lambda^2)}$
$SC7_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(\mu 2-4)+4\lambda^2)^2}$	$\frac{2\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta(\beta\eta(\mu_2-4)+4\lambda^2)}$
$SC8_{G2}$	$\frac{\beta(\alpha\eta-\beta c\eta+2\lambda)^2}{2(\beta\eta(\mu_2+2\mu\mathrm{M}+4\mu_{\mathrm{R}}-8)+6\lambda^2)^2}$	$\frac{2\lambda(-\alpha\eta+\beta c\eta-2\lambda)}{\eta(\beta\eta(\mu_2+2\mu_{\mathrm{M}}-4)+4\lambda^2)}$

Table C.6.: Optimal Consumer Surplus and Green Degree of Product of a Supply Chain with Two-Part Tariff Contract and Governmental Intervention

D. Mathematical Proof

D.1. Model 1: Wholesale-Price Contract

Proof of Scenario 0. Consider the profit function π_R given in Equation B.13. We seek to optimize the retail price p to maximize the profit function. To do this, we first compute the first-order condition by setting $\frac{\delta \pi_R}{\delta p} = 0$. We obtain

$$p = \frac{\alpha + \theta\lambda + \beta w}{2\beta} \tag{D.1}$$

Substituting this p into equation Equation B.15, we obtain

$$V_M = \frac{\mu_1(\alpha + \theta\lambda - \beta w)^2 - 4\beta\left((c - w)(\alpha + \theta\lambda - \beta w) + \eta\theta^2\right)}{8\beta} \tag{D.2}$$

We maximize this V_M by optimizing w and θ simultaneously, that is, $\frac{\delta V_M}{\delta w} = 0$, $\frac{\delta V_M}{\delta \theta} = 0$. We obtain Equation A.7 and Equation A.8. Substituting Equation A.7 and Equation A.8 in p we obtain Equation A.6.

Proof of Scenario 1. Consider the utility function V_R given in Equation B.17. From $\frac{\delta V_R}{\delta p} = 0$, $\frac{\delta V_R}{\delta \theta} = 0$, we obtain

$$p = -\frac{-\alpha\eta\mu_1 + \alpha\eta + \beta\eta w + \lambda^2(-w)}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2} \tag{D.3}$$

and

$$\theta = -\frac{\alpha\lambda - \beta\lambda w}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2}. \tag{D.4}$$

Substituting this p and θ into Equation B.18, we obtain

$$\pi_M = \frac{\beta\eta(c - w)(\alpha - \beta w)}{\beta\eta(\mu_1 - 2) + \lambda^2} \tag{D.5}$$

From $\frac{\delta \pi_M}{\delta w} = 0$ we obtain Equation A.14. Substituting Equation A.14 in p and θ, we obtain Equation A.13 and Equation A.15.

Proof of Scenario 2. Consider the profit function π_R given in Equation B.19. From $\frac{\delta \pi_R}{\delta p} = 0$, $\frac{\delta \pi_R}{\delta \theta} = 0$, we obtain

$$p = -\frac{-\alpha\eta - \beta\eta w + \lambda^2 w}{2\beta\eta - \lambda^2} and \tag{D.6}$$

$$\theta = -\frac{\lambda(\beta w - \alpha)}{2\beta\eta - \lambda^2} \tag{D.7}$$

Substituting this p and θ into Equation B.21, we obtain

$$V_M = \frac{\beta\eta(\alpha - \beta w)\left(\eta\mu_1(\alpha - \beta w) - 2(c - w)\left(2\beta\eta - \lambda^2\right)\right)}{2\left(\lambda^2 - 2\beta\eta\right)^2} \tag{D.8}$$

From $\frac{\delta V_M}{\delta w} = 0$ we obtain Equation A.21. Substituting Equation A.21 in p and θ, we obtain Equation A.20 and Equation A.22.

Proof of Scenario 3. Consider the utility function V_R given in Equation B.23. We seek to optimize the retail price p to maximize the utility function. To do this, we first compute the first-order condition by setting $\frac{\delta V_R}{\delta p} = 0$. We obtain

$$p = \frac{\alpha\mu_1 - \alpha + \theta\lambda\mu_1 - \theta\lambda - \beta w}{\beta(\mu_1 - 2)} \tag{D.9}$$

Substituting this p into Equation B.24, we obtain

$$\pi_M = \frac{2(c - w)(\alpha + \theta\lambda - \beta w) - \eta\theta^2\mu_1 + 2\eta\theta^2}{2(\mu_1 - 2)} \tag{D.10}$$

We maximize this π_M by optimizing w and θ simultaneously, that is, $\frac{\delta V_M}{\delta w} = 0$, $\frac{\delta V_M}{\delta \theta} = 0$. We obtain Equation A.28 and Equation A.29. Substituting Equation A.28 and Equation A.29 in p we obtain Equation A.27.

Proof of Scenario 4. Consider the utility function V_R given in Equation B.26. We seek to optimize the retail price p to maximize the utility function. To do this, we first compute the first-order condition by setting $\frac{\delta V_R}{\delta p} = 0$. We obtain

$$p = \frac{\alpha\mu_{\mathrm{R}} - \alpha + \theta\lambda\mu_{\mathrm{R}} - \theta\lambda - \beta w}{\beta(\mu_{\mathrm{R}} - 2)} \tag{D.11}$$

Substituting this p into Equation B.28, we obtain

$$V_M = \frac{\begin{array}{c}\alpha^2\mu_{\mathrm{M}} + \theta\left(\lambda\mu_{\mathrm{M}}(2\alpha + \theta\lambda) - \beta\eta\theta(\mu_{\mathrm{R}} - 2)^2\right) + 2\beta c(\mu_{\mathrm{R}} - 2)(\alpha + \theta\lambda - \beta w) \\ +\beta^2 w^2(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) - 2\beta w(\mu_{\mathrm{M}} + \mu_{\mathrm{R}} - 2)(\alpha + \theta\lambda)\end{array}}{2\beta(\mu_{\mathrm{R}} - 2)^2} \tag{D.12}$$

We maximize this V_M by optimizing w and θ simultaneously, that is, $\frac{\delta V_M}{\delta w} = 0$, $\frac{\delta V_M}{\delta \theta} = 0$. We obtain Equation A.35 and Equation A.36. Substituting Equation A.35 and Equation A.36 in p we obtain Equation A.34.

Proof of Scenario 5. Consider the utility function V_R given in Equation B.30. From $\frac{\delta V_R}{\delta p} = 0$, $\frac{\delta V_R}{\delta \theta} = 0$, we obtain

$$p = -\frac{-\alpha\eta\mu_{\mathrm{R}} + \alpha\eta + \beta\eta w + \lambda^2(-w)}{\beta\eta\mu_{\mathrm{R}} - 2\beta\eta + \lambda^2} \tag{D.13}$$

and

$$\theta = -\frac{\alpha\lambda - \beta\lambda w}{\beta\eta\mu_{\mathrm{R}} - 2\beta\eta + \lambda^2} \tag{D.14}$$

Substituting this p and θ into Equation B.32, we obtain

$$V_M = \frac{\beta\eta(\alpha - \beta w)\left(\alpha\eta\mu_{\mathrm{M}} + 2c\left(\beta\eta(\mu_{\mathrm{R}} - 2) + \lambda^2\right) - w\left(\beta\eta(\mu_{\mathrm{M}} + 2\mu_{\mathrm{R}} - 4) + 2\lambda^2\right)\right)}{2\left(\beta\eta(\mu_{\mathrm{R}} - 2) + \lambda^2\right)^2} \tag{D.15}$$

From $\frac{\delta V_M}{\delta w} = 0$ we obtain Equation A.43. Substituting Equation A.43 in p and θ, we obtain Equation A.42 and Equation A.44.

Proof of Scenario 6. Consider the profit function π_R given in Equation B.33. From $\frac{\delta \pi_R}{\delta p} = 0$, $\frac{\delta \pi_R}{\delta \theta_R} = 0$, we obtain

$$p = -\frac{-\alpha\eta - \eta\theta\mathrm{M}\lambda - \beta\eta w + \lambda^2 w}{2\beta\eta - \lambda^2} \tag{D.16}$$

and

$$\theta_R = -\frac{-\alpha\lambda - \theta\mathrm{M}\lambda^2 + \beta\lambda w}{2\beta\eta - \lambda^2} \tag{D.17}$$

Substituting this p and θ_R into Equation B.35, we obtain

$$V_M = \frac{\eta(\left(2\beta\eta - \lambda^2\right)\left(-2\beta\eta\theta\mathrm{M}^2 + 2\beta(c - w)(\beta w - \alpha) + 2\beta\theta\mathrm{M}\lambda(w - c) + \theta\mathrm{M}^2\lambda^2\right) + \beta\eta\mu_1(\alpha + \theta\mathrm{M}\lambda - \beta w)^2)}{2\left(\lambda^2 - 2\beta\eta\right)^2} \tag{D.18}$$

We maximize this V_M by optimizing w and θ_M simultaneously, that is, $\frac{\delta V_M}{\delta w} = 0$, $\frac{\delta V_M}{\delta \theta_M} = 0$. We obtain Equation A.51 and Equation A.53. Substituting Equation A.51 and Equation A.53 in p and θ_R we obtain Equation A.50 and Equation A.52.

Proof of Scenario 7. Consider the utility function V_R given in Equation B.37. From $\frac{\delta V_R}{\delta p} = 0$, $\frac{\delta V_R}{\delta \theta_R} = 0$, we obtain

$$p = -\frac{-\alpha\eta\mu_1 + \alpha\eta - \eta\theta\mathrm{M}\lambda\mu_1 + \eta\theta\mathrm{M}\lambda + \beta\eta w + \lambda^2(-w)}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2} \tag{D.19}$$

and

$$\theta_R = -\frac{\alpha\lambda + \theta\mathrm{M}\lambda^2 - \beta\lambda w}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2} \tag{D.20}$$

Substituting this p and θ_R into Equation B.38, we obtain

$$\pi_M = -\frac{\eta\left(\theta\mathrm{M}^2\left(\beta\eta(\mu_1-2)+\lambda^2\right)-2\beta c(\alpha+\theta\mathrm{M}\lambda-\beta w)-2\beta^2w^2+2\beta w(\alpha+\theta\mathrm{M}\lambda)\right)}{2\left(\beta\eta(\mu_1-2)+\lambda^2\right)} \tag{D.21}$$

We maximize this π_M by optimizing w and θ_M simultaneously, that is, $\frac{\delta\pi_M}{\delta w}=0$, $\frac{\delta\pi_M}{\delta\theta_M}=0$. We obtain Equation A.59 and Equation A.61. Substituting Equation A.59 and Equation A.61 in p and θ_R we obtain Equation A.58 and Equation A.60.

Proof of Scenario 8. Consider the utility function V_R given in Equation B.40. From $\frac{\delta V_R}{\delta p}=0$, $\frac{\delta V_R}{\delta\theta_R}=0$, we obtain

$$p = -\frac{-\alpha\eta\mu_\mathrm{R}+\alpha\eta-\eta\theta\mathrm{M}\lambda\mu_\mathrm{R}+\eta\theta\mathrm{M}\lambda+\beta\eta w+\lambda^2(-w)}{\beta\eta\mu_\mathrm{R}-2\beta\eta+\lambda^2} \tag{D.22}$$

$$\theta_R = -\frac{\alpha\lambda+\theta\mathrm{M}\lambda^2-\beta\lambda w}{\beta\eta\mu_\mathrm{R}-2\beta\eta+\lambda^2} \tag{D.23}$$

Substituting this p and θ_R into Equation B.42, we obtain

$$V_M = \frac{1}{2}\eta\left(\frac{2\beta(c-w)(\alpha+\theta\mathrm{M}\lambda-\beta w)}{\beta\eta(\mu_\mathrm{R}-2)+\lambda^2}-\theta\mathrm{M}^2+\frac{\beta\eta\mu_\mathrm{M}(\alpha+\theta\mathrm{M}\lambda-\beta w)^2}{\left(\beta\eta(\mu_\mathrm{R}-2)+\lambda^2\right)^2}\right) \tag{D.24}$$

We maximize this V_M by optimizing w and θ_M simultaneously, that is, $\frac{\delta V_M}{\delta w}=0$, $\frac{\delta V_M}{\delta\theta_M}=0$. We obtain Equation A.67 and Equation A.69. Substituting Equation A.67 and Equation A.69 in p and θ_R we obtain Equation A.66 and Equation A.68.

D.2. Model 2: Two-Part Tariff Contract

Proof of Scenario 0_2. Consider the profit function π_R given in Equation B.43. We seek to optimize the retail price p to maximize the profit function. To do this, we first compute the first-order condition by setting $\frac{\delta\pi_R}{\delta p}=0$. We obtain

$$p = \frac{\alpha+\theta\lambda+\beta w}{2\beta} \tag{D.25}$$

Substituting this p into Equation B.43 and from $\frac{\delta\pi_R}{\delta F}=0$ we obtain

$$F = \frac{(\alpha+\theta\lambda-\beta w)^2}{4\beta} \tag{D.26}$$

Substituting this p and F into Equation B.45, we obtain

$$V_M = \frac{\begin{array}{c}2\left(\alpha^2+\alpha(2\theta\lambda-2\beta c)-2\beta c\theta\lambda+\beta\left(\beta w(2c-w)-2\eta\theta^2\right)+\theta^2\lambda^2\right)\\ +\mu_1(\alpha+\theta\lambda-\beta w)^2\end{array}}{8\beta}/. \tag{D.27}$$

We maximize this V_M by optimizing w and θ simultaneously, that is, $\frac{\delta V_M}{\delta w}=0$, $\frac{\delta V_M}{\delta\theta}=0$. We obtain Equation A.76 and Equation A.78. Substituting Equation A.76 and Equation A.78 in p and F we obtain Equation A.75 and Equation A.77.

Proof of Scenario 1_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.84, Equation A.83, Equation A.85 and Equation A.86.

Proof of Scenario 2_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.92, Equation A.91, Equation A.93 and Equation A.94.

Proof of Scenario 3_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.100, Equation A.99, Equation A.101 and Equation A.102.

Proof of Scenario 4_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.108, Equation A.107, Equation A.109 and Equation A.110.

Proof of Scenario 5_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.117, Equation A.116, Equation A.118 and Equation A.119.

Proof of Scenario 6_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.126, Equation A.125, Equation A.127, Equation A.128 and Equation A.129.

Proof of Scenario 7_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.135, Equation A.134, Equation A.136, Equation A.137 and Equation A.138.

Proof of Scenario 8_2. This proof is analogous to paragraph D.1 with the inclusion of the franchise Fee F as presented in paragraph D.2. We obtain Equation A.144, Equation A.143, Equation A.145, Equation A.146 and Equation A.147.

D.3. Model 3: Wholesale Price Contract with Governmental Intervention

Proof of Scenario 0_G. Consider the profit function π_R given in Equation B.73. We seek to optimize the retail price p to maximize the profit function. To do this, we first compute the first-order condition by setting $\frac{\delta \pi_R}{\delta p} = 0$. We obtain

$$p = \frac{\alpha - \beta\tau + \theta\lambda + \beta w}{2\beta} \tag{D.28}$$

Substituting this p into Equation B.75, we obtain

$$V_M = \frac{\begin{array}{c}\alpha^2\mu_1 + \theta(\lambda\mu_1(2\alpha+\theta\lambda) - 4\beta\eta\theta) - 2\beta\mu_1\tau(\alpha+\theta\lambda) \\ +\beta^2\mu_1\tau^2 + 4\beta c(-\alpha-\theta\lambda+\beta(\tau+w)) \\ +\beta^2(\mu_1-4)w^2 - 2\beta(\mu_1-2)w(\alpha-\beta\tau+\theta\lambda)\end{array}}{8\beta} \tag{D.29}$$

We maximize this V_M by optimizing w and θ simultaneously, that is, $\frac{\delta V_M}{\delta w} = 0$, $\frac{\delta V_M}{\delta \theta} = 0$. We obtain

$$w = -\frac{-\alpha\eta\mu_1 + 2\alpha\eta + \beta\eta\mu_1\tau - 2\beta\eta\tau + 2\beta c\eta - c\lambda^2}{\beta\eta\mu_1 - 4\beta\eta + \lambda^2} \tag{D.30}$$

and

$$\theta = -\frac{\lambda(\alpha - \beta\tau - \beta c)}{\beta\eta\mu_1 - 4\beta\eta + \lambda^2} \tag{D.31}$$

Substituting w and θ into Equation D.28, we obtain

$$p = \frac{\alpha\eta(\mu_1-3) - \beta\eta(\mu_1-3)\tau + c\left(\lambda^2 - \beta\eta\right)}{\beta\eta(\mu_1-4) + \lambda^2} \tag{D.32}$$

Substituting this p, w and θ into Equation B.76, we obtain

$$V_G = \frac{\begin{array}{c}(\beta(c+\tau)-\alpha) \\ \left(\beta\eta\left(-\alpha\eta\mu_2 + 2\lambda^2\tau + 2\lambda(\mu_1-4)\right) + \beta^2\eta^2(c\mu_2 + \tau(2\mu_1+\mu_2-8)) + 2\lambda^3\right)\end{array}}{2\left(\beta\eta(\mu_1-4)+\lambda^2\right)^2} \tag{D.33}$$

From $\frac{\delta V_G}{\delta \tau} = 0$ we obtain Equation A.162. Substituting Equation A.162 in p, w and θ, we obtain Equation A.160, Equation A.161 and Equation A.163.

Proof of Scenario 1_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.171, Equation A.169, Equation A.170 and Equation A.172.

Proof of Scenario 2_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.180, Equation A.178, Equation A.179 and Equation A.181.

Proof of Scenario 3_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.189, Equation A.187, Equation A.188 and Equation A.190.

Proof of Scenario 4_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.198, Equation A.196, Equation A.197 and Equation A.199.

Proof of Scenario 5_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.208, Equation A.206, Equation A.207 and Equation A.209.

Proof of Scenario 6_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.218, Equation A.216, Equation A.217, Equation A.220 and Equation A.219.

Proof of Scenario 7_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.228, Equation A.226, Equation A.227, Equation A.230 and Equation A.229.

Proof of Scenario 8_G. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ as presented in paragraph D.3. We obtain Equation A.238, Equation A.236, Equation A.237, Equation A.240 and Equation A.239.

D.4. Model 4: Two-Part Tariff Contract with Governmental Intervention

Proof of Scenario 0_{G2}. Consider the profit function π_R given in Equation B.112. We seek to optimize the retail price p to maximize the profit function. To do this, we first compute the first-order condition by setting $\frac{\delta \pi_R}{\delta p} = 0$. We obtain

$$p = \frac{\alpha - \beta\tau + \theta\lambda + \beta w}{2\beta} \tag{D.34}$$

Substituting this p into Equation B.112 and from $\frac{\delta \pi_R}{\delta F} = 0$ we obtain

$$F = \frac{(\alpha - \beta\tau + \theta\lambda - \beta w)^2}{4\beta} \tag{D.35}$$

Substituting this p and F into Equation B.114, we obtain

$$V_M = \frac{\begin{array}{c}\alpha^2(\mu_1+2) + \beta^2(\mu_1+2)\tau^2 - 4\beta\eta\theta^2 \\ -2\alpha(\beta(\mu_1+2)\tau + 2\beta c - \theta\lambda(\mu_1+2) + \beta\mu_1 w) \\ +4\beta c(\beta(\tau+w) - \theta\lambda) + \theta^2\lambda^2\mu_1 + 2\theta^2\lambda^2 \\ +\beta^2\mu_1 w^2 - 2\beta^2 w^2 + 2\beta\tau(\beta\mu_1 w - \theta\lambda(\mu_1+2)) - 2\beta\theta\lambda\mu_1 w\end{array}}{8\beta} \tag{D.36}$$

We maximize this V_M by optimizing w and θ simultaneously, that is, $\frac{\delta V_M}{\delta w} = 0$, $\frac{\delta V_M}{\delta \theta} = 0$. We obtain

$$w = -\frac{-\alpha\eta\mu_1 + \beta\eta\mu_1\tau + 2\beta c\eta - c\lambda^2}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2} \tag{D.37}$$

and

$$\theta = \frac{\lambda(-\alpha + \beta\tau + \beta c)}{\beta\eta\mu_1 - 2\beta\eta + \lambda^2} \tag{D.38}$$

Substituting w and θ into Equation D.34 and Equation D.35, we obtain

$$p = \frac{\alpha\eta(\mu_1 - 1) - \beta\eta(\mu_1 - 1)\tau + c\left(\lambda^2 - \beta\eta\right)}{\beta\eta(\mu_1 - 2) + \lambda^2} \tag{D.39}$$

and

$$F = \frac{\beta\eta^2(\alpha - \beta(c + \tau))^2}{\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{D.40}$$

Substituting this p, F, w and θ into Equation B.115, we obtain

$$V_G = \frac{\begin{array}{c}(\beta(c + \tau) - \alpha)(\beta\eta\left(-\alpha\eta\mu_2 + 2\lambda^2\tau + 2\lambda(\mu_1 - 2)\right) \\ +\beta^2\eta^2(c\mu_2 + \tau(2\mu_1 + \mu_2 - 4)) + 2\lambda^3)\end{array}}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2} \tag{D.41}$$

From $\frac{\delta V_G}{\delta \tau} = 0$ we obtain Equation A.250. Substituting Equation A.250 in p, w, F and θ we obtain Equation A.247, Equation A.248, Equation A.249 and Equation A.251.

Proof of Scenario 1_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.260, Equation A.257, Equation A.258, Equation A.259 and Equation A.261.

Proof of Scenario 2_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.270, Equation A.267, Equation A.268, Equation A.269 and Equation A.271.

Proof of Scenario 3_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.280, Equation A.277, Equation A.278, Equation A.279 and Equation A.281.

Proof of Scenario 4_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.290, Equation A.287, Equation A.288, Equation A.289 and Equation A.291.

Proof of Scenario 5_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.301, Equation A.298, Equation A.299, Equation A.300 and Equation A.302.

Proof of Scenario 6_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.312, Equation A.309, Equation A.310, Equation A.311, Equation A.314 and Equation A.313.

Proof of Scenario 7_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.323, Equation A.320, Equation A.321, Equation A.322, Equation A.325 and Equation A.324.

Proof of Scenario 8_{G2}. This proof is analogous to paragraph D.1 with the inclusion of the governmental tax τ and franchise fee F as presented in paragraph D.4. We obtain Equation A.334, Equation A.331, Equation A.332, Equation A.333, Equation A.336 and Equation A.335.

E. Proof of Propositions

E.1. Proof of Proposition 1

The ranking of the scenarios is based on a comparison of the equilibrium values for each scenario. In the following, the proofs for Proposition 1 and Proposition 2 are presented as examples. The proofs for Propositions 3, 4, 8, and 9 follow analogously.

Green Degree of Product

We define the equilibrium green degree θ_i under five scenarios of ESG responsibility allocation with a WP contract. These equilibrium values are functions of model parameters $\alpha, \beta, c, \eta, \gamma, \mu_1$.
The scenarios and their corresponding green degrees are defined in Equation A.2, Equation A.8, Equation A.15, Equation A.22 and Equation A.29.

All parameters satisfy the following assumptions: $\alpha, \beta, \lambda, c, \eta > 0, 0 \leq \mu_1 \leq 1, \beta\eta > \lambda^2, \alpha > \beta c$.

Proof of $\theta_C > \theta_1$
Taking the difference between θ_C and θ_1, we obtain:

$$\theta_C - \theta_1 = \frac{\beta c\lambda - \alpha\lambda}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

To determine the sign of this expression, we analyze the numerator and denominator separately.
Numerator: Since $\alpha > \beta c$ and $\lambda > 0$, it follows that:

$$\beta c\lambda - \alpha\lambda < 0$$

so the numerator is negative.
Denominator: Since $\mu_1 \in [0, 1]$, we have $\mu_1 - 2 \in [-2, -1]$, and thus:

$$\beta\eta(\mu_1 - 2) + \lambda^2 < \lambda^2$$

Given the assumption $\beta\eta > \lambda^2$, we conclude:

$$\beta\eta(\mu_1 - 2) + \lambda^2 < 0$$

so the denominator is also negative.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$\theta_C - \theta_1 > 0 \quad \Rightarrow \quad \theta_C > \theta_1$$

Proof of $\theta_1 > \theta_2$
Taking the difference between θ_1 and θ_2, we obtain:

$$\theta_1 - \theta_2 = \frac{\beta\eta\lambda\mu_1(\alpha - \beta c)}{2\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

To determine the sign of this expression, we analyze the numerator and denominator separately.
Numerator: Since $\mu_1 \geq 0$, $\lambda > 0$, and $\alpha - \beta c > 0$, it follows that:

$$\beta\eta\lambda\mu_1(\alpha - \beta c) > 0$$

so the numerator is positive.
Denominator: Since $\mu_1 \in [0, 1]$, we have $\mu_1 - 4 < -3$ and $\mu_1 - 2 < -1$. Since $\beta\eta > \lambda^2$, it follows that both:

$$\beta\eta(\mu_1 - 4) + 2\lambda^2 < 0, \quad \text{and} \quad \beta\eta(\mu_1 - 2) + \lambda^2 < 0$$

so the entire denominator is the product of two negative terms, which is positive.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$\theta_1 - \theta_2 > 0 \quad \Rightarrow \quad \theta_1 > \theta_2$$

Proof of $\theta_1 > \theta_3$
Taking the difference between θ_1 and θ_3, we obtain:

$$\theta_1 - \theta_3 = \frac{\lambda^3(\alpha - \beta c)}{2\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

To determine the sign of this expression, we analyze the numerator and denominator separately.
Numerator: Since $\lambda > 0$ and $\alpha - \beta c > 0$, it follows that:

$$\lambda^3(\alpha - \beta c) > 0$$

so the numerator is positive.
Denominator: For all $\mu_1 \in [0, 1]$, we have $\mu_1 - 2 < -1$. Given that $\beta\eta > \lambda^2$, it follows that both:

$$\beta\eta(\mu_1 - 2) + \lambda^2 < 0, \quad \text{and} \quad 2\beta\eta(\mu_1 - 2) + \lambda^2 < 0$$

so the denominator is a product of two negative terms, which is positive.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$\theta_1 - \theta_3 > 0 \quad \Rightarrow \quad \theta_1 > \theta_3$$

Proof of $\theta_2 > \theta_0$
Taking the difference between θ_2 and θ_0, we obtain:

$$\theta_2 - \theta_0 = \frac{\lambda^3(\alpha - \beta c)}{(\beta\eta(\mu_1 - 4) + \lambda^2)\,(\beta\eta(\mu_1 - 4) + 2\lambda^2)}$$

To determine the sign of this expression, we analyze the numerator and denominator separately.
Numerator: Since $\lambda > 0$ and $\alpha - \beta c > 0$, it follows that:

$$\lambda^3(\alpha - \beta c) > 0$$

so the numerator is positive.
Denominator: For all $\mu_1 \in [0, 1]$, we have $\mu_1 - 4 \leq -3$. Given $\beta\eta > \lambda^2$, both:

$$\beta\eta(\mu_1 - 4) + \lambda^2 < 0 \quad \text{and} \quad \beta\eta(\mu_1 - 4) + 2\lambda^2 < 0$$

so the denominator is a product of two negative terms, which is positive.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$\theta_2 - \theta_0 > 0 \quad \Rightarrow \quad \theta_2 > \theta_0$$

Proof of $\theta_3 > \theta_0$
Taking the difference between θ_3 and θ_0, we obtain:

$$\theta_3 - \theta_0 = \frac{\beta\eta\lambda\mu_1(\alpha - \beta c)}{(\beta\eta(\mu_1 - 4) + \lambda^2)\,(2\beta\eta(\mu_1 - 2) + \lambda^2)}$$

Numerator: Since $\mu_1 \geq 0$, $\lambda > 0$, and $\alpha - \beta c > 0$, it follows that:

$$\beta\eta\lambda\mu_1(\alpha - \beta c) > 0$$

so the numerator is positive.
Denominator: Since $\mu_1 \in [0, 1]$, we have $\mu_1 - 4 \leq -3$ and $\mu_1 - 2 \leq -1$. Given $\beta\eta > \lambda^2$, both:

$$\beta\eta(\mu_1 - 4) + \lambda^2 < 0 \quad \text{and} \quad 2\beta\eta(\mu_1 - 2) + \lambda^2 < 0$$

so the denominator is a product of two negative terms, which is positive.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$\theta_3 - \theta_0 > 0 \quad \Rightarrow \quad \theta_3 > \theta_0$$

Consumer Surplus

We define the equilibrium consumer surplus CS_i under five scenarios of ESG responsibility allocation with a WP contract. These equilibrium values are functions of model parameters $\alpha, \beta, c, \eta, \gamma, \mu_1$.
The scenarios and their corresponding consumer surplus are defined in Equation A.5, Equation A.12, Equation A.19, Equation A.26 and Equation A.33.

All parameters satisfy the following assumptions: $\alpha, \beta, \lambda, c, \eta > 0, 0 \leq \mu_1 \leq 1, \beta\eta > \lambda^2, \alpha > \beta c$.

Proof of $CS_C > CS_1$

Taking the difference between CS_C and CS_1, we obtain:

$$CS_C - CS_1 = \frac{3\beta\eta^2(\alpha - \beta c)^2}{8\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2}$$

To determine the sign of this expression, we analyze the numerator and denominator separately.
Numerator: Since $\alpha - \beta c > 0$, $\beta > 0$, and $\eta > 0$, the square of the term $(\alpha - \beta c)^2$ is positive. Therefore, the entire numerator is positive.
Denominator: Since $\mu_1 \in [0, 1]$, we have $\mu_1 - 2 \leq -1$. Given the assumption $\beta\eta > \lambda^2$, it follows that:

$$\beta\eta(\mu_1 - 2) + \lambda^2 < 0$$

Thus, the denominator is the square of a negative term, and hence is positive.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$CS_C - CS_1 > 0 \quad \Rightarrow \quad CS_C > CS_1$$

Proof of $CS_1 > CS_2$

Taking the difference between CS_1 and CS_2, we obtain:

$$CS_1 - CS_2 = \frac{1}{8}\beta\eta^2(\alpha - \beta c)^2 \left(\frac{1}{(\beta\eta(\mu_1 - 2) + \lambda^2)^2} - \frac{4}{(\beta\eta(\mu_1 - 4) + 2\lambda^2)^2} \right)$$

Numerator: The entire expression is multiplied by $\frac{1}{8}\beta\eta^2(\alpha - \beta c)^2$, which is positive under the assumptions $\alpha - \beta c > 0$, $\beta > 0$, and $\eta > 0$.
Denominator: Each inner fraction has its own denominator, which are squared and positive under $\beta\eta > \lambda^2$. The term inside the parentheses is positive because:

$$\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)^2 < \left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)^2$$

and therefore the fraction on the left is greater than the one on the right.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$CS_1 - CS_2 > 0 \quad \Rightarrow \quad CS_1 > CS_2$$

Proof of $CS_2 > CS_0$
Taking the difference between CS_2 and CS_0, we obtain:

$$CS_2 - CS_0 = -\frac{\beta\eta^2(\alpha-\beta c)^2\left(2\beta\eta\lambda^2(\mu_1-4)+3\lambda^4\right)}{2\left(\beta\eta(\mu_1-4)+\lambda^2\right)^2\left(\beta\eta(\mu_1-4)+2\lambda^2\right)^2}$$

Numerator: The numerator contains a negative sign in front of an expression that is negative. Under the assumption that $\alpha - \beta c > 0$, it follows that:

$$\beta\eta^2(\alpha-\beta c)^2 > 0$$

Since $\mu_1 \in [0,1]$, we have $\mu_1 - 4 \leq -3$, and given $\beta > 0$, $\eta > 0$, and $\lambda > 0$, it follows that:

$$2\beta\eta\lambda^2(\mu_1-4)+3\lambda^4 < 0$$

Thus, the numerator is positive.
Denominator: Each term in the denominator is squared, and since $\beta\eta > \lambda^2$, the full expression is positive.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$CS_2 - CS_0 > 0 \quad \Rightarrow \quad CS_2 > CS_0$$

Proof of $CS_3 > CS_0$
Taking the difference between CS_3 and CS_0, we obtain:

$$CS_3 - CS_0 = \frac{1}{2}\beta\eta^2(\alpha-\beta c)^2\left(\frac{1}{(2\beta\eta(\mu_1-2)+\lambda^2)^2} - \frac{1}{(\beta\eta(\mu_1-4)+\lambda^2)^2}\right)$$

Numerator: The entire expression is multiplied by $\frac{1}{2}\beta\eta^2(\alpha-\beta c)^2$, which is positive under the assumptions $\alpha - \beta c > 0$, $\beta > 0$, and $\eta > 0$.
Denominator: Each inner fraction has its own denominator, which are squared and positive under $\beta\eta > \lambda^2$. The term inside the parentheses is positive because:

$$\left(2\beta\eta(\mu_1-2)+\lambda^2\right)^2 > \left(\beta\eta(\mu_1-4)+\lambda^2\right)^2$$

and therefore the fraction on the left is greater than the one on the right.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$CS_3 - CS_0 > 0 \quad \Rightarrow \quad CS_3 > CS_0$$

E.2. Proof of Proposition 2

Wholesale Price

We define the equilibrium wholesale price w_i under five scenarios of ESG responsibility allocation with a WP contract. These equilibrium values are functions of model parameters

$\alpha, \beta, c, \eta, \gamma, \mu_1$.
The scenarios and their corresponding wholesale price are defined in Equation A.7, Equation A.14, Equation A.21 and Equation A.28.

All parameters satisfy the following assumptions: $\alpha, \beta, \lambda, c, \eta > 0, 0 \leq \mu_1 \leq 1, \beta\eta > \lambda^2, \alpha > \beta c$.

Proof of $w_3 > w_1$
Taking the difference between w_3 and w_1, we obtain:

$$w_3 - w_1 = \frac{\lambda^2(\beta c - \alpha)}{2\beta\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

Numerator: Since $\alpha - c\beta > 0$, it follows that $\beta c - \alpha < 0$. With $\lambda > 0$, the numerator is negative.
Denominator: Since $\mu_1 \in [0, 1] \Rightarrow \mu_1 - 2 \in [-2, -1]$, and $\beta\eta > \lambda^2$, we have $2\beta\eta(\mu_1 - 2) + \lambda^2 < 0$. Thus, the denominator is negative.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$w_3 - w_1 > 0 \quad \Rightarrow \quad w_3 > w_1$$

Proof of $w_3 > w_0$
Taking the difference between w_3 and w_0, we obtain:

$$w_3 - w_0 = \frac{\beta\eta^2(\mu_1 - 2)\mu_1(\beta c - \alpha)}{\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

Numerator: Since $\alpha - c\beta > 0 \Rightarrow \beta c - \alpha < 0$, and since $\mu_1 \in (0, 1]$, we have $\mu_1 \geq 0$ and $\mu_1 - 2 \leq 0$. Therefore, the product

$$\beta\eta^2(\mu_1 - 2)\mu_1(\beta c - \alpha)$$

has sign $(+)(-)(+)(-) = (+)$. Thus, the numerator is positive.
Denominator: Since $\mu_1 \in [0, 1]$ and $\beta\eta > \lambda^2$, we have

$$\beta\eta(\mu_1 - 4) + \lambda^2 < 0 \quad \text{and} \quad 2\beta\eta(\mu_1 - 2) + \lambda^2 < 0$$

Thus, the denominator is positive.
Conclusion: Since both the numerator and the denominator are positive, the expression is positive:

$$w_3 - w_0 > 0 \quad \Rightarrow \quad w_3 > w_0$$

Proof of $w_1 > w_2$
Taking the difference between w_1 and w_2, we obtain:

$$w_1 - w_2 = \frac{\eta\mu_1(\beta c - \alpha)}{2\beta\eta(\mu_1 - 4) + 4\lambda^2}$$

Numerator: Since $\alpha - c\beta > 0$, we have $\beta c - \alpha < 0$. Given $\mu_1 \geq 0$ and $\eta > 0$, the numerator is negative.
Denominator: Since $\mu_1 \in (0, 1]$, we have $\mu_1 - 4 \leq -3$. Since $\beta > 0$, $\eta > 0$, and $\lambda > 0$, it follows that

$$2\beta\eta(\mu_1 - 4) + 4\lambda^2 < 0,$$

so the denominator is negative.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$w_1 - w_2 > 0 \quad \Rightarrow \quad w_1 > w_2$$

Proof of $w_0 > w_2$
Taking the difference between w_0 and w_2, we obtain:

$$w_0 - w_2 = \frac{\lambda^2 \left(2\beta\eta - \lambda^2\right)(\alpha - \beta c)}{\beta\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)}$$

Numerator: Under the assumption $\alpha - \beta c > 0$, and since $\beta\eta > \lambda^2$, it follows that $2\beta\eta - \lambda^2 > 0$. With $\lambda > 0$, the numerator is positive.
Denominator: Given $\mu_1 \in [0, 1]$, we have $\mu_1 - 4 \leq -3$. Since $\beta > 0$, $\eta > 0$, and $\lambda > 0$, both terms

$$\beta\eta(\mu_1 - 4) + \lambda^2 < 0 \quad \text{and} \quad \beta\eta(\mu_1 - 4) + 2\lambda^2 < 0$$

are negative. Thus, their product is positive, and the denominator is positive.
Conclusion: Since both the numerator and the denominator are positive, the expression is positive:

$$w_0 - w_2 > 0 \quad \Rightarrow \quad w_0 > w_2$$

Retail Price

We define the equilibrium retail price p_i under five scenarios of ESG responsibility allocation with a WP contract. These equilibrium values are functions of model parameters $\alpha, \beta, c, \eta, \gamma, \mu_1$.
The scenarios and their corresponding retail price are defined in Equation A.1, Equation A.6, Equation A.13, Equation A.20 and Equation A.27.

Proof of $p_1 > p_C$
Taking the difference between p_1 and p_C, we obtain:

$$p_1 - p_C = -\frac{(\beta\eta - \lambda^2)(\alpha - \beta c)}{2\beta\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

Numerator: Given the assumption $\alpha - \beta c > 0$, we have $(\alpha - \beta c) > 0$. Also, since $\beta\eta > \lambda^2$, it follows that $\beta\eta - \lambda^2 > 0$. However, due to the negative sign in front, the numerator is negative.
Denominator: For $\mu_1 \in [0, 1]$, we have $\mu_1 - 2 \leq -1$, and since $\beta > 0$, $\eta > 0$, and $\lambda > 0$, it follows that:

$$\beta\eta(\mu_1 - 2) + \lambda^2 < 0$$

Thus, the denominator is negative.
Conclusion: Since both the numerator and the denominator are negative, the expression is positive:

$$p_1 - p_C > 0 \quad \Rightarrow \quad p_1 > p_C$$

Proof of $p_0 > p_2$
Taking the difference between p_0 and p_2, we obtain:

$$p_0 - p_2 = \frac{\lambda^2(\beta\eta - \lambda^2)(\alpha - \beta c)}{\beta\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)}$$

Numerator: Since $\alpha - \beta c > 0$, $\lambda > 0$, and $\beta\eta > \lambda^2$, it follows that all three factors in the numerator are positive. Thus, the numerator is positive.
Denominator: For $\mu_1 \in [0, 1]$, we have $\mu_1 - 4 \leq -3$. Since $\beta > 0$, $\eta > 0$, $\lambda > 0$ and $\beta\eta > \lambda^2$, the expressions $\beta\eta(\mu_1 - 4) + \lambda^2$ and $\beta\eta(\mu_1 - 4) + 2\lambda^2$ are both negative. Thus, the product of two negative terms is positive, and the denominator is positive.
Conclusion: Since both the numerator and the denominator are positive, the expression is positive:

$$p_0 - p_2 > 0 \quad \Rightarrow \quad p_0 > p_2$$

Proof of $p_0 > p_3$
Taking the difference between p_0 and p_3, we obtain:

$$p_0 - p_3 = \frac{\eta\mu_1(\beta\eta - \lambda^2)(\alpha - \beta c)}{\left(\beta\eta(\mu_1 - 4) + \lambda^2\right)\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

Numerator: Since $\alpha - \beta c > 0$, $\mu_1 \geq 0$, $\eta > 0$, and $\beta\eta > \lambda^2$, all factors in the numerator are positive. Therefore, the numerator is positive.
Denominator: Since $\mu_1 \in [0, 1]$, we have $\mu_1 - 4 \leq -3$ and $\mu_1 - 2 \leq -1$. Since $\beta > 0$, $\eta > 0$, $\lambda > 0$ and $\beta\eta > \lambda^2$ both terms are negative, and their product is positive. Thus, the denominator is positive.

Conclusion: Since both the numerator and the denominator are positive, the expression is positive:

$$p_0 - p_3 > 0 \quad \Rightarrow \quad p_0 > p_3$$

Proof of $p_2 > p_1$
Taking the difference between p_2 and p_1, we obtain:

$$p_2 - p_1 = \frac{\eta\mu_1(\beta\eta - \lambda^2)(\alpha - \beta c)}{2\left(\beta\eta(\mu_1 - 4) + 2\lambda^2\right)\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

Numerator: Since $\mu_1 > 0$, $\beta\eta > \lambda^2$, $\alpha - \beta c > 0$, and $\eta > 0$, the numerator is positive.
Denominator: Since $\mu_1 \in [0, 1]$, we have $\mu_1 - 4 \leq -3$ and $\mu_1 - 2 \leq -1$, Since $\beta > 0$, $\eta > 0$, $\lambda > 0$ and $\beta\eta > \lambda^2$ both terms are negative, and their product is positive. Thus, the denominator is positive.
Conclusion: Since both the numerator and the denominator are positive, the expression is positive:

$$p_2 - p_1 > 0 \quad \Rightarrow \quad p_2 > p_1$$

Proof of $p_3 > p_1$
Taking the difference between p_3 and p_1, we obtain:

$$p_3 - p_1 = \frac{\lambda^2(\beta\eta - \lambda^2)(\alpha - \beta c)}{2\beta\left(\beta\eta(\mu_1 - 2) + \lambda^2\right)\left(2\beta\eta(\mu_1 - 2) + \lambda^2\right)}$$

Numerator: Since $\lambda > 0$, $\beta\eta > \lambda^2$, and $\alpha - \beta c > 0$, the numerator is positive.
Denominator: Since $\mu_1 \in [0, 1]$, we have $\mu_1 - 2 \leq -1$. Since $\beta > 0$, $\eta > 0$, $\lambda > 0$ and $\beta\eta > \lambda^2$ both terms are negative, and their product is positive. Thus, the denominator is positive.
Conclusion: Since both the numerator and the denominator are positive, the expression is positive:

$$p_3 - p_1 > 0 \quad \Rightarrow \quad p_3 > p_1$$

E.3. Proof of Proposition 5

Comparative static analysis for the decision variables (retail price, wholesale price, and green degree) was carried out by computing the partial derivatives with respect to the following parameters:

- α: Market potential
- η: Green cost coefficient
- λ: Green demand expansion coefficient
- c: Unit production cost

The sign of each derivative was analyzed symbolically using *Wolfram Mathematica*. Under the assumptions of the model (e.g. $\alpha > c\beta$, $\beta\eta > \lambda^2$, and $\mu_i \in [0,1]$), it was determined whether each parameter has a positive, negative, or ambiguous effect on the respective decision variable.

In the following, the proof for for Scenario 0-3 of Proposition 5 (comparative statics of the retail price under a WP contract) is presented. The proofs for Propositions 6, 7, 10, 11 (a), 12 and 13 follow analogously.

Scenario 0

Effect of Market Potential α

Taking the derivative of the equilibrium retail price p_0 with respect to the market potential parameter α, we obtain:

$$\frac{\partial p_0}{\partial \alpha} = \frac{\eta(\mu_1 - 3)}{\beta\eta(\mu_1 - 4) + \lambda^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\eta > 0$ and $\mu_1 \in [0,1]$, it follows that $\mu_1 - 3 < 0$. Therefore, the numerator is negative.

Denominator: For all $\mu_1 \in [0,1]$, the worst-case value is $\mu_1 = 1$, yielding:

$$\beta\eta(\mu_1 - 4) + \lambda^2 = \beta\eta(-3) + \lambda^2$$

Under the assumption $\beta\eta > \lambda^2$, this implies:

$$-3\beta\eta + \lambda^2 < 0$$

Thus, the denominator is also negative.

Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_0}{\partial \alpha} > 0$$

Accordingly, the equilibrium retail price p_0 increases with α.

Effect of Green Cost Coefficient η

Taking the derivative of the equilibrium retail price p_0 with respect to the green cost coefficient η, we obtain:

$$\frac{\partial p_0}{\partial \eta} = \frac{(\alpha - c\beta)\lambda^2(\mu_1 - 3)}{(\lambda^2 + \beta\eta(\mu_1 - 4))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\alpha > c\beta$, $\lambda > 0$, and $\mu_1 \in [0,1]$, it follows that $\alpha - c\beta > 0$, $\lambda^2 > 0$, and $\mu_1 - 3 < 0$. Therefore, the numerator is negative.

Denominator: The denominator is a square term and thus always positive for all

admissible values of the parameters.
Conclusion: Since the numerator is negative and the denominator is positive, the derivative is negative:

$$\frac{\partial p_0}{\partial \eta} < 0$$

Therefore, the equilibrium retail price p_0 decreases with η.

Effect of Green Demand Coefficient λ

Taking the derivative of the equilibrium retail price p_0 with respect to the green demand coefficient λ, we obtain:

$$\frac{\partial p_0}{\partial \lambda} = -\frac{2(\alpha - c\beta)\eta\lambda(\mu_1 - 3)}{(\lambda^2 + \beta\eta(\mu_1 - 4))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: Since $\alpha > c\beta$, $\eta > 0$, $\lambda > 0$, and $\mu_1 \in [0, 1]$, it follows that $\alpha - c\beta > 0$, $\mu_1 - 3 < 0$, and thus the product $(\alpha - c\beta)\eta\lambda(\mu_1 - 3)$ is negative. The leading negative sign in front of the fraction then makes the entire numerator positive.
Denominator: The denominator is a square term and thus always positive for all admissible values of the parameters.
Conclusion: Since both the numerator and denominator are positive, the derivative is positive:

$$\frac{\partial p_0}{\partial \lambda} > 0$$

Therefore, the equilibrium retail price p_0 increases with λ.

Effect of Cost Parameter c

Taking the derivative of the equilibrium retail price p_0 with respect to the cost parameter c, we obtain:

$$\frac{\partial p_0}{\partial c} = \frac{-\beta\eta + \lambda^2}{\lambda^2 + \beta\eta(\mu_1 - 4)}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: Under the assumption $\beta\eta > \lambda^2$, it follows that $-\beta\eta + \lambda^2 < 0$. Therefore, the numerator is negative.
Denominator: For $\mu_1 \in [0, 1]$, the worst-case value is $\mu_1 = 1$, giving:

$$\lambda^2 + \beta\eta(\mu_1 - 4) = \lambda^2 - 3\beta\eta$$

Since $\beta\eta > \lambda^2$, this expression is negative. Therefore, the denominator is also negative.
Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_0}{\partial c} > 0$$

Therefore, the equilibrium retail price p_0 increases with c.

Scenario 1

Effect of Market Potential α

Taking the derivative of the equilibrium retail price p_1 in Scenario 1 with respect to the market potential parameter α, we obtain:

$$\frac{\partial p_1}{\partial \alpha} = \frac{\lambda^2 + \beta\eta(-3 + 2\mu_1)}{2\beta(\lambda^2 + \beta\eta(-2 + \mu_1))}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: For $\mu_1 \in [0, 1]$, the worst-case value is $\mu_1 = 1$, yielding:

$$\lambda^2 + \beta\eta(-3 + 2\mu_1) = \lambda^2 - \beta\eta$$

Under the assumption $\beta\eta > \lambda^2$, this implies:

$$\lambda^2 - \beta\eta < 0$$

Therefore, the numerator is negative.

Denominator: For $\mu_1 = 1$, we get:

$$2\beta(\lambda^2 + \beta\eta(-2 + \mu_1)) = 2\beta(\lambda^2 - \beta\eta)$$

Again, since $\beta\eta > \lambda^2$, this implies:

$$\lambda^2 - \beta\eta < 0$$

Therefore, the denominator is also negative.

Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_1}{\partial \alpha} > 0$$

Therefore, the equilibrium retail price p_1 increases with α.

Effect of Green Cost Coefficient η

Taking the derivative of the equilibrium retail price p_1 in Scenario 1 with respect to the green cost coefficient η, we obtain:

$$\frac{\partial p_1}{\partial \eta} = \frac{(\alpha - c\beta)\lambda^2(\mu_1 - 1)}{2(\lambda^2 + \beta\eta(\mu_1 - 2))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\alpha > c\beta$, $\lambda > 0$, and $\mu_1 \in [0, 1]$, it follows that $\mu_1 - 1 \leq 0$, with strict inequality when $\mu_1 < 1$. Therefore, the numerator is negative when $\mu_1 < 1$, and zero when $\mu_1 = 1$.

Denominator: The denominator is a square term and thus always positive for all admissible values of the parameters.
Conclusion: For $\mu_1 < 1$, the numerator is negative and the denominator is positive, so the derivative is negative:

$$\frac{\partial p_1}{\partial \eta} < 0$$

This implies that the equilibrium retail price p_1 decreases as the green cost coefficient η increases, unless the retailer acts as a full social welfare maximizer ($\mu_1 = 1$), in which case the price is not affected by η.

Effect of Green Demand Coefficient λ

Taking the derivative of the equilibrium retail price p_1 in Scenario 1 with respect to the green demand coefficient λ, we obtain:

$$\frac{\partial p_1}{\partial \lambda} = -\frac{(\alpha - c\beta)\eta\lambda(\mu_1 - 1)}{(\lambda^2 + \beta\eta(\mu_1 - 2))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: Since $\alpha > c\beta$, $\eta > 0$, and $\lambda > 0$, the sign of the numerator depends on μ_1. For $\mu_1 \in [0, 1]$, we have $\mu_1 - 1 < 0$, so the product $(\alpha - c\beta)\eta\lambda(\mu_1 - 1)$ is negative, and the leading minus sign makes the entire numerator positive. However, when $\mu_1 = 1$, the numerator becomes zero.
Denominator: The denominator is a square term and therefore strictly positive for all admissible parameter values.
Conclusion: For $\mu_1 < 1$, both the numerator and denominator are positive, so the derivative is positive:

$$\frac{\partial p_1}{\partial \lambda} > 0$$

This implies that the equilibrium retail price p_1 increases with λ, unless the retailer acts as a full social welfare maximizer ($\mu_1 = 1$), in which case the price is not affected by λ.

Effect of Cost Parameter c

Taking the derivative of the equilibrium retail price p_1 in Scenario 1 with respect to the cost parameter c, we obtain:

$$\frac{\partial p_1}{\partial c} = \frac{-\beta\eta + \lambda^2}{2(\lambda^2 + \beta\eta(\mu_1 - 2))}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: Under the assumption $\beta\eta > \lambda^2$, it follows that $-\beta\eta + \lambda^2 < 0$. Therefore, the numerator is negative.
Denominator: For $\mu_1 \in [0, 1]$, the worst-case value is $\mu_1 = 1$, yielding:

$$2(\lambda^2 + \beta\eta(\mu_1 - 2)) = 2(\lambda^2 - \beta\eta)$$

Since $\beta\eta > \lambda^2$, the denominator is also negative.
Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_1}{\partial c} > 0$$

Therefore, the equilibrium retail price p_1 increases with c.

Scenario 2

Effect of Market Potential α

Taking the derivative of the equilibrium retail price p_2 in Scenario 2 with respect to the market potential parameter α, we obtain:

$$\frac{\partial p_2}{\partial \alpha} = \frac{\lambda^2 + \beta\eta(-3 + \mu_1)}{\beta(2\lambda^2 + \beta\eta(-4 + \mu_1))}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: For $\mu_1 \in [0, 1]$, we have $-3 + \mu_1 \leq -2$, so $\lambda^2 + \beta\eta(-3 + \mu_1) < \lambda^2 - 2\beta\eta$. Under the assumption $\beta\eta > \lambda^2$, this implies the numerator is negative.
Denominator: The expression becomes $\beta(2\lambda^2 + \beta\eta(-4 + \mu_1))$. For $\mu_1 \in [0, 1]$, the worst-case value is $\mu_1 = 1$, giving:

$$\beta(2\lambda^2 - 3\beta\eta) < 0$$

Therefore, the denominator is also negative.
Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_2}{\partial \alpha} > 0$$

Therefore, the equilibrium retail price p_2 increases with α.

Effect of Green Cost Coefficient η

Taking the derivative of the equilibrium retail price p_2 in Scenario 2 with respect to the green cost coefficient η, we obtain:

$$\frac{\partial p_2}{\partial \eta} = \frac{(\alpha - c\beta)\lambda^2(\mu_1 - 2)}{(2\lambda^2 + \beta\eta(-4 + \mu_1))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: Since $\alpha > c\beta$ and $\lambda > 0$, and $\mu_1 \in [0, 1]$, it follows that $\mu_1 - 2 < 0$. Therefore, the numerator is negative.
Denominator: The denominator is a square term and thus strictly positive for all admissible parameter values.

Conclusion: Since the numerator is negative and the denominator is positive, the derivative is negative:

$$\frac{\partial p_2}{\partial \eta} < 0$$

This implies that the equilibrium retail price p_2 decreases with η.

Effect of Green Demand Coefficient λ

Taking the derivative of the equilibrium retail price p_2 in Scenario 2 with respect to the green demand coefficient λ, we obtain:

$$\frac{\partial p_2}{\partial \lambda} = -\frac{2(\alpha - c\beta)\eta\lambda(\mu_1 - 2)}{(2\lambda^2 + \beta\eta(-4 + \mu_1))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\alpha > c\beta$, $\eta > 0$, and $\lambda > 0$, the sign of the numerator depends on μ_1. For all $\mu_1 \in [0, 1]$, we have $\mu_1 - 2 < 0$, so the product is negative. The leading minus sign makes the full numerator positive.

Denominator: The denominator is a square term and thus strictly positive for all admissible parameter values.

Conclusion: Since both the numerator and denominator are positive, the derivative is positive:

$$\frac{\partial p_2}{\partial \lambda} > 0$$

Therefore, the equilibrium retail price p_2 increases with λ.

Effect of Cost Parameter c

Taking the derivative of the equilibrium retail price p_2 in Scenario 2 with respect to the cost parameter c, we obtain:

$$\frac{\partial p_2}{\partial c} = \frac{-\beta\eta + \lambda^2}{2\lambda^2 + \beta\eta(-4 + \mu_1)}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Under the assumption $\beta\eta > \lambda^2$, it follows that $-\beta\eta + \lambda^2 < 0$, so the numerator is negative.

Denominator: For $\mu_1 \in [0, 1]$, the worst-case value is $\mu_1 = 1$, yielding:

$$2\lambda^2 + \beta\eta(-3) = 2\lambda^2 - 3\beta\eta < 0$$

Therefore, the denominator is also negative.

Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_2}{\partial c} > 0$$

This implies that the equilibrium retail price p_2 increases with c.

Scenario 3

Effect of Market Potential α

Taking the derivative of the equilibrium retail price p_3 in Scenario 3 with respect to the market potential parameter α, we obtain:

$$\frac{\partial p_3}{\partial \alpha} = \frac{\eta(-3 + 2\mu_1)}{\lambda^2 + 2\beta\eta(-2 + \mu_1)}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: Since $\eta > 0$ and $\mu_1 \in [0, 1]$, it follows that $-3 + 2\mu_1 < 0$. Therefore, the numerator is negative.
Denominator: For $\mu_1 = 1$, the expression becomes:

$$\lambda^2 + 2\beta\eta(-1) = \lambda^2 - 2\beta\eta$$

Under the assumption $\beta\eta > \lambda^2$, it follows that the denominator is negative for all $\mu_1 \in [0, 1]$.
Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_3}{\partial \alpha} > 0$$

Therefore, the equilibrium retail price p_3 increases with α.

Effect of Green Cost Coefficient η

Taking the derivative of the equilibrium retail price p_3 in Scenario 3 with respect to the green cost coefficient η, we obtain:

$$\frac{\partial p_3}{\partial \eta} = \frac{(\alpha - c\beta)\lambda^2(-3 + 2\mu_1)}{(\lambda^2 + 2\beta\eta(-2 + \mu_1))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.
Numerator: Since $\alpha > c\beta$, $\lambda > 0$, and $\mu_1 \in [0, 1]$, it follows that $-3+2\mu_1 < 0$. Therefore, the product $(\alpha - c\beta)\lambda^2(-3 + 2\mu_1)$ is negative.
Denominator: The denominator is a square term and thus always positive for all admissible parameter values.
Conclusion: Since the numerator is negative and the denominator is positive, the derivative is negative:

$$\frac{\partial p_3}{\partial \eta} < 0$$

Therefore, the equilibrium retail price p_3 decreases with η.

Effect of Green Demand Coefficient λ

Taking the derivative of the equilibrium retail price p_3 in Scenario 3 with respect to the green demand coefficient λ, we obtain:

$$\frac{\partial p_3}{\partial \lambda} = -\frac{2(\alpha - c\beta)\eta\lambda(-3 + 2\mu_1)}{(\lambda^2 + 2\beta\eta(-2 + \mu_1))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\alpha > c\beta$, $\eta > 0$, $\lambda > 0$, and $\mu_1 \in [0, 1]$, it follows that $-3 + 2\mu_1 < 0$. Therefore, the product $(\alpha - c\beta)\eta\lambda(-3 + 2\mu_1)$ is negative, and the leading minus sign makes the full numerator positive.

Denominator: The denominator is a square term and thus strictly positive for all admissible parameter values.

Conclusion: Since both the numerator and denominator are positive, the derivative is positive:

$$\frac{\partial p_3}{\partial \lambda} > 0$$

Therefore, the equilibrium retail price p_3 increases with λ.

Effect of Cost Parameter c

Taking the derivative of the equilibrium retail price p_3 in Scenario 3 with respect to the cost parameter c, we obtain:

$$\frac{\partial p_3}{\partial c} = \frac{-\beta\eta + \lambda^2}{\lambda^2 + 2\beta\eta(-2 + \mu_1)}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Under the assumption $\beta\eta > \lambda^2$, we have $-\beta\eta + \lambda^2 < 0$. Therefore, the numerator is negative.

Denominator: For $\mu_1 = 1$, the denominator becomes:

$$\lambda^2 + 2\beta\eta(-1) = \lambda^2 - 2\beta\eta$$

Since $\beta\eta > \lambda^2$, it follows that the denominator is negative for all $\mu_1 \in [0, 1]$.

Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_3}{\partial c} > 0$$

Therefore, the equilibrium retail price p_3 increases with c.

Scenario C (Centralized)

Effect of Market Potential α

Taking the derivative of the equilibrium retail price p_C in the centralized scenario with respect to the market potential parameter α, we obtain:

$$\frac{\partial p_C}{\partial \alpha} = -\frac{\eta(1-\mu_1)}{-2\beta\eta + \lambda^2 + \beta\eta\mu_1}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\eta > 0$ and $\mu_1 \in [0,1]$, the expression $1-\mu_1 \geq 0$, with strict inequality when $\mu_1 < 1$. Therefore, the numerator is negative when $\mu_1 < 1$ and zero when $\mu_1 = 1$.

Denominator: The expression simplifies to $-2\beta\eta + \lambda^2 + \beta\eta\mu_1$. Under the assumption $\beta\eta > \lambda^2$, it follows that this expression is negative for all $\mu_1 \in [0,1]$.

Conclusion: When $\mu_1 < 1$, both the numerator and denominator are negative, so the derivative is positive:

$$\frac{\partial p_C}{\partial \alpha} > 0$$

This implies that the equilibrium retail price p_C increases with α, unless the retailer acts as a full social welfare maximizer ($\mu_1 = 1$), in which case the price is not affected by α.

Effect of Green Cost Coefficient η

Taking the derivative of the equilibrium retail price p_C in the centralized scenario with respect to the green cost coefficient η, we obtain:

$$\frac{\partial p_C}{\partial \eta} = \frac{(\alpha - c\beta)\lambda^2(\mu_1 - 1)}{(\lambda^2 + \beta\eta(\mu_1 - 2))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\alpha > c\beta$, $\lambda > 0$, and $\mu_1 \in [0,1]$, it follows that $\mu_1 - 1 \leq 0$, with strict inequality when $\mu_1 < 1$. Therefore, the numerator is negative when $\mu_1 < 1$, and zero when $\mu_1 = 1$.

Denominator: The denominator is a square term and thus strictly positive for all admissible parameter values.

Conclusion: For $\mu_1 < 1$, the numerator is negative and the denominator is positive, so the derivative is negative:

$$\frac{\partial p_C}{\partial \eta} < 0$$

This implies that the equilibrium retail price p_C decreases with η, unless the retailer acts as a full social welfare maximizer ($\mu_1 = 1$), in which case the price is not affected by η.

Effect of Green Demand Coefficient λ

Taking the derivative of the equilibrium retail price p_C in the centralized scenario with respect to the green demand coefficient λ, we obtain:

$$\frac{\partial p_C}{\partial \lambda} = -\frac{2(\alpha - c\beta)\eta\lambda(\mu_1 - 1)}{(\lambda^2 + \beta\eta(\mu_1 - 2))^2}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Since $\alpha > c\beta$, $\eta > 0$, and $\lambda > 0$, the sign of the numerator depends on μ_1. For $\mu_1 \in [0, 1]$, we have $\mu_1 - 1 < 0$, so the product $(\alpha - c\beta)\eta\lambda(\mu_1 - 1)$ is negative, and the leading minus sign makes the full numerator positive. When $\mu_1 = 1$, the numerator becomes zero.

Denominator: The denominator is a square term and thus strictly positive for all admissible parameter values.

Conclusion: For $\mu_1 < 1$, both the numerator and denominator are positive, so the derivative is positive:

$$\frac{\partial p_C}{\partial \lambda} > 0$$

This implies that the equilibrium retail price p_C increases with λ, unless the retailer acts as a full social welfare maximizer ($\mu_1 = 1$), in which case the price is unaffected by λ.

Effect of Cost Parameter c

Taking the derivative of the equilibrium retail price p_C in the centralized scenario with respect to the cost parameter c, we obtain:

$$\frac{\partial p_C}{\partial c} = \frac{-\beta\eta + \lambda^2}{\lambda^2 + \beta\eta(-2 + \mu_1)}$$

To determine the sign of this derivative, we analyze the numerator and denominator separately.

Numerator: Under the assumption $\beta\eta > \lambda^2$, we have $-\beta\eta + \lambda^2 < 0$. Therefore, the numerator is negative.

Denominator: For $\mu_1 \in [0, 1]$, the worst-case value is $\mu_1 = 1$, yielding:

$$\lambda^2 + \beta\eta(-1) = \lambda^2 - \beta\eta < 0$$

So the denominator is also negative.

Conclusion: Since both the numerator and denominator are negative, the derivative is positive:

$$\frac{\partial p_C}{\partial c} > 0$$

Therefore, the equilibrium retail price p_C increases with c.

F. Overview Model Selection

Title	Author	ESG		Decision Variable	SC Structure		Channel Structure	Scenario	Equilibirum	Competition	
		Dimension	Variable		Two-Level	Three-Level				Structure	Competitors
A game theoretic approach for green and non-green product pricing in chain-to-chain competitive sustainable and regular dual-channel supply chains	Jamali M.; Rasti-Barzoki M.	Environment	green vs. non-green product	1) final price of product 2) green degree of product	manufactuer, retailer		Direct Channel (M - C) Indirect Channel (M - R - C)	Decentralized Centralized	Manfacturer Stackelberg leader Nash between manufacturers Nash between retailers Nash between 2 supply chains	Inter supply chain	two supply chains
A game theoretic approach for pricing, greening, and social welfare policies in a supply chain with government intervention	Sinayi M.,; Rasti-Barzoki M.	Environment Social	green product consumer surplus	1) final price of product 2) wholesale price 3) green degree of product 4) government tax 5) franchise fee	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	Manfacturer Stackelberg leader	monopolistic	
A game theoretic approach to investigate the effects of third-party logistics in a sustainable supply chain by reducing delivery time and carbon emissions	Jamali M.; Rasti-Barzoki M.	Environment Social	green vs. non-green product, environmental pollution, greenhouse gas emissions customer satisfaction	1) final price of product 2) wholesale price 3) amount of CO2 gas 4) green degree of product 5) delivery time of product		manufacturer, retailer, 3PL	Indirect Channel (M - 3PL - R - C)	Decentralized Centralized	Manfacturer Stackelberg leader 3PL Stackelberg leader Nash between manufacturers and retailer	intra supply chain	two manufacturers
Chain-to-chain competition on product sustainability	Li X.; Li Y.	Environment	sustainability of product	1) wholesale price 2) green degree of product	supplier, manufacturer		Direct Channel (S - M)	Decentralized Centralized	supplier Stackelberg leader nash between two suppliers nash between two manufacturers manufacturer Stackelberg leader	Inter supply chain competition	two supply chains
Game analysis of environmental cost allocation in green supply chain under fairness preference	Qin Q. et al.	Environment	green investment	1) final price of product 2) wholesale price 3) manufacturer's green innovation input	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader	monopolistic	
Game-theoretical analysis for supply chain with consumer preference to low carbon	Du S. et al.	Environment	effort of emission reduction	1) retail price 2) optimal effort level of emission reduction	manufacturer/ supplier retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader	monopolistic	
Governmental cap regulation and manufacturer's low carbon strategy in a supply chain with different power structures	Zahng S. et al.	Environment Social	Reduction of carbon emission Social welfare	1) Production quantity of the manufacturer 2) Wholesale price of unit product 3) Emission Cap Index 4) Abatement level of product	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader retailer Stackelberg leader Vertical Nash model (manufactuer and retailer make decisions simultaneously)	monopolistic	
Green design strategies of competing manufacturers in a sustainable supply chain	Du P. et al.	Environment	green degree of product (lower carbon emission and environmental imapct)	1) Wholesale price 2) Retail price 3) Level of green degree	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized 1) Neither manufacturer adopting green strategey 2) One manufacturer adopting green strategy 3) Both manufacturer adopting green	manfacturer Stackelberg leader Nash between two manufacturers	intra supply chain	two manufacturers
Green supply chain game model and analysis under revenue-sharing contract	Song H.; Gao X.	Environment	green vs. non-green product	1) green products 2) wholesale price 3) retail price 4) retailer's margin 5) revenue-sharing ratio	manufactuer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader	monopolistic	

Figure F.1.: Classification Selected Models (Models 1-9)

Title	Author	ESG Dimension	ESG Variable	Decision Variable	SC Structure Two-Level	SC Structure Three-Level	Channel Structure	Scenario	Equilibirum	Competition Structure	Competition Competitors
Greening products in a supply chain under market segmentation and different channel power structures	Agi M.; Yan X.	Environment	green vs. non-green product	1) wholesale price 2) retail price or marginal profit of two products	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader retailer Stackelberg leader	monopolistic	
Improving corporate social responsibility in a supply chain through a new revenue sharing contract	Hsueh C.	Social	CSR	1) order quantity of CSR 2) wholesale price 3) revenue sharing ratio	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	newsvendor model	monopolistic	
Low-carbon supply policies and supply chain performance with carbon concerned demand	Du S. et al.	Environment	reduction of carbon emissions	1) low-carbon investment per product of manufacturer 2) low-carbon investment per product of retailer 3) wholesale price 4) retail price	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader	monopolistic	
Manufacturer and retailer coordination for environmental and economic competitiveness: A power perspective	Chen X. et al.	Environment	reduction of carbon emissions	1) Unit carbon emissions 2) wholesale price 3) retail price 4) lump-sum fee	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader retailer Stackelberg leader Vertical Nash model	monopolistic	
Pricing strategies and profit coordination under a double echelon green supply chain	Du P. et al.	Environment	green degree of product	1) green degree 2) retail price 3) wholesale price 4) fixed fee 5) cost sharing ratio of retailer	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manfacturer Stackelberg leader	intra supply chain	two retailers
Research on pricing and coordination strategy of green supply chain under hybrid production mode	Zhang C. et al.	Environment	green vs. non-green product	1) price for raw materials of green products 2) price for raw mateirlas of non-green products 3) selling price of green products 4) selling price of non-green products	supplier, manufacturer		Direct Channel (S - M)	Decentralized Centralized	supplier Stackelberg leader Rubinstein bargaining model	monopolistic	
Supply chain coordination model for green product with different payment strategies: A game theoretic approach	Ghosh P. et al.	Environment	green degree of product	1) Green level 2) Sales effort 2) Wholesale price 3) Selling price	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized	manufacturer stackelberg game model	intra supply chain	multi-retailers
Supply chain coordination with green technology under cap-and-trade regulation	Xu X. et al.	Environment	reduction of carbon emissions	1) wholesale price 2) manufacturer's profit 3) retailer's order quantity 4) retailer's profit 5) abatement level of product	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized	manufacturer stackelberg game model	monopolistic	
Supply chain analysis under green sensitive consumer demand and cost sharing contract	Ghosh and Shah	Environment	green degree of product	1) Green level 2) Wholesale Price 3) Retail price	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manufacturer stackelberg game model	monopolistic	

Figure F.2.: Classification Selected Models (Models 10-18)

Title	Author	ESG		Decision Variable	SC Structure		Channel Structure	Scenario	Equilibirum	Competition	
		Dimension	Variable		Two-Level	Three-Level				Structure	Competitors
A two-period game of a closed-loop supply chain	De Giovanni P.; Zaccour G.	Environment	Remanufacturing	1) Wholesale price for periodes 1 and 2 2) Retail price for periodes 1 and 2 3) green activity programs (GAP) investment levels by manufacturer or external third-party	manufacturer, retailer, 3PL		Indirect Channel (M - R - C) and reverse (C-3PL-M)	Decentralized	manufacturer stackelberg game model	monopolistic	
Bargaining framework for competitive green supply chains under governmental financial intervention	Sheu J.	Environment, Social	Remacturing, Social Welfare as consumer surplus	1) green tax for each product produced 2) green subsidies to those managing the recycling of end-of-life (EOL) product units		government, producer, supplier	Indirect Channel (G - P - S)	Decentralized	asymmetrical nash bargaining game via backward induction Cournot oligopoly competition in production	Inter supply chain competition	two supply chains
Closed-Loop Supply Chain Models with Product Remanufacturing	Savaskan R.; Bhattacharya S.; Van Wassenhove L.	Environment	Remacturing	1) wholesale price 2) retail price 3) porduct return rate	manufacturer, retailer, 3PL		Indirect Channel (M - R - C) and reverse (C-3PL-M)	Decentralized Centralized	manufacturer stackelberg game model	monopolistic	
Closed-loop supply chain models with product take-back and hybrid remanufacturing under technology licensing	Huang Y.; Wang Z.	Environment	Remacturing	1) wholesale price 2) retail price 3) unit transfer price of returned product 4) acquisition price for used product from consumers 5) remanufactzring ability of distributor/3rd PL	manufacturer, retailer, 3PL		Indirect Channel (M - R - C) and reverse (C-3PL-M)	Decentralized	manufacturer stackelberg game model	monopolistic	
Consumer environmental awareness and channel coordination with two substitutable products	Zhang L.; Wang J.; You J.	Environment	Green vs. brown product, recycling	1) order quantity of brown and green product 2) wholesale price of brown and green product 3) return credits by manufacturer for unsols products	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manufacturer stackelberg game model	monopolistic	
Environmental-regulation pricing strategies for green supply chain management	Chen Y.; Sheu J.	Environment, Social	Recycling, Social expectations represented by government (?)	1) price 2) recyclability effors 3) recycling treatment fees	manufacturer, retailer, treatment agency		Indirect Channel (M - R - C)	Decentralized	Differential game model with simultaneous decision making --> Markovian Nash equilibirum	intra supply chain	2 manufacturers
Impact of government financial intervention on competition among green supply chains	Sheu J.; Chen Y.	Environment, Social	Recycling, Social welfare (as objective function of government)	1) green taxes 2) green subsidies		government, manufacturer, supplier	Indirect Channel (G-M - R - C)	Decentralized	manufacturer stackelberg game model using backward induction Cournot competition	Inter supply chain competition	multiple supply ch
Reverse Channel Design: The Case of Competing Retailers	Savaskan R.; Van Wassenhove L.	Environment	Remanufacturing	1) wholesale price 2) retail price 3) collection effort	manufacturer, retailer		Indirect Channel (M - R - C) and Direct Channel (N-C) concerning the return of products	Decentralized Centralized	manufacturer stackelberg game model using	intra supply chain	2 retailers
Reverse logistics pricing strategy for a green supply chain: A view of customers' environmental awareness	Chen D et al.	Environment	Remanufacturing	1) recycling price paid from m to r 2) recycling price paid from r to c 3) marginal profit rate earned by retailer	manufacturer, retailer		Indirect Channel (M - R - C)	Decentralized Centralized	manufacturer stackelberg game model using	monopolistic	

Figure F.3.: Classification Selected Models (Models 19-27)