The Effects of Competition on Corporate Sustainability

Titing Cui
Katz Graduate School of Business, University of Pittsburgh, Pittsburgh, PA 15260, tic54@pitt.edu

Esther Gal-Or
Katz Graduate School of Business, University of Pittsburgh, Pittsburgh, PA 15260, esther@pitt.edu

Mike M. Gordon
Pamplin College of Business, Virginia Tech, Blacksburg, VA 24061, mmgordon@vt.edu

Michael L. Hamilton
Katz Graduate School of Business, University of Pittsburgh, Pittsburgh, PA 15260, mhamilton@katz.pitt.edu

Jennifer Shang
Katz Graduate School of Business, University of Pittsburgh, Pittsburgh, PA 15260, shang@katz.pitt.edu

Problem Definition: We investigate the complex relationship between competition and corporate sustainability, with a focus on understanding which types of markets are most conducive to the adoption of green production policies.

Methodology/Results: We study location models in which producers can offer one of two substitutable goods: one that is more expensive but sustainably produced, referred to as the green product, and another that is inexpensive to produce but less environmentally responsible, referred to as the non-green product. We analyze producers' optimal/equilibrium policies when cooperating or competing in the market. We discover a dichotomous relationship between competition and sustainable behavior where, for markets where both green and non-green goods are present, lowering the cost of green production induces more green market share and socially responsible investment growth when producers cooperate. On the other hand, when the green product is absent from the market (due to prohibitively high costs), reductions in green production cost more readily lead to the introduction of the green good in competitive markets. Moreover, when producers can endogenously choose which good to produce, cooperative markets always lead to higher green market share.

Managerial Implications: Our results have significant implications for policy-making as they provide insight into which types of markets are most impacted by reductions in the cost of green production, such as those resulting from government subsidies or technological innovation. We also highlight some surprising non-linear market responses that correspond to market conditions where a small reduction in the cost of green production can lead to large gains in green product market share.

Key words: Sustainability, Corporate Social Responsibility, ESG, Greening, Competitive Markets
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1. Introduction

Environmental degradation, most prominently due to climate change from increasing carbon emissions (Wuebbles et al. 2017), but also from deforestation (Nunez 2022), ecological collapse (Cavicchioli et al. 2019), soil depletion (Handelsman and Cohen 2021), and so on are shaping our global environment in increasingly dramatic fashion. In the coming century, either industrial and manufacturing practices will shift to become more sustainable, or the planet's ability to support status quo production will collapse. In response to these pressing challenges, growing segments of customers are prioritizing sustainable businesses (McKinsey 2020), corporate shareholders are increasingly advocating for sustainable mission plans (Eccles and Klimenko 2019), and governing bodies are seeking to encourage a global transition to sustainable production through accords such as the Paris Agreement and the UN 2030 Agenda for Sustainable Development.

For companies evaluating their own sustainable practices, the current moment presents with both peril and opportunity. On the one hand, the increasingly competitive global economy makes innovating on tried and true business practice risky. On the other hand, incorporating new advances in sustainable technologies can help companies reach new segments of customers (Nyangchak 2022). Indeed, modern customers are currently paying more attention to corporate practices than ever before, and are making purchasing decisions based not only on product information but also on firm-level information, including a firm's sustainable practices and its broader impact on society. Notably, customers are increasingly willing to pay more for sustainable brands (Nielsen 2015), especially among younger generations. For instance, Gen Z customers will reportedly pay as much as a 10% premium on average for sustainable products (Insight 2020), and 75% of Millennials report considering sustainability when making a purchase (McKinsey 2020). The underlying expectation from these customers is that firms demonstrate environmental concern and a commitment to prosocial values (Nielsen 2015). In this way, companies that prioritize sustainability can improve both their reputation and their bottom line.

Of course, a firm can improve its reputation among customers in a competitive market without necessarily changing its manufacturing processes. For instance, Coca-Cola, the world's worst plastic polluter five years running (Gallagher 2022), has invested $5.4 million in charitable grants to increase recycling rates in seven US cities (Moye 2019) in an attempt to "green" its brand image. This investment is an example of corporate social responsibility

(CSR), a common form of advertising and brand outreach. This instance, where the CSR efforts are focused on corporate image enhancement rather than effectively reducing the firm's environmental footprint, is viewed as *greenwashing* (Dangelico and Pujari 2010, Wu et al. 2019), where a public display of social investment is meant to cover up less visible non-green practices.

Both greening manufacturing practices and CSR investment fall under a broad definition of *sustainability* as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). In line with this definition, corporate sustainability can be divided into three pillars: social (people), environmental (planet), and economic (profit). To be truly sustainable, a company must engage in all forms of sustainable activity. Indeed, even an environmentally sustainable company must also consider its social impact, and will engage in CSR investment (often with even greater returns due to the *halo effect* (Jin and Lee 2019)). For example consider Everlane, an environmentally sustainable clothing manufacturer (`https://www.everlane.com/2021-impact-report`) which also invests in social sustainability via donations to local nonprofits after store openings in Seattle and Washington DC. Although some view CSR as a type of corporate advertising that aims to attract customers, or as greenwashing, CSR at its core is a charitable act. It appeals to customers who care about making a positive difference in the community, and as a result it enhances customers' willingness to pay, and allows Everlane to further capitalize on their strong brand perception. As such, CSR investment is a net positive prosocial corporate behavior, as opposed to general advertising, which is a more neutral activity.

In this paper, we study relationship between the competitive character of a marketplace, CSR investment, and environmentally sustainable production. In a novel set of analytical models we will identify market conditions that can best drive the transition toward true environmentally sustainable production.

Motivating example: The case of electric vehicle adoption

The scenario studied in this research is exemplified by the competition in the automobile industry between conventional internal combustion vehicles (ICVs) and electric vehicles (EVs). In the intensely competitive car market, some firms focus on ICVs, others on electric vehicles exclusively, and others still offer both ICVs and CVs as complementary product lines. The vehicle types are substitutable for travel, but each type has specific features

Figure 1 Electric vehicles versus internal combustion vehicles

Note. Above is a comparison of conventional internal combustion vehicles (ICVs) and electric vehicles (EVs), emphasizing the key differences we model in this work.

that are valued differently. EVs operate at a substantially lower environmental impact per mile driven, but are more expensive to manufacture. ICVs are not as environmentally friendly as their electric cousins, but economies of scale and decades of innovation have driven down their production costs. ICV producers are also some of the most influential global companies. They exhibit tremendous social integration and invest heavily in socially sustainable causes such as academic research, sponsorship, advertising during major events, and charities.

All other things being equal, the decision of whether a customer will buy an EV and from whom depends on (i) affordability, (ii) the firm's CSR investment level, and (iii) the extent to which the customer values such investment (Spencer and Funk 2021). Undoubtedly, the final vehicle price is also influenced by technological progress, legislative/regulatory initiatives, and company market power. Forward-looking governments understand that reducing EV manufacturing costs (for instance through manufacturer subsidy DoE (2023)) can incentivize consumers to purchase EVs and reduce the industry's carbon footprint. In this study we explore if and when lowering the green production cost can effectively increase the market share of an environmentally sustainable product like an EV, by modeling markets with two or more firms selling green and non-green products. Fig. 1 contrasts ICVs and EVs, our general model looks at firms which produce goods that abstractly capture these differences (cf. Section 2).

1.1. Our Contributions

To understand the interaction between competition and sustainability we set up a location model representing a market with green and non-green producers. We then consider two cases: (i) when green and non-green producers operate cooperatively (e.g. as a monopolistic firm with multiple product lines), and (ii) when the green and non-green producers compete (e.g., each product is sold by a separate firm). We then solve for the resulting optimal/equilibrium pricing and CSR investment in both cases. Finally, we compare the cooperative and competitive solutions, examining the difference in conditions for the viability of a green product in the marketplace, and the ways these markets react as the cost of green production falls.

The main contributions of our research are threefold:

1. First, we consider two producers positioned on Salop's circular city model (equivalent to Hotelling's linear city model), where one manufactures a green product, and the other a non-green product. We characterize the optimal/equilibrium policies when the producers cooperate/compete (cf. Propositions 1 and 2), then study how these solutions shift as the cost of green production varies. We find that lowering the cost of green production increases the overall green market share and total CSR investment in both cooperative and competitive markets, but the induced growth in green market share and CSR investment is greater when the producers cooperate. However, the conditions for when a green product can enter the market are less restrictive when producers compete (cf. Theorem 1).
2. We then extend our model to the case where producers are *flexible* and can decide to produce either a green or non-green product (cf. Section 4). When there are two flexible producers, we find that flexible markets exhibit *tipping points*, where small changes in the cost of green production can induce rapid adoption of the green product. We characterize these tipping points (cf. Propositions 3 and 4), and find that unlike the previously observed dichotomous relationship, when producers are flexible the green market share and CSR investment are always higher when producers cooperate (cf. Theorem 2).
3. Finally, we generalize our model to the case of many producers of green or non-green products, now arranged at equispaced points on Salop's circle. We imagine these producers proliferating in such a way that the number of green and non-green producers is *balanced*, capturing a notion of increasing competition intensity (cf. Section 5). In this generalized case, we again study how the green market share and total CSR investment changes as the cost of green production falls. We find that when (either flexible or inflexible) producers cooperate there is significantly faster induced growth in green market share (cf. Theorems 3 and 4), and these effects intensify as the number of producers increases.

Overall, our models demonstrate a dichotomous relationship between the competitive character of a market and the malleability of the market outcomes. For legislators, our work highlights a tension between regulating markets to make them more competitive (often increasing customer utility) and subsidizing green technology to hasten the adoption of environmentally sustainable production. If the goal is to hasten the adoption of green technologies, our work provides guidelines for the types of market that most readily respond to interventions which reduce the cost of green production, such as additional government subsidy, or increased technological investment.

1.2. Literature Review

The three streams of literature most relevant to our research are corporate social responsibility, environmental sustainability, and their intersection. We discuss some of the pertinent literature and connect it to our work.

Corporate Social Responsibility (CSR). CSR refers to a company's commitment to the social welfare of its community. The literature studying the impacts of CSR on corporate strategy focuses on the relationship between the customer, the retailer, and a supplier. For customers, their response to CSR programs vary depending on perceptions of program choice, fit, and authenticity (Sen and Bhattacharya 2001, Du et al. 2007, 2011). These attributes play an important role in customers' attitudes toward firms, especially when the CSR investment is aligned with the firm's core competency (Jin and Lee 2019, Gao 2020). Customer attitude also serves as a competitive instrument when firms look to differentiate themselves within a market (Flammer 2015, Ballings et al. 2018, Dupire and M'Zali 2018). For retailers and suppliers, recent literature has examined who should bear the cost of CSR investment. Ni et al. (2010), Ni and Li (2012), Ma et al. (2017) show that profits and social welfare cannot simultaneously be optimized regardless of the leading firm in the supply chain. Our work focuses on competition between firms employing different types of sustainable investment, both of which use socially focused CSR but only some of which are environmentally sustainable (i.e. green) as well.

Environmentally Focused Sustainability. Our work connects with a stream of literature analyzing the interaction between green products and customer adoption. Chen et al. (2006) and Dangelico and Pujari (2010) study how producers weigh the additional green costs against potential long-term savings and gains from positive customer sentiment from the sustainably-positioned product, an effect we will model explicitly. Green product design is particularly beneficial when aligned with customer's expectations (Toolsema 2009, Chen and Ho 2019). The mix of environmentally sustainable designed products must carefully match customer segments (Yenipazarli and Vakharia 2017). We study how market composition and competition can impact the green production decisions. Other work has considered the impact of potential regulation via subsidies to steer markets toward green products (Guo et al. 2020, He et al. 2021, Wang et al. 2021, Chemama et al. 2019, Yu et al. 2018, 2020, Cohen et al. 2016). Some early work has posited that price competition can increase the equilibrium amount of environmental innovation (Park et al. 2015, Zhu and He 2017, Jamali and Rasti-Barzoki 2018, Wu et al. 2019). Our work puts a caveat on such analyses. We find competition can stimulate the introduction of green products, but cooperation will more readily steer the market into a green-product dominated marketplace when certain conditions are met.

Strategic Investment in Sustainability. In our models we consider the market interactions between eco-friendly green products, and less environmentally sustainable non-green products. For both green and non-green products, we model a firms level of CSR investment. One line of literature that examines how non-green producers engage in CSR investment to compensate terms such investment *greenwashing*. Lyon and Maxwell (2011) introduce greenwashing and (Lyon and Maxwell 2008, 2011, Lyon and Montgomery 2015, Uyar et al. 2020, Wu et al. 2019) develop the concept and discuss its strategic value as a revenue maximizing policy. Our work implicitly models greenwashing as we study green and non-green firms engaging in CSR investment. One key assumption of our work is that greenwashing results in less effective CSR than it would be if the company was truly environmentally sustainable. This assumption is supported by Jin and Lee (2019), who find evidence of a CSR halo effect where a truly environmentally sustainable company's CSR is more highly valued due to its association with the brand.

The remainder of the paper is organized as follows. In Section 2 we introduce our model components. In Section 3 we study the case where there is one green producer and one non-green producer. In Section 4 we examine the extend our analysis to the case when producers can flexibly decide to produce either the green or non-green product. In Section 5 we generalize our models to n green producers and n non-green producers. Finally, in Section 6 we summarize the insights gleaned from our models and highlight avenues for future work.

Proofs for all results can be found in Section A of the Appendix. For convenience and reproducibility, details of all computations described in this work can be replicated via a set of corresponding Wolfram Mathematica 13.1 notebooks, which are publicly available at `https://github.com/tcui-pitt/Sustainable_Investment`.

2. Models and Assumptions

In this section, we introduce the basic model elements and assumptions for our subsequent study. We consider markets of producers who are selling one of two horizontally differentiated goods which we refer to as the *green product* (G), and the *non-green product* (N). These producers are located at equispaced positions on Salop's circle (Salop 1979), a location model where customers are uniformly distributed around the circle, and customer preference is a function of distance to the producer on the circle. For each product, the producer sets the price and the level of corporate socially responsible (CSR) investment so as to maximize profit.

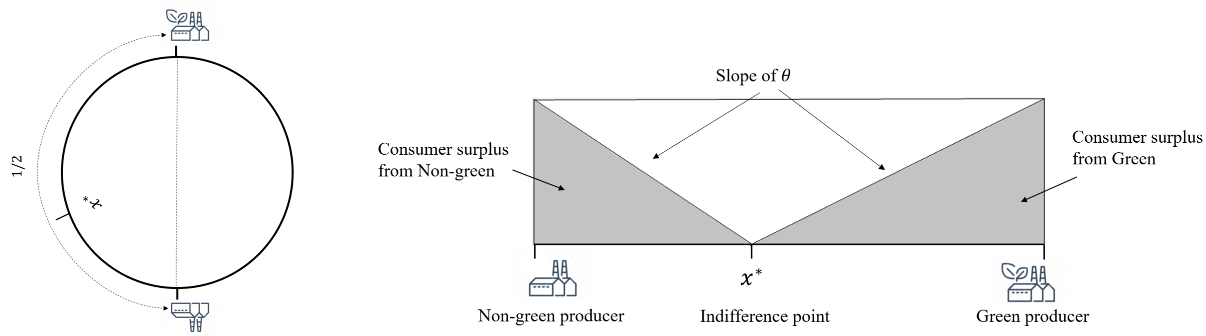
We consider the producers facing a market of customers for the products who have unit-demand. Customers are described by a fixed common base valuation for the products v, preference intensity θ, and a location x which describes their preferences between the products. Each customer considers the product (either green or non-green) sold by producer i at price p_i and observes the level of i's CSR investment, s_i. Customers value producers' CSR investment at a rate of $B_i \in \{B_G, B_N\}$, where rates B_G and B_N correspond to whether they are a green or non-green producer. Customers purchase the product that maximizes their utility. Specifically, a customer at location x derives utility U_i from the product offered by producer i located at x_i as,

$$U_i(x) = v - \theta|x - x_i| - p_i + B_i s_i, \tag{1}$$

where $|x - x_i|$ is distance between x and i^{th} seller on Salop's circle.

Note, the customer's net utility depends on the distance between themselves and the product captured by their location x and the *unit transportation cost* θ, as well as the intensity s_i and effectiveness B_i of the producer i's CSR investment. A large value of θ denotes a market of polarized customers who exhibit strong preferences between the producers. Similarly, as B_i denotes the effectiveness of CSR investment, a large positive difference between B_G and B_N corresponds to markets where customers greatly prefer

Figure 2 Salop's circle with two producers



Note. Left depicts Salop's circle when there are two producers, one making a non-green product and the other a green product. Customers are uniformly distributed around the circle and value the products based on their distance from the producer on the circle. Right is a depiction of customer preference including the indifference point x^*. Note that as Salop's circle is symmetric, the left and right halves of the circle are equivalent.

environmentally sustainable producers. Fig. 2 shows how Salop's circle model segments customers when there is one green producer and one non-green producer.

In our models, the customer's choice of product to purchase depends on their idiosyncratic preferences via x and θ, the producer's type, and the prices and levels of CSR investment. We are particularly interested in the interplay between price competition, CSR investment, and the resulting green market share. To isolate these dynamics, we will assume that the common valuation v is sufficiently large so as to ensure that every customer chooses to participate in the market. We note that this assumption is common in the literature (for instance see Amaldoss and Jain (2015)) and also not strictly necessary. Indeed, all results can be extended to models without this assumption. However this assumption is technically convenient and allows us to focus on the market's competitive dynamics.

For producers, let the green and non-green products per-unit-cost be k_G and k_N, respectively, and producer i incurs unit cost $k_i \in \{k_G, k_N\}$. Similarly, let CSR investment cost for green or non-green producers be $\frac{c_i s_i^2}{2}$, where s_i is producer i's level of CSR investment, and c_i is the cost parameter of producer i's CSR investment. Given the prices and levels of CSR investment, the positions of the producers, and the fact that customers are uniformly distributed around the circle, we can derive an induced market share for producer i, denoted as $\mathcal{M}_i$. Let $\mathcal{R}_i(p_i, s_i)$ be the profit of producer i choosing price p_i and CSR investment s_i. The profit function can be expressed as,

$$\mathcal{R}_i(p_i, s_i) = (p_i - k_i)\,\mathcal{M}_i - \frac{c_i s_i^2}{2}. \tag{2}$$

When p_i and s_i are clear from the context, we will denote the profit of producer i as just $\mathcal{R}_i$. Note that in our model costs increase quadratically in the level of CSR investment. Quadratic cost functions are commonly used to model corporate investment (Ma et al. 2017, Yang et al. 2020), and capture an intuitive notion of diminishing return for these investments.

Finally, we assume that the manufacturing cost of the green product is higher than that of the non-green product, and normalize the unit production cost of the non-green producer N to zero. For simplicity, the unit production cost for a green producer G is denoted as k. We also assume customers more readily respond to CSR investment from environmentally sustainable producers, and that the cost of CSR investment is identical for green and non-green producers. These assumptions can be formally written as the following constraints on the model parameters:

$$B_G > B_N, \quad k_G = k > k_N = 0, \quad c_i = c_j = c.$$

As with the assumption of sufficiently large v, all models in this paper can be solved without restrictions on these parameters. However, these assumptions capture the key aspects of the real-world markets we wish to model and understand.

In this setup, we study the relationship between competition, green production, and CSR investment, paying special attention to factors that increase green market share. It is noteworthy that our models capture the market features highlighted in the motivating example, including higher green production cost (via k) and higher customer receptivity to CSR investment (from $B_G > B_N$) for the green product. In the next section, we will analyze markets with one green producer and one non-green producer, when the producers either cooperate (as a monopoly) or compete (as a duopoly).

3. Cooperation and Competition between Two Producers

In this section, we investigate the effect of cooperation/competition between one green and one non-green producer, as depicted in Fig. 2. In both cases we solve for the resulting optimal/equilibrium prices and CSR investments, and compare the outcomes to understand the impact of competition on green market share and CSR investment.

When the producers cooperate (i.e. are non-competitive), they form a monopoly and coordinate their prices and CSR investment to maximize collective profit. In Proposition 1, we characterize the profit-maximizing prices and CSR investments for cooperating green and non-green producers.

Proposition 1 **(Two Producers, Cooperative Solution)**. *Suppose* $B_N^2 \le c(\theta - k)$ *and* $B_G^2 \le c(\theta + k)$*, then the optimal prices, CSR investments, and induced market shares when a non-green and a green producer cooperate are:*

(a) $p_N = v - \frac{\left(2B_N^2 - c\theta\right)\left(c(\theta+k) - B_G^2\right)}{2c\left(2c\theta - B_N^2 - B_G^2\right)}$, $p_G = v - \frac{\left(2B_G^2 - c\theta\right)\left(c(\theta-k) - B_N^2\right)}{2c\left(2c\theta - B_N^2 - B_G^2\right)}$,

(b) $s_N = \frac{B_N\left(c(\theta+k) - B_G^2\right)}{c\left(2c\theta - B_N^2 - B_G^2\right)}$, $s_G = \frac{B_G\left(c(\theta-k) - B_N^2\right)}{c\left(2c\theta - B_N^2 - B_G^2\right)}$,

(c) $\mathcal{M}_N = \frac{c(\theta+k) - B_G^2}{2c\theta - B_N^2 - B_G^2}$, $\mathcal{M}_G = \frac{c(\theta-k) - B_N^2}{2c\theta - B_N^2 - B_G^2}$.

In Proposition 1m, the two conditions on the parameters, $B_N^2 \le c(\theta - k)$ and $B_G^2 \le c(\theta + k)$, guarantee that both the green and the non-green producers participate in the market i.e., the conditions ensure that $\mathcal{M}_N > 0$ and $\mathcal{M}_G > 0$. If $B_N^2 > c(\theta - k)$ while $B_G^2 \le c(\theta + k)$, the non-green producer captures the whole market, and vice versa (see Section B and Fig. EC.1 in the Appendix for a complete discussion). When both conditions hold, both producers can survive, reflecting the market situations we wish to understand. We will make similar assumptions to ensure both types of production occur in throughout this work. Finally, we observe that the profit-maximizing prices, CSR investments, and market shares for both the green and non-green products in this case are linear in the green production cost k.

Next, when producers compete, they form a duopoly and in equilibrium, each chooses its price and CSR investment to maximize its own profits. In Proposition 2, we characterize the equilibrium prices and CSR investments of competing green and non-green producers.

Proposition 2 **(Two Producers, Competitive Solution)**. *Suppose* $B_N^2 \le c(1.5\theta - k)$ *and* $B_G^2 \le c(1.5\theta + k)$*, then the equilibrium prices, CSR investments, and induced market shares when a non-green and a green producer compete are:*

(a) $p_N = \frac{\theta\left(c(1.5\theta+k) - B_G^2\right)}{\left(3c\theta - B_N^2 - B_G^2\right)}$, $p_G = \frac{c\theta(2k+1.5\theta) - B_G^2 k - B_N^2(k+\theta)}{\left(3c\theta - B_N^2 - B_G^2\right)}$,

(b) $s_N = \frac{B_N\left(c(1.5\theta+k) - B_G^2\right)}{c\left(3c\theta - B_N^2 - B_G^2\right)}$, $s_G = \frac{B_G\left(c(1.5\theta-k) - B_N^2\right)}{c\left(3c\theta - B_N^2 - B_G^2\right)}$,

(c) $\mathcal{M}_N = \frac{c(1.5\theta+k) - B_G^2}{3c\theta - B_N^2 - B_G^2}$, $\mathcal{M}_G = \frac{c(1.5\theta-k) - B_N^2}{3c\theta - B_N^2 - B_G^2}$.

Proposition 2 again includes conditions which now ensure that the equilibrium market shares of both producers is positive. We note that these conditions are less restrictive than the conditions in Proposition 1. Thus for every set of market parameters, if the green product has non-zero market share when producers cooperate, it definitely has non-zero market share when producers compete. Moreover, for some market parameters the green product has non-zero market share only when producers compete. This implies that the green product is more likely to be viable in a competitive market. For a deeper discussion of these conditions, again see Section B in the Appendix. Also note that the equilibrium prices, CSR investments, and market shares of both the green and non-green products are again linear in the green production cost k.

Using Propositions 1 and 2, we can compare the cooperative and competitive cases in terms of the green product's viability, its market share, and the total CSR investment, as implied by the value k. Let $\mathcal{M}_G^M$ and $\mathcal{M}_G^D$ be the resulting green market share in the cooperative (**M**onopoly) and competitive (**D**uopoly) cases. Similarly, let S^M and S^D denote the total CSR investment under cooperation and competition, respectively. In Theorem 1, we compare the resulting green market share and total CSR investment as k varies.

THEOREM 1 **(Cooperation vs. Competition between Two Producers)**. *Suppose there are two profit-maximizing producers, one producing the green product and one producing the non-green product, located at opposing points on Salop's circle.*

(a) If the parameters satisfy the conditions for Propositions 1 and 2, then the market share of the green product when green production costs are low is higher under cooperation than competition, and this relation reverses for higher production costs. That is, $\mathcal{M}_G^M(0) \geq \mathcal{M}_G^D(0)$ *and* $\frac{\partial \mathcal{M}_G^M(k)}{\partial k} \leq \frac{\partial \mathcal{M}_G^D(k)}{\partial k} \leq 0$.

(b) If the parameters satisfy the conditions for Propositions 1 and 2, then the total CSR investment when green production costs are low is higher under cooperation than competition, and this relation reverses for higher production costs. That is, $S^M(0) \geq S^D(0) \geq 0$, *and* $\frac{\partial S^M(k)}{\partial k} \leq \frac{\partial S^D(k)}{\partial k} \leq 0$.

(c) If the parameters satisfy the conditions for Proposition 2 but not the conditions for Proposition 1, then $\mathcal{M}_G^D > \mathcal{M}_G^M = 0$.

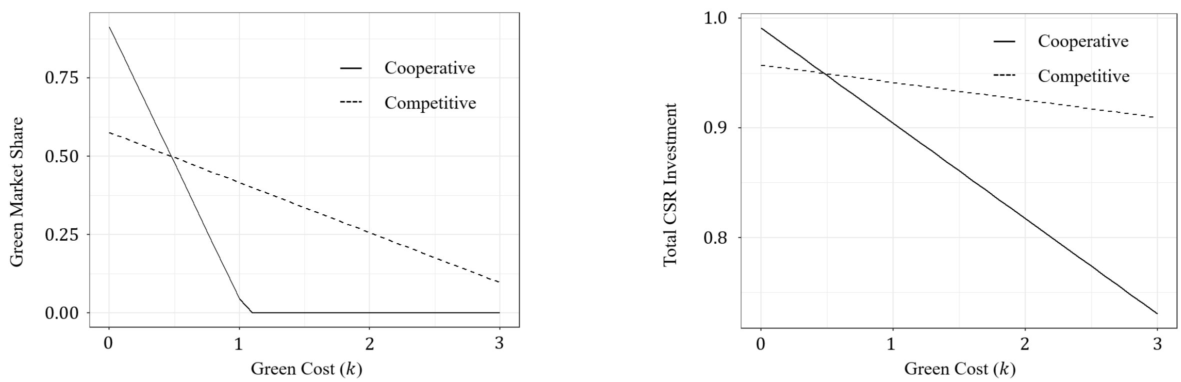
Theorem 1 shows how the green market share and total CSR investment vary with changes in the cost of green production. We emphasize that green market share and total CSR investment are common goals for policymakers who wish to encourage environmentally sustainable production practices and pro-social corporate behavior. Therefore it is of great interest to understand how these outcomes change as a function of market conditions. We focus specifically on the additional cost of green over non-green production k, as not only does it represent the barrier to green production, but it is also the market parameter most readily impacted by policy decisions in the form of government subsidies, tax breaks, investment in publicly-funded technological research, etc.

Theorem 1(a) characterizes of the relationship between green market share and competition as a function of green production costs. When k is high, the green market share will be higher in a competitive marketplace - in fact, Theorem 1 (c) states that when k is very high, competition results in a non-zero green market share even when a monopolist does not choose to sell the green product at all. Thus, when k is large it is easier to introduce green products into competitive markets. On the other hand, as the cost of green production starts to fall, the cooperative market is more sensitive to such a decline and therefore the resulting green market share increases faster than it does in a competitive market. In particular, when the cost of the green production falls to zero (i.e. is the same as the cost of non-green production), the overall green market share is greater in a cooperative market. Thus, competition has a dampening effect on the full transition to environmentally sustainable production.

Theorem 1 (b) shows that total CSR investment follows the same pattern as the green market share. When k is low, the total CSR investment is higher when the green and non-green producers cooperate than when they compete. Moreover, the total CSR investment decreases more sharply in k when the producers cooperate than when they compete. We depict the relationship between green market share/CSR investment and competition as k varies in Fig. 3. We note that although Theorem 1 simply proves dominance relations on the slopes, qualitatively the difference in the slopes, and thus the rates of reactive sustainable production and investment uptake, are quite substantial for reasonable ranges of market parameters.

Taken together, Theorem 1 implies that government intervention in the form of subsidy (directly reducing k) is more effective at both encouraging CSR investment and improving green market share when the producers are cooperative. When k is reduced substantially (i.e. k is close to 0) the overall green market share will be higher in cooperative markets. However, when there is no viable green product in the market, it is easier for new green products to emerge in competitive markets than cooperative ones. This implies a simple policy recommendation, when k cannot be reduced (because it is too high to be

Figure 3 **Green market share and total CSR investment of a green and non-green producer as k varies.**



Note. Depicted is the change in green market share and total CSR investment as the cost of green production k varies, and when $B_N = 4.5$, $B_G = 5$, $c = 5$, $\theta = 5.1$. In the left panel, we observe the green market share is higher in the cooperative case when k small, and this market share decreases when k increases for both cooperative and competitive markets, crossing over at $k = 0.475$. We observe the same trend for the total CSR investment in the right panel.

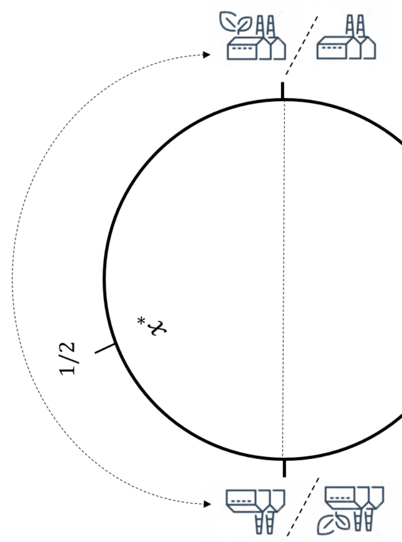
meaningfully impacted by subsidy, or when it is technologically too difficult), encouraging competition in the market improves outcomes with respect to sustainable investment. However when k is small, competition in the market may actually be counter-productive to the goal of improving green product adoption. In this case, coordination/consolidation may hasten the transition to green production.

This interaction between competition and the effect of subsidy on improving green market share is the major insight of this section. However, one drawback of our analysis is that we have assumed that the producer type is fixed. It is interesting to investigate how our results change when producers can flexibly choose whether to produce either the green or non-green product. In Section 4, we study flexible producers using the analysis in Section 3 as a building block.

4. Cooperation and Competition between Two Flexible Producers

We have hitherto considered models where each producer's type $i \in \{G, N\}$ was assumed to be fixed and immutable. In this section, we endogenize the production choice and consider models where producers can *flexibly* choose their type. Given that much of our discussion in Section 3 was centered on how market outcomes change as the cost of green production varies, it is sensible to predict that producers can also pivot their manufacturing process from non-green to green and vice versa, in addition to changing their prices and CSR investments in response to changes in market conditions.

Figure 4 Salop's circle with two flexible producers.

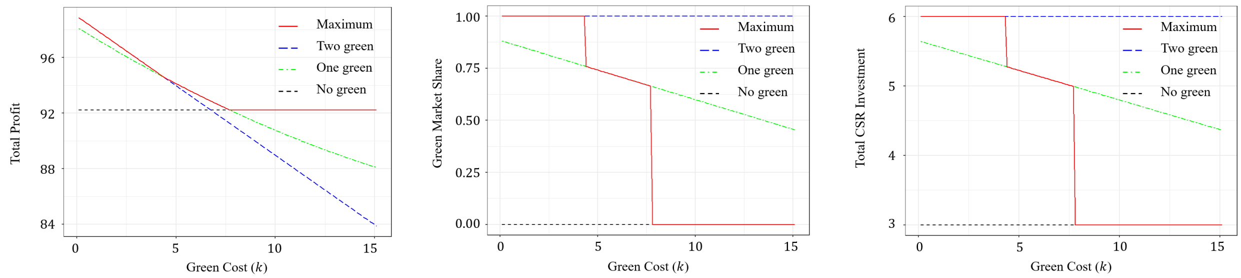


Note. Depicted a Salop's circle model with two flexible producers. Note this model is identical to Fig. 2, but now each producer can choose whether to produce a green or a non-green product.

Specifically, we extend the model of Section 3 to the case when the two producers are flexible, as depicted in Fig. 4. As before, we study the market outcomes when these producers cooperate/compete. However, because we allow producers to flexibly change their type, the optimal policies producers pursue when they cooperate/compete will be discontinuous at the points where they choose to switch production type. We will call the values of k where producers switch production type, *tipping points*.

To develop a sense of what the market dynamics look like when producers are flexible, in Fig. 5 we numerically study how profit, green market share, and total CSR investment change for two flexible producers in cooperation (i.e. as a monopoly) in response to changes in the cost of green production. We observe that similar to the inflexible case, in the case of cooperating flexible producers, when the cost of green production decreases, the profit, green market share, and total CSR investment all increase. The difference is, especially with respect to the green market share and total CSR investment, the increase is are no longer linear. Instead, we observe dramatic jumps in green market share and CSR investment at a few key tipping points in k. Reading Fig. 5 from right to left (i.e. as k falls) a tipping point occurs at $k \approx 8$ when one of the cooperating producers switches its type from non-green to green. Then another tipping point occurs at $k \approx 4.5$, when the second cooperating producer follows suit and also switches to green production.

Figure 5 Flexible cooperative market outcomes as k varies.



Note. Consider a market with two flexible, cooperating producers, and with markets parameters $v = 100$, $c = 1$, $\theta = 40.1$, $B_N = 3$, $B_G = 6$. Depicted is the change in profit (left), green market share (center), and total CSR investment (right), as the cost of green production k varies from 0 to 15.

In Proposition 3, we derive these two tipping points. Fixing the the value of all market parameters except k and allowing the cost of green production to vary, we give closed form expressions for the two values of k at which cooperating producers change their production type.

PROPOSITION 3 **(Tipping Points in Cooperative Markets)**. *Suppose $B_N^2 \le c\theta$ and $B_G^2 \le c\theta$, then:*

(a) If $k \le \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_G^2)}}{\sqrt{2}c} - \frac{c\theta - B_G^2}{c}$, the optimal policy is to produce only green products.

(b) If $\frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_G^2)}}{\sqrt{2}c} - \frac{c\theta - B_G^2}{c} \le k \le \frac{c\theta - B_N^2}{c} - \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_N^2)}}{\sqrt{2}c}$, the optimal policy is to produce both green and non-green products.

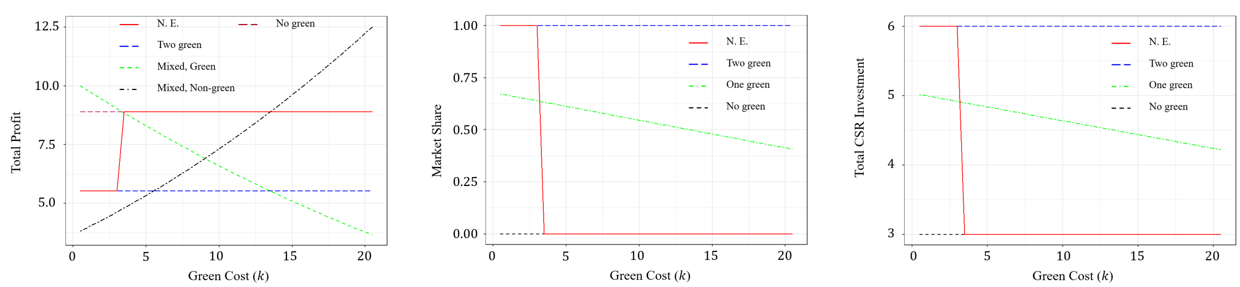
(c) If $k \ge \frac{c\theta - B_N^2}{c} - \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_N^2)}}{\sqrt{2}c}$, the optimal policy is to produce only non-green products.

Thus tipping points occur at $k_1 = \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_G^2)}}{\sqrt{2}c} - \frac{c\theta - B_G^2}{c}$ and $k_2 = \frac{c\theta - B_N^2}{c} - \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_N^2)}}{\sqrt{2}c}$.

From Proposition 3, we observe that when producers can cooperate, they react to changing market conditions, first switching to one green production of one product as k declines, then fully switching over to only producing the green product when k is sufficiently low.

The case when two flexible producers compete is somewhat more complicated. In Fig. 6 we numerically study how profit, green market share, and total CSR investment change when two flexible producers compete (i.e. as a duopoly) in response to changes in the cost of green production. Focusing on the left most panel of Fig. 6 and reading the plot from right to left, we observe that when k is large (≥ 5.5), the profit of a non-green producer (maroon long dashed line) is higher than its profit would be if it unilaterally deviates to product of a green product (blue long dashed line). Thus, there is a pure strategy Nash equilibrium where both producers choose their type as non-green. As k decreases, specifically when $k \leq 4$, on Salop's circle with one non-green producer and one green producer, the profit of the green producer (green dashed line) is higher than the profit it would obtain if it were to unilaterally deviate to the non-green product (maroon long-dashed line). Thus, there is a pure strategy Nash equilibrium where both producers choose their type as green, as reflected in the left part of the solid line in Fig. 6. For k between 4 and 5.5, there are two pure strategy Nash equilibria: purely green and purely non-green. We emphasize via the solid line the equilibria that obtains higher overall profit (pure non-green production for $k \geq 4$), and assume the more profitable symmetric Nash equilibria is always the one chosen by producers.

Figure 6 **Flexible competitive market outcomes as k varies.**



Note. Consider a market with two competitive producers who can flexibly produce either the green or non-green product, and with markets parameters $v = 100$, $c = 1$, $\theta = 40.1$, $B_N = 3$, $B_G = 6$. Depicted is the change in equilibrium profit (left), green market share (center), and total CSR investment (right) in a market as the cost of green production k varies from 0 to 20. *N.E.* is the market outcomes in the profit-maximizing Nash equilibrium, *Two-green* is the outcomes of either producer when they both choose to produce the green product, *Mixed-Green* and *Mixed Non-Green* are the profit of the green and non-green producer under mixed production in the left panel, respectively, and are combined into *One green* in the middle and right panel, and *No-green* is the outcomes of either producer when they both choose to produce the non-green product.

To summarize, Fig. 6 illustrates that the flexible competitive market also exhibits a tipping point value k. However there appears to be only one value at which both producers switch from non-green to green production. In Proposition 4, we derive this tipping point.

PROPOSITION 4 **(Tipping Point in Competitive Markets)**. *Suppose $B_N^2 \leq c\theta$ and $B_G^2 \leq c\theta$, then:*

(a) If $k \leq \frac{3c\theta - 2B_N^2 - \left(3c\theta - B_N^2 - B_G^2\right)\sqrt{\left(2c\theta - B_N^2\right)/\left(2c\theta - B_G^2\right)}}{2c}$, the unique Nash equilibrium is for both producers to produce the green product.

(b) If $k \geq \frac{3c\theta - 2B_N^2 - \left(3c\theta - B_N^2 - B_G^2\right)\sqrt{\left(2c\theta - B_N^2\right)/\left(2c\theta - B_G^2\right)}}{2c}$, the unique profit-maximizing Nash equilibrium is for both producers to produce the non-green product.

Thus, single tipping point occurs at $k = \frac{3c\theta - 2B_N^2 - \left(3c\theta - B_N^2 - B_G^2\right)\sqrt{\left(2c\theta - B_N^2\right)/\left(2c\theta - B_G^2\right)}}{2c}$.

Using Propositions 3 and 4, we can compare the market outcomes for flexible producers under cooperation and competition. To build intuition, consider Figs. 5 and 6 and note that for every value of k, the cooperative market leads to higher green market share and total CSR investment. Additionally, the cooperative market is more responsive to reductions in k, with the first tipping point occurring when green production costs are moderately high, whereas in the competitive market producers are unable to take advantage of the falling costs until they are extremely low. Thus, it appears that when producers are flexible, the impact of competition is similar to that in the inflexible case. However, with flexible producers the disparity in the ability to switch to green production between the cooperative and competitive regimes is even more dramatic. Moreover, the benefit of competitive markets in the inflexible case of making it easier for a green producer to enter no longer holds when producers can flexibly choose their type. In Theorem 2 we formally prove these observations.

THEOREM 2 **(Cooperation vs. Competition between Two Flexible Producers)**. *Suppose there are two profit-maximizing flexible producers located at opposing points on Salop's circle. If the parameters satisfy $B_N^2 \leq c\theta$ and $B_G^2 \leq c\theta$, then the resulting market share for the green product and the total CSR investment is always higher when producers cooperate than when producers compete.*

Surprisingly, when producers are flexible Theorem 2 shows cooperation always leads to more sustainable market outcomes. In many ways this result is intuitive, competition forces producers to fight for market share which reduces the effectiveness of their CSR investment, and tempers any advantage the green product has at appealing to environmentally conscious consumers. Cooperating producers, by side-stepping competitive deadlock, can adaptively react to changing market conditions and optimally offer the green product as costs decrease or consumer sentiment shifts.

Moreover, by comparing Theorem 2 with Theorem 1, we find that product-type flexibility for producers can be an important consideration for governmental regulators looking to encourage the adoption of green technologies. The existence of tipping points, demonstrated in both the flexible cooperative and flexible competitive cases, implies that for certain markets if the conditions are ripe (i.e. k is near the points prescribed in Propositions 3 and 4), a small amount of either market subsidy or technological innovation to reduce k can produce a rapid shift towards green production. Thus identifying markets close to these tipping points can be critical for cost-effective market intervention to induce green adoption.

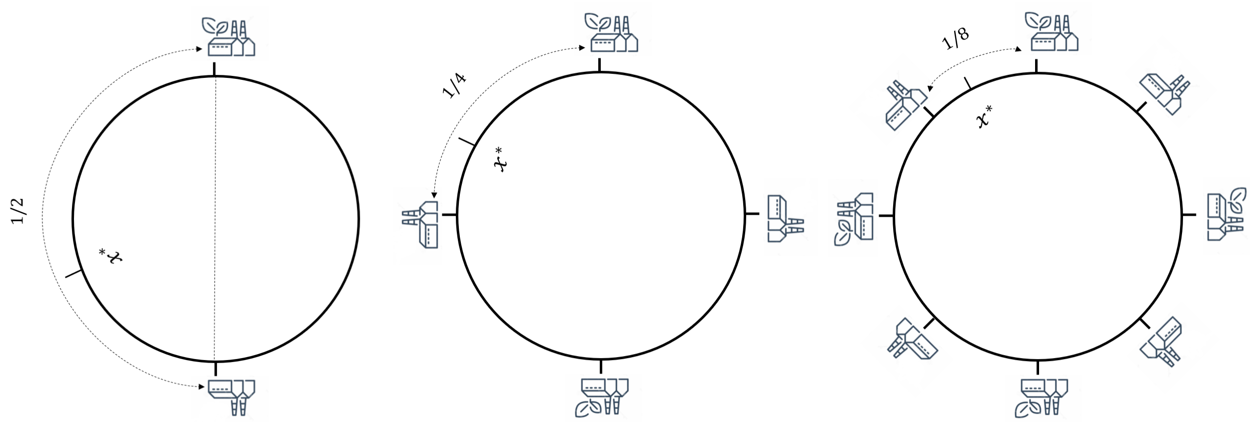
For simplicity, so far we have focused on markets with two producers. Such a simplification may not be reflective of markets with many product lines and subsidiary companies (which would imply large scale cooperation) or intense competition from many producers. In Section 5, we generalize our model to the case of many producers in cooperation/competition, and study how the insights from the two producer cases translates to more general settings.

5. Cooperation and Competition between Many Producers

In this section, we expand our model to multiple producers, enabling us to investigate the impact of intensified competition. To illustrate, a monopoly is less competitive than a duopoly, and a duopoly is less competitive than a market with many producers, and so on. Thus, increasing the number of green and non-green producers increases the intensity of competition in the market. Specifically, we consider market outcomes for $2n$ producers for some $n \in \mathbb{N}$. As in Section 2, customer preference among these producers is represented via a location model, where producers are now placed at evenly spaced points on Salop's circle.

We start by considering the inflexible case where producer type is fixed (as in Section 3), and assume that there are n green producers and n non-green producers. Note in generalizing from 2 to $2n$, our space for possible arrangements of green and non-green producers on the circle increases combinatorially on the order of $\binom{2n}{n}$. For tractability, we focus on what we term the *balanced* case, where green and non-green producers alternate on the circle (see Fig. 7 for a depiction). We will further focus on the symmetric policy/equilibria the n green producers all act *identically* i.e., the effectiveness of their CSR investment is the same, and they all choose the same price p and level of investment s, as do the n non-green producers. This assumption is without loss of generality when producers are in competition, the alternating symmetry enforces that producers of the same type act the same, but is restrictive when the producers cooperate. The upside of the balance assumptions is that it keeps our parameter space fixed as n increases, which allows us to isolate the interaction between competition intensity and green investment. We emphasize that this model strictly generalizes the model in Section 3.

Figure 7 **Balanced Salop's circle model.**



Note. Depicted are three balanced markets with $n = 1$, 2, and 4 pairs of producers, respectively. A sample indifference point between the green and non-green producer is shown for all three models. We note that while there are many indifference points for each market, by symmetry they occur at the same position in each segment between a green and non-green producer. Thus, for each model, we uniquely refer to one point as x^*.

In Proposition 5, we generalize the analysis in Proposition 1, and characterize the profit-maximizing prices and CSR investments for $2n$ cooperating balanced producers, n of which identically produce the green product, and n of which identically produce the non-green product.

PROPOSITION 5 **(2n Balanced Producers, Cooperative Solution)**. *Suppose* $B_N^2 \leq c(\theta - kn)$ *and* $B_G^2 \leq c(\theta + kn)$, *then the optimal prices, CSR investments, and induced market shares when the* $2n$ *producers are balanced and cooperate are:*

(a) $p_N = v - \frac{\left(c\theta - 2B_N^2\right)\left(c(\theta+kn) - B_G^2\right)}{2cn\left(2c\theta - B_N^2 - B_G^2\right)}$, $p_G = v - \frac{\left(c\theta - 2B_G^2\right)\left(c(\theta-kn) - B_N^2\right)}{2cn\left(2c\theta - B_N^2 - B_G^2\right)}$,

(b) $s_N = \frac{B_N\left(c(\theta+kn)-B_G^2\right)}{cn\left(2c\theta-B_N^2-B_G^2\right)}$, $s_G = \frac{B_G\left(c(\theta-kn)-B_N^2\right)}{cn\left(2c\theta-B_N^2-B_G^2\right)}$,

(c) $\mathcal{M}_N = \frac{c(\theta+kn)-B_G^2}{2c\theta-B_N^2-B_G^2}$, $\mathcal{M}_G = \frac{c(\theta-kn)-B_N^2}{2c\theta-B_N^2-B_G^2}$.

Proposition 5 presents the profit-maximizing prices, CSR investments, and total market share for both the green and non-green products. We emphasize that even though the producers are cooperative, we assume all green (non-green) producers use the same price and level of CSR investment. Thus there is only a single pair of parameters p_G, s_G (p_N, s_N) which applies to all n green (non-green) producers. Further, note $\mathcal{M}_G$ and $\mathcal{M}_N$ now represent the *cumulative* market share for the green and non-green products (for producer level market share simply divide by n). Compared with Proposition 1, we observe that as n increases the green market share decreases, and the feasible region where the green product is viable shrinks (for a complete discussion of the feasible conditions, see Section B).

Next, we generalize the analysis in Proposition 2, and characterize the equilibrium prices and CSR investments when the $2n$ producers are balanced and compete.

PROPOSITION 6 **(2n Balanced Producers, Competitive Solution)**. *Suppose* $B_N^2 \leq c(1.5\theta - kn)$ *and* $B_G^2 \leq c(1.5\theta + kn)$*, then the optimal prices, CSR investments, and induced market shares when the* $2n$ *producers are balanced and compete are:*

(a) $p_N = \frac{\theta\left(1.5c\theta+ckn-B_G^2\right)}{n\left(3c\theta-B_N^2-B_G^2\right)}$, $p_G = \frac{c\theta(2kn+1.5c\theta)-B_G^2kn-B_N^2(kn+\theta)}{n\left(3c\theta-B_N^2-B_G^2\right)}$,

(b) $s_N = \frac{B_N\left(c(1.5\theta+kn)-B_G^2\right)}{cn\left(3c\theta-B_N^2-B_G^2\right)}$, $s_G = \frac{B_G\left(c(1.5\theta-kn)-B_N^2\right)}{cn\left(3c\theta-B_N^2-B_G^2\right)}$,

(c) $\mathcal{M}_N = \frac{c(1.5\theta+kn)-B_G^2}{3c\theta-B_N^2-B_G^2}$, $\mathcal{M}_G = \frac{c(1.5\theta-kn)-B_N^2}{3c\theta-B_N^2-B_G^2}$.

Proposition 6 presents the profit-maximizing prices, CSR investments, and market shares for the green and non-green products in equilibrium. We emphasize that when all producers compete and the market is balanced, all green (non-green) producers use the same price and level of CSR investment at the symmetric equilibria. Compared with Proposition 2, we again observe that as n increases, the green market share decreases, and the feasible region where the green product is viable decreases. Also note, from Propositions 5 and 6, that the feasible region supporting the competitive case is still always larger than the cooperative case. Finally, both CSR investment and market share remain linear in k.

In Theorem 3 we generalize Theorem 1 to the case of increasing market intensity, indexed by the number of producers of each type n. Let $\mathcal{M}_G^M$ and $\mathcal{M}_G^D$ be the total green market share for the now $2n$ balanced producers under cooperation and competition, respectively, and let S^M and S^D be denote the CSR investments.

THEOREM 3 **(Cooperation vs. Competition when the Market is Balanced)**. *Suppose there are $2n$ profit-maximizing producers, n of which identically produce the green product, and n of which identically produce the non-green product, located at evenly spaced, alternating locations on Salop's circle.*

(a) If the parameters satisfy conditions for Propositions 5 and 6, the total market share of the green product when green production costs are low is higher when the market is cooperative than when the market is competitive, and this relation reverses for higher production costs. That is, $\mathcal{M}_G^M(0) \geq \mathcal{M}_G^D(0)$ and $\frac{\partial \mathcal{M}_G^M(k)}{\partial k} \leq \frac{\partial \mathcal{M}_G^D(k)}{\partial k} \leq 0$.

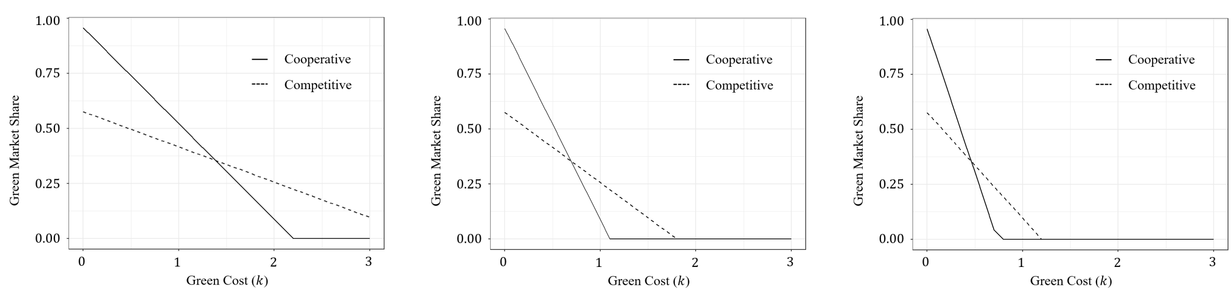
(b) If the parameters satisfy conditions for Propositions 5 and 6, the total CSR investment across the $2n$ producers when green production costs are low is higher when the market is cooperative than when the market is competitive, and this relation reverses for higher production costs. That is, $S^M(0) \geq S^D(0) \geq 0$, and $\frac{\partial S^M(k)}{\partial k} \leq \frac{\partial S^D(k)}{\partial k} \leq 0$.

(c) If the parameters satisfy the condition for Proposition 6 but not the conditions for Proposition 5, then $\mathcal{M}_G^D > \mathcal{M}_G^M = 0$.

(d) If the parameters satisfy conditions for Propositions 5 and 6 when $n = 1$, then the green market share is decreasing in n in both cooperative and competitive balanced markets. Further, as n tends to infinity, green market share tends to zero in both cases i.e., $\lim_{n\to\infty} \mathcal{M}_G^M = 0$, and $\lim_{n\to\infty} \mathcal{M}_G^D = 0$.

Following Theorem 1, in Theorem 3(a,b,c) we prove that the dichotomous relationship between the cooperative and competitive cases continues to hold. Even with $2n$ producers, it is still easier for a green product to emerge when the producers are in competition. However, the market transitions more readily to green product dominance when the producers cooperate. What varies as competition intensifies is the intensity of these relationships. In Fig. 8 we plot the relationship between k and the green market share when there are 2, 4, and 6 balanced producers (i.e. $n = 1, 2, 3$). Note that as the number of producers, and thus the intensity of competition, increases, the feasible region for the green product decreases quite sharply. When $n = 1$, the green product is feasible in the market for $k = 2$, but when $n = 3$ the green product is no longer viable even when k is as low as one. Moreover, the rate of green market share growth when the green product is feasible rapidly increases, as indicated by the slopes in Fig. 8. In fact, as the number of producer pairs n increases, the green market share at each level of k is strictly decreasing, and the adoption rate when the green product is feasible is strictly increasing. A similar relationship also holds for total CSR, for a depiction see Fig. EC.4. Returning to our regulatory motivation, this implies that in intensely contested markets with many firms, reducing the cost of green production in a neutral way (i.e. not in a way that discriminates between producers) via tax incentives or technological innovation is even more effective at encouraging green adoption, than in the case of two producers that we considered earlier.

Figure 8 **Green market share of $2n$ balanced producers as k varies.**



Note. Depicted is the change in green market share for $2n$ producers when $n=1$ (left), $n=2$ (middle), and $n=3$ (right), as the cost of green production k varies. The remaining market parameters are set to $B_N=4.5$, $B_G=5$, $c=5$, $\theta=5.1$. In the left panel, we observe the green market share is higher in the cooperative case when k small, and it decreases when k increases for both cooperative and competitive markets. A similar plot for how total CSR investment changes as k varies can be found at Fig. EC.4 in the Appendix.

Finally, in Theorem 3(d) we examine the limits of increasing competition intensity. We find that increasing competition always has a dampening effect on green market share, and in the limit actually suppress the green product completely. The intuition behind the result is as follows: in either case, as the market gets more competitive, the resulting market share any single green producer can capture is too small to support the expenditure of CSR investment. Thus, at the limit of competitive intensity, we uncover the conflict between competition in the market and green product adoption. When margins are so thin as to not support CSR investment, the green producer can not adequately reach its customer base, who would otherwise pay a premium for its goods. For a regulator, this may mean that, for the goal of green product adoption, they may prioritize subsidizing cooperative or non-competitive/centralized markets with fewer product lines (i.e. with more corporate consolidation) as such markets may be better able to take advantage of the subsequent drop in green product cost.

In the next subsection we will further generalize our results to the case of balanced, *flexible* producers.

5.1. Cooperation and Competition in Balanced, Flexible Markets

As in Sections 3 and 4, we can use the analysis of balanced inflexible producers to study balanced flexible producers. For tractability, we will assume that the market can only take certain forms in parallel to our previous balance assumption. Specifically, in this subsection we assume that the $2n$ producers can flexibly choose to either purely produce the non-green product, have n green producers and n non-green producers arranged in alternation around the circle, or purely produce the green product. In each of the three outcomes we assume that producers of the same type use the same price and level of CSR investment. We call a group of producers choosing among these three outcomes in this way flexible and balanced. Note this balanced, flexible model strictly generalizes the two flexible producer model studied in Section 4.

The upside of our flexible balance assumptions is that it keeps our parameter space fixed as n increases, which allows us to generalize the results of Theorem 2. In Theorem 4, we compare the market outcomes for balanced, flexible producers when they cooperate or compete, respectively.

THEOREM 4 **(Cooperation vs. Competition between Balanced, Flexible Producers)**. *Suppose there are* $2n$ *profit-maximizing balanced, flexible producers located at evenly spaced points on Salop's circle. If the parameters satisfy* $B_N^2 \le c\theta$ *and* $B_G^2 \le c\theta$*, then:*

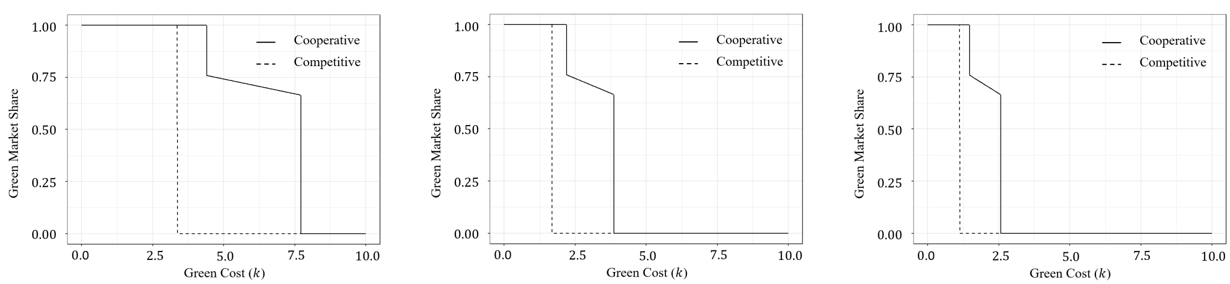
(a) The resulting market share for the green product, and the total CSR investment, is always higher when producers cooperate than when producers compete.

(b) As n *increases, the green market share is always non-increasing.*

Theorem 4 completes our analysis, presenting a sharp comparison of market outcomes under cooperation/competition when there are many producers who endogenously choose their production type. To prove Theorem 4, we characterize the tipping points for the balanced, flexible markets, as in Propositions 3 and 4. Also like before, there are two tipping points for the balanced, flexible cooperative market, and a single tipping point for the balanced, flexible competitive market. The proof of Theorem 4 then follows by comparing the markets at those points. The location of the tipping points now vary as n increases. Specifically, in Fig. 9, we observe that as n increases *all* tipping points decrease. A similar relationship also holds for total CSR investment, for a depiction see Fig. EC.5.

Taken together, this means that as competition intensifies, shifting the balanced, flexible market to green production and total CSR investment becomes more and more difficult. For a regulator, this may mean that, for the goal of green product adoption, subsidizing/investing in markets which exhibit high levels of corporate concentration (i.e. few producers) may yield the most return since they may more readily reach tipping points in those markets.

Figure 9 **Green market share of $2n$ balanced flexible producers as k varies.**



Note. Depicted is the change in green market share for $2n$ balanced, flexible producers when $n=1$ (left), $n=2$ (middle), and $n=3$ (right), as the cost of green production k varies. The remaining market parameters are set to $v=100$, $c=1$, $\theta=40.1$, $B_N=3$, $B_G=6$. From the left to the right panel, we observe the tipping points decrease for both cooperative and competitive market. A similar plot for how total CSR investment changes as k varies can be found at Fig. EC.5 in the Appendix.

6. Conclusions

In this paper, we propose a series of natural location models via which we study the complex interaction between competition, socially responsible investment, and green production. In Section 3 we study a base model with two producers, one green and one non-green, and characterize the optimal policies under cooperation and competition. Using this market characterization we examine how two key market outcomes, green market share and total CSR investment, change as the cost of green production falls. We find that reducing green manufacturing costs enhances the green market share and total CSR investment in both cooperative and competitive markets. Interestingly, the growth in green market share and CSR investment is greater when the producers cooperate, assuming the green product is present in the market. In Section 4 we endogenize the choice of production type allowing producers to choose whether to be green or non-green. When producers are flexible, we find that cooperative markets dominate the equilibrium outcomes of competitive markets in terms of the adoption of environmentally sustainable (green) production, and total CSR investment. Finally in Section 5, we generalize our model to the case of many balanced producers and find that when the cost of green production falls, similar dynamics play-out where competition dampens the feasibility of green products, but if the green product is viable then subsidisation can yield fast rates of green production adoption.

Taken together, our models demonstrate a compelling relationship between the competitive character of a market and the malleability of the product composition in the marketplace. For legislators, our work highlights the tension between regulating a market to make it more competitive, and subsidizing green technologies to accelerate the adoption of sustainable production/consumption. Traditionally, increasing the competitive nature of a market has been a policy goal; competition often spurs innovation and results in a greater surplus for customers in the market. Our work puts a twist on this conventional wisdom by showing that in cooperative (centralized, or non-competitive) markets, coordination between producers allows them to easily respond to changing market conditions and embrace green technologies faster, whereas competition can induce deadlock making it harder for the market players to adapt.

Overall, this research studies how the competitive characteristics of markets impact green production adoption, and makes a case that cooperative markets may more easily transition to environmentally sustainable practices. There are many exciting and important directions left to consider for future work, we highlight two of them here. First, we have chosen to emphasize a reduction in the additional cost of green production in this work. A parallel story can be told in our models parameterizing instead by increasing customer preference for environmentally sustainable products. Specifically, we could have studied models where two (or more) flexible producers in cooperation/competition react as customer sentiment, measured by $B_G - B_N$, varies. In preliminary numerics for this case, we find qualitatively similar results to the case where k changes, see Figs. EC.2 and EC.3 in Appendix for details. Second, we consider the cost of green production k as exogenous, and suppose producers can only invest in CSR essentially as a form of advertising. It would be interesting to consider models where producers can invest directly in reducing the future cost of green production, by introducing a multi-stage model. In such an extension we can again study the impact of competition on the producers' strategic decision to invest in reducing the cost of green production.

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Appendix

Appendix A: Omitted Proofs

For all the proofs in this section, the computations are conducted in Wolfram Mathematica 13.1. All relevant Mathematica notebooks can be found at `https://github.com/tcui-pitt/Sustainable_Investment`.

A.1. Omitted Proofs from Section 3

For this section, the relevant Mathematica codes where computations are conducted are `Monopoly.nb` (Proposition 1) and `Duopoly.nb` (Proposition 2).

Proof of Proposition 1. Let x^* be the indifference point between the non-green and green products in one segment as depicted in Fig. 2. By definition, the customer at x^* is indifferent between non-green and green product. Further, since the producers are cooperative, they can raise the prices together such that utility at the indifferent point is zero. Thus:

$$U_N(x^*) = v + B_N s_N - \theta x^* - p_N = U_G(x^*) = v + B_G s_G - \theta\left(\frac{1}{2} - x^*\right) - p_G = 0.$$

Solving the equation above, we get equations for the indifference point and the price of the green product in terms of p_N, s_N, and s_G:

$$x^* = \frac{v + B_N s_N - p_N}{\theta}, \quad p_G = 2v + B_N s_N + B_G s_G - p_N - \frac{\theta}{2}. \tag{EC.1}$$

Due to the symmetry of the two segments on Salop's circle, the total market share of the non-green producer is $2x^*$, and the total market share of the one green producer is $2\left(\frac{1}{2} - x^*\right)$. The total profit of the cooperative green and non-green producers is then:

$$\begin{aligned}
\mathcal{R}(p_G, s_G, p_N, s_N) &:= \mathcal{R}_G(p_G, s_G) + \mathcal{R}_N(p_N, s_N) \\
&= \left(2x^* p_N - \frac{c s_N^2}{2} + 2\left(\frac{1}{2} - x^*\right)(p_G - k) - \frac{c s_G^2}{2}\right) \\
&= 2\left(\frac{(v + B_N s_N - p_N)p_N}{\theta} + \left(\frac{1}{2} - \frac{v + B_N s_N - p_N}{\theta}\right)\left(2v + B_N s_N + B_G s_G - p_N - \frac{\theta}{2} - k\right)\right) - \frac{c\left(s_N^2 + s_G^2\right)}{2}.
\end{aligned}$$

To maximize the total profit, we check the first order of condition for the three remaining independent variables, s_N, s_G and p_N:

$$\begin{aligned}
\frac{\partial \mathcal{R}(p_G, s_G, p_N, s_N)}{\partial s_N} &= \frac{2B_N(k + 3p_N - B_G s_G + \theta - 3v) - 4B_N^2 s_N}{\theta} - c s_N = 0, \\
\frac{\partial \mathcal{R}(p_G, s_G, p_N, s_N)}{\partial s_G} &= B_G\left(1 - \frac{2(v + B_N s_N - p_N)}{\theta}\right) - c s_G = 0, \\
\frac{\partial \mathcal{R}(p_G, s_G, p_N, s_N)}{\partial p_N} &= -\frac{2(k + \theta + (4p_N - 3B_N s_N - B_G s_G - 4v))}{\theta} = 0.
\end{aligned}$$

Solving the system of first order conditions, we can get the profit-maximizing price and investment for the green and non-green product:

$$\begin{aligned}
p_N &= v - \frac{(2B_N^2 - c\theta)(c(\theta + k) - B_G^2)}{2c(2c\theta - B_N^2 - B_G^2)}, \quad p_G = v - \frac{(2B_G^2 - c\theta)(c(\theta - k) - B_N^2)}{2c(2c\theta - B_N^2 - B_G^2)}, \\
s_N &= \frac{B_N(c(\theta + k) - B_G^2)}{c(2c\theta - B_N^2 - B_G^2)}, \quad s_G = \frac{B_G(c(\theta - k) - B_N^2)}{c(2c\theta - B_N^2 - B_G^2)}.
\end{aligned}$$

Plugging back into our equation for the indifference point, the market share for the green and non-green products under the profit-maximizing prices and CSR investment is:

$$\mathcal{M}_N = \frac{c(\theta+k) - B_G^2}{2c\theta - B_N^2 - B_G^2}, \quad \mathcal{M}_G = \frac{c(\theta-k) - B_N^2}{2c\theta - B_N^2 - B_G^2}.$$

Note that both $\mathcal{M}_N$ and $\mathcal{M}_G$ are positive due to the condition $B_N^2 \leq c(\theta-k)$ and $B_G^2 \leq c(\theta+k)$ and thus represents an interior solution for the marketplace.

□

Proof of Proposition 2 As in the proof of the previous proposition, let x^* be the indifference point between the non-green and green products in one segment as depicted in Fig. 2. By definition, the customer at $x^*$is indifferent between green and non-green product, i.e.:

$$U_N(x^*) = v + B_N s_N - \theta x^* - p_N = U_G(x^*) = v + B_G s_G - \theta\left(\frac{1}{2} - x^*\right) - p_G.$$

Note above we no longer assume the customer's utility is 0 at the indifference point as it was when the producers were cooperating. Solving the equation for the indifference point, we get the market share of non-green product in one segment is:

$$x^* = \frac{1}{4} + \frac{(B_N s_N - p_N) - (B_G s_G - p_G)}{2\theta}.$$

Due to the symmetry of Salop's circle, the market share of one non-green producer is $2x^*$, and the market share of one green producer is $2\left(\frac{1}{2} - x^*\right)$. Therefore, the profit of non-green producer and green producer are:

$$\mathcal{R}_N(p_N, s_N) = 2x^* p_N - \frac{cs_N^2}{2} = \left(\frac{1}{2} + \frac{(B_N s_N - p_N) - (B_G s_G - p_G)}{\theta}\right) p_N - \frac{cs_N^2}{2},$$
$$\mathcal{R}_G(p_G, s_G) = 2\left(\frac{1}{2} - x^*\right)(p_G - k) - \frac{cs_G^2}{2} = \left(\frac{1}{2} + \frac{(B_G s_G - p_G) - (B_N s_N - p_N)}{\theta}\right) p_G - \frac{cs_G^2}{2}.$$

Now, we will solve for the Nash equilibrium price and CSR investment by solving the linear system of first order conditions; for an extensive discussion of solving for Nash equilibrium, see Fudenberg and Tirole (1991):

$$\frac{\partial \mathcal{R}_N(p_N, s_N)}{\partial s_N} = \frac{B_N p_N}{\theta} - cs_N = 0,$$
$$\frac{\partial \mathcal{R}_G(p_G, s_G)}{\partial s_G} = \frac{B_G p_G}{\theta} - cs_G = 0,$$
$$\frac{\partial \mathcal{R}_N(p_N, s_N)}{\partial p_N} = \frac{1}{2} + \frac{(B_N s_N - 2p_N) - (B_G s_G - p_G)}{\theta} = 0,$$
$$\frac{\partial \mathcal{R}_G(p_G, s_G)}{\partial p_G} = \frac{1}{2} + \frac{(B_G s_G - 2p_G) - (B_N s_N - p_N)}{\theta} = 0.$$

Solving the linear system of first-order conditions, we obtain the equilibrium price and investment for the green and non-green producers as:

$$p_N = \frac{\theta\left(c(1.5\theta+k) - B_G^2\right)}{(3c\theta - B_N^2 - B_G^2)}, \quad p_G = \frac{c\theta(2k+1.5\theta) - B_G^2 k - B_N^2(k+\theta)}{(3c\theta - B_N^2 - B_G^2)},$$
$$s_N = \frac{B_N\left(c(1.5\theta+k) - B_G^2\right)}{c\left(3c\theta - B_N^2 - B_G^2\right)}, \quad s_G = \frac{B_G\left(c(1.5\theta-k) - B_N^2\right)}{c\left(3c\theta - B_N^2 - B_G^2\right)}.$$

Plugging back into our initial equation for the indifference point, the competitive market share for the green and non-green producers under equilibrium price and investment will be:

$$\mathcal{M}_N = \frac{c(1.5\theta + k) - B_G^2}{3c\theta - B_N^2 - B_G^2}, \quad \mathcal{M}_G = \frac{c(1.5\theta - k) - B_N^2}{3c\theta - B_N^2 - B_G^2}.$$

Note that both $\mathcal{M}_N$ and $\mathcal{M}_G$ are positive due to the condition $B_N^2 \leq c(1.5\theta - k)$ and $B_G^2 \leq c(1.5\theta + k)$ and thus represents an interior solution for the marketplace. □

Proof of Theorem 1 From Propositions 1 and 2 we have closed-form expressions for the total green market share and total CSR investment in both cooperative and competitive markets. As a function of the cost of green production, the green market share and CSR investment can be written as:

$$\mathcal{M}_G^M(k) = \frac{c(\theta - k) - B_N^2}{2c\theta - B_N^2 - B_G^2},$$
$$\mathcal{M}_G^D(k) = \frac{c(1.5\theta - k) - B_N^2}{3c\theta - B_N^2 - B_G^2},$$
$$S^M(k) = \frac{B_N\left(c(\theta + k) - B_G^2\right)}{c\left(2c\theta - B_N^2 - B_G^2\right)} + \frac{B_G\left(c(\theta - k) - B_N^2\right)}{c\left(2c\theta - B_N^2 - B_G^2\right)},$$
$$S^D(k) = \frac{B_N\left(c(1.5\theta + k) - B_G^2\right)}{c\left(3c\theta - B_N^2 - B_G^2\right)} + \frac{B_G\left(c(1.5\theta - k) - B_N^2\right)}{c\left(3c\theta - B_N^2 - B_G^2\right)}.$$

where recall, the superscript M and D denotes the cooperative and competitive solution, respectively. In the following parts, we will compare these functions as k varies.

Part a) First when $k = 0$, the green market share when cooperating is:

$$\begin{aligned}\mathcal{M}_G^M(0) &= \frac{c\theta - B_N^2}{2c\theta - B_N^2 - B_G^2} \\ &= \frac{c\theta - 0.5B_N^2 - 0.5B_G^2 - 0.5B_N^2 + 0.5B_G^2}{2c\theta - B_N^2 - B_G^2} \\ &= \frac{1}{2} + \frac{0.5\left(B_G^2 - B_N^2\right)}{2c\theta - B_N^2 - B_G^2}.\end{aligned}$$

While the green market share under competition is:

$$\begin{aligned}\mathcal{M}_G^D(0) &= \frac{1.5c\theta - B_N^2}{3c\theta - B_N^2 - B_G^2} \\ &= \frac{1.5c\theta - 0.5B_N^2 - 0.5B_G^2 - 0.5B_N^2 + 0.5B_G^2}{3c\theta - B_N^2 - B_G^2} \\ &= \frac{1}{2} + \frac{0.5\left(B_G^2 - B_N^2\right)}{3c\theta - B_N^2 - B_G^2}.\end{aligned}$$

Therefore:

$$\mathcal{M}_G^M(0) - \mathcal{M}_G^D(0) = \frac{0.5\left(B_G^2 - B_N^2\right)}{2c\theta - B_N^2 - B_G^2} - \frac{0.5\left(B_G^2 - B_N^2\right)}{3c\theta - B_N^2 - B_G^2} \geq 0,$$

where the inequality follows from the fact that $B_G^2 - B_N^2 \geq 0$ by assumption, and $3c\theta - B_N^2 - B_G^2 \geq 2c\theta - B_N^2 - B_G^2 > 0$, by the conditions in Propositions 1 and 2.

Now we will take the derivative of the green market share with respect to k:

$$\frac{\partial \mathcal{M}_G^M(k)}{\partial k} = \frac{-c}{2c\theta - B_N^2 - B_G^2},$$
$$\frac{\partial \mathcal{M}_G^D(k)}{\partial k} = \frac{-c}{3c\theta - B_N^2 - B_G^2}.$$

Again we have $3c\theta - B_N^2 - B_G^2 \geq 2c\theta - B_N^2 - B_G^2 > 0$ by the conditions in Propositions 1 and 2, thus we conclude that:

$$\frac{\partial \mathcal{M}_G^M(k)}{\partial k} \leq \frac{\partial \mathcal{M}_G^D(k)}{\partial k} < 0.$$

Part b) First, when $k=0$, the total CSR investment when cooperating is:

$$\begin{aligned} S^M(0) &= \frac{B_N\left(c(\theta+0)-B_G^2\right)}{c\left(2c\theta-B_N^2-B_G^2\right)} + \frac{B_G\left(c(\theta-0)-B_N^2\right)}{c\left(2c\theta-B_N^2-B_G^2\right)} \\ &= \frac{B_N\left(c\theta-0.5B_N^2-0.5B_G^2-0.5B_G^2+0.5B_N^2\right)}{c\left(2c\theta-B_N^2-B_G^2\right)} + \frac{B_G\left(c\theta-0.5B_N^2-0.5B_G^2-0.5B_N^2+0.5B_G^2\right)}{c\left(2c\theta-B_N^2-B_G^2\right)} \\ &= B_N\left(\frac{1}{2c}-\frac{0.5B_G^2-0.5B_N^2}{c\left(2c\theta-B_N^2-B_G^2\right)}\right) + B_G\left(\frac{1}{2c}+\frac{0.5B_G^2-0.5B_N^2}{c\left(2c\theta-B_N^2-B_G^2\right)}\right) \\ &= \frac{B_N+B_G}{2c} + \frac{0.5\left(B_G-B_N\right)\left(B_G^2-B_N^2\right)}{c\left(2c\theta-B_N^2-B_G^2\right)}, \end{aligned}$$

where the final equality follows from the fact that $-B_N\left(\frac{0.5B_G^2-0.5B_N^2}{c\left(2c\theta-B_N^2-B_G^2\right)}\right)+B_G\left(\frac{0.5B_G^2-0.5B_N^2}{c\left(2c\theta-B_N^2-B_G^2\right)}\right)=\frac{0.5(B_G-B_N)\left(B_G^2-B_N^2\right)}{c\left(2c\theta-B_N^2-B_G^2\right)}$. Similarly, when $k=0$, the total CSR investment under competition is:

$$\begin{aligned} S^D(0) &= \frac{B_N\left(c(1.5\theta+0)-B_G^2\right)}{c\left(3c\theta-B_N^2-B_G^2\right)} + \frac{B_G\left(c(1.5\theta-0)-B_N^2\right)}{c\left(3c\theta-B_N^2-B_G^2\right)} \\ &= \frac{B_N+B_G}{2c} + \frac{0.5\left(B_G-B_N\right)\left(B_G^2-B_N^2\right)}{c\left(3c\theta-B_N^2-B_G^2\right)}. \end{aligned}$$

Therefore:

$$S^M(0)-S^D(0) = \frac{0.5\left(B_G-B_N\right)\left(B_G^2-B_N^2\right)}{c\left(2c\theta-B_N^2-B_G^2\right)} - \frac{0.5\left(B_G-B_N\right)\left(B_G^2-B_N^2\right)}{c\left(3c\theta-B_N^2-B_G^2\right)} \geq 0,$$

where the inequality follows from $B_G-B_N\geq 0$ and $3c\theta-B_N^2-B_G^2\geq 2c\theta-B_N^2-B_G^2\geq 0$.

The derivatives of $S^M(k)$ and $S^D(k)$ with respect to k are:

$$\begin{aligned} \frac{\partial S^M(k)}{\partial k} &= \frac{cB_N}{c\left(2c\theta-B_N^2-B_G^2\right)} - \frac{cB_G}{c\left(2c\theta-B_N^2-B_G^2\right)} = \frac{-c(B_G-B_N)}{c\left(2c\theta-B_N^2+B_G^2\right)}, \\ \frac{\partial S^D(k)}{\partial k} &= \frac{cB_N}{c\left(3c\theta-B_N^2-B_G^2\right)} - \frac{cB_G}{c\left(3c\theta-B_N^2-B_G^2\right)} = \frac{-c(B_G-B_N)}{c\left(3c\theta-B_N^2+B_G^2\right)}. \end{aligned}$$

Thus, by the condition of Proposition 1 and Proposition 2, $3c\theta-B_N^2-B_G^2\geq 2c\theta-B_N^2-B_G^2\geq 0$, we obtain:

$$\frac{\partial S^M(k)}{\partial k} \leq \frac{\partial S^D(k)}{\partial k} < 0.$$

Part c) If the conditions of Proposition 2 are satisfied while the condition of Proposition 1 are not, i.e., $B_N^2+B_G^2-3c\theta<0\leq B_N^2+B_G^2-2c\theta$, we will get a corner solution for the cooperative case, namely, $\mathcal{M}_G^M=0$. However, the green market share for the competitive case is still positive, $\mathcal{M}_G^D=\frac{B_N^2-c(1.5\theta-k)}{B_N^2+B_G^2-3c\theta}>0$. For additional details see Section B. □

A.2. Omitted Proofs from Section 4

For this section, the relevant Mathematica codes where the computations are conducted are `Flexible_Monopoly.nb` (Proposition 3), `Flexible_Competitive.nb` (Proposition 4), and `Flexible_Dominance.nb` (Theorem 2).

Proof of Proposition 3 First, we give the optimal profit functions for cooperative markets of mixed green and non-green production, purely green production, and purely non-green production, parameterized by the cost of green production k. Let $\mathcal{R}_{GN}(p_G,s_G,p_N,s_N)$ be the *total* profit for two cooperating producers who opt for a mixed policy of green and non-green production, using prices and CSR investment p_G, s_G, p_N, and s_N. According to Proposition 1, the optimal total profit of mixed green and non-green production can be obtained by plugging in the optimal prices and CSR investment, which, suppressing the computation of these prices and investment levels and plugging in, is given by,

$$\mathcal{R}_{GN}(k) := \max_{p_G, s_G, p_N, s_N} \mathcal{R}_{GN}(p_G, s_G, p_N, s_N) = v - \frac{\theta}{2} - \frac{c^2(k-\theta)^2 - B_N^2(B_G^2 - 2ck)}{2c(B_N^2 + B_G^2 - 2c\theta)}.$$

Similarly, let $\mathcal{R}_{GG}(p_G, s_G)$ be the total profit of purely green production. By the same type of calculation, the optimal total profit of purely green production is give by

$$\mathcal{R}_{GG}(k) := \max_{p_G, s_G} \mathcal{R}_{GG}(p_G, s_G) = v - \frac{\theta}{4} - k + \frac{B_G^2}{4c}.$$

Finally, let $\mathcal{R}_{NN}(p_N, s_N)$ be the total profit of purely non-green production, and note that purely non-green production can be computed as a special case of purely green, where $k = 0$ and $B_G = B_N$. Therefore, the optimal total profit of purely non-green production is

$$\mathcal{R}_{NN}(k) := \max_{p_N, s_N} \mathcal{R}_{NN}(p_N, s_N) = v - \frac{\theta}{4} + \frac{B_N^2}{4c}.$$

Let k_1 and k_2 be the first and second tipping points, respectively, and note there can be no more than two tipping points because the three profit functions listed above all cross each other at most once[1]. Now, we will calculate the first tipping point. It can be easily checked that the optimal total profit of purely green production is greater than the optimal total profit of mixed production before the the first tipping point. Thus, the first tipping point k_1 satisfies:

$$\mathcal{R}_{GG}(k_1) = v - \frac{\theta}{4} - k_1 + \frac{B_G^2}{4c} = v - \frac{\theta}{2} - \frac{c^2(k_1-\theta)^2 - B_N^2(B_G^2 - 2ck_1)}{2c(B_N^2 + B_G^2 - 2c\theta)} = \mathcal{R}_{GN}(k_1).$$

Solve the condition above, we obtain a closed form expression for k_1,

$$k_1 = \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_G^2)}}{\sqrt{2}c} - \frac{c\theta - B_G^2}{c}.$$

Now for the second tipping point k_2, for all k sufficiently large the total profit of purely non-green production is greater than the total profit of mixed production, and as k decreases these two profit have a unique crossing which satisfies,

$$\mathcal{R}_{NN}(k_2) = v - \frac{\theta}{4} + \frac{B_N^2}{4c} = v - \frac{\theta}{2} - \frac{c^2(k_2-\theta)^2 - B_N^2(B_G^2 - 2ck_2)}{2c(B_N^2 + B_G^2 - 2c\theta)} = \mathcal{R}_{GN}(k_2).$$

Solve the condition above, we obtain a closed form expression for k_2,

$$k_2 = \frac{c\theta - B_N^2}{c} - \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_N^2)}}{\sqrt{2}c}.$$

Therefore, when $\frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_G^2)}}{\sqrt{2}c} - \frac{c\theta - B_G^2}{c} \leq k \frac{c\theta - B_N^2}{c} - \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_N^2)}}{\sqrt{2}c}$ the profit of mixed production is larger than two non-green producers, when $k \geq \frac{c\theta - B_N^2}{c} - \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_N^2)}}{\sqrt{2}c}$, the profit of two non-green producers dominates. □

[1] These crossings can be checked to be unique by examining first order conditions for the difference of each pair of profit functions, in the interest of brevity these details are omitted.

Proof of Proposition 4 First, we will give the profit of the green producer in the mixed competitive equilibrium of green and non-green production. Let $\mathcal{R}_{GN}^{G}$ be the equilibrium profit of the green producer in the mixed green and non-green production. By Proposition 2, plugging in the equilibrium prices and CSR investments, the equilibrium profit of the green producer under mixed production is given by,

$$\mathcal{R}_{GN}^{G} = \frac{\left(2B_N^2 + 2ck - 3c\theta\right)^2 \left(2c\theta - B_G^2\right)}{8c\left(B_N^2 + \left(B_G^2 - 3c\theta\right)\right)^2}.$$

Similarly, let $\mathcal{R}_{NN}^{N}$ be the equilibrium profit of one non-green producer in purely non-green production. Following the same procedure as above, we obtain the equilibrium profit of one non-green producer under purely non-green production,

$$\mathcal{R}_{NN}^{N} = \frac{2c\theta - B_N^2}{8c}.$$

Further, let $\mathcal{R}_{GG}^{G}$ be the equilibrium profit of one green producer under purely green production. Like before, the equilibrium profit of one green producer in the purely green production is given by,

$$\mathcal{R}_{GG}^{G} = \frac{2c\theta - B_G^2}{8c}.$$

Note that $\mathcal{R}_{GG}^{G} \leq \mathcal{R}_{NN}^{N}$ since $B_G \geq B_N$.

Now, we will derive the tipping point for the two flexible producers in the competitive market. Note this tipping point is unique since when k is the small, the equilibrium profit of the green producer in the case of mixed green and non-green production is greater than the equilibrium profit of one non-green producer under purely non-green production, i.e., $\mathcal{R}_{GN}^{G} \geq \mathcal{R}_{NN}^{N}$, thus the producer under purely non-green production has the incentive to switch from non-green production to green production. On the other hand, for mixed non-green and green production, the non-green producer also has the incentive to switch from non-green to green, as the market share and profit will increase. Therefore, for k less than the tipping point, the equilibrium profit of the green producer under mixed production is greater than the profit of one non-green producer, and so the Nash equilibrium production is green and green. After the tipping point, no producer has an incentive to deviate from purely non-green production, hence the Nash equilibrium production will then be non-green and non-green. For a depiction of these dynamics see Fig. 6.

Let k_c be this tipping point. As clear from the discussion above, the tipping point k_c occurs when the profit of the green producer under production is greater than the profit of one non-green producer under purely non-green production, and thus the tipping point satisfies,

$$\mathcal{R}_{GN}^{G} = \frac{\left(2B_N^2 + 2ck_c - 3c\theta\right)^2 \left(2c\theta - B_G^2\right)}{8c\left(B_N^2 + \left(B_G^2 - 3c\theta\right)\right)^2} = \frac{2c\theta - B_N^2}{8c} = \mathcal{R}_{NN}^{N}.$$

Solving the condition above, we obtain a closed form expression for k_c,

$$k_c = \frac{3c\theta - 2B_N^2 - \left(3c\theta - B_N^2 - B_G^2\right)\sqrt{\left(2c\theta - B_N^2\right)/\left(2c\theta - B_G^2\right)}}{2c}.$$

Thus, when $k \leq \frac{3c\theta - 2B_N^2 - \sqrt{\left(3c\theta - B_N^2 - B_G^2\right)^2\left(2c\theta - B_N^2\right)/\left(2c\theta - B_G^2\right)}}{2c}$, the Nash equilibrium production is green and green, otherwise, the Nash equilibrium production is non-green and non-green. □

Proof of Theorem 2 First we will prove dominance for the resulting green market share when producers cooperate. To show the resulting market share for the green product is always higher, note that by Propositions 3 and 4, we only need to show the first tipping point in the cooperative market, k_1, is greater than the unique tipping point in the competitive market, k_c. This is because for all k such that $k \le k_c, k_1$, the green market share is 1 (i.e. only green production) in both the cooperative and competitive markets. Further, if k is greater than k_c, the green market share in the competitive market is 0 (i.e. only non-green production). Thus to prove the claim we need only show $k_1 \ge k_c$ to prove dominance. Here, in the interest of clarity (as the full proof is quite algebraically heavy), we will give only an informal proof of this fact using Taylor expansion, centered for the case $B_G - B_N$ is small, which will capture the main proof ideas. A full, formal algebraic proof can be found in `Flexible_Dominance.nb`.

To this end, combining Propositions 3 and 4, we obtain that:

$$
\begin{aligned}
k_1 - k_c &= \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_G^2)}}{\sqrt{2}c} - \frac{c\theta - B_G^2}{c} - \frac{3c\theta - 2B_N^2 - (3c\theta - B_N^2 - B_G^2)\sqrt{\frac{(2c\theta - B_N^2)}{(2c\theta - B_G^2)}}}{2c} \\
&= \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(2c\theta - 2B_G^2)}}{2c} - \frac{2c\theta - 2B_G^2}{2c} - \frac{3c\theta - 2B_N^2 - (3c\theta - B_N^2 - B_G^2)\sqrt{\frac{(2c\theta - B_N^2)}{(2c\theta - B_G^2)}}}{2c} \\
&= \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(2c\theta - 2B_G^2)} + (3c\theta - B_N^2 - B_G^2)\sqrt{\frac{(2c\theta - B_N^2)}{(2c\theta - B_G^2)}} - (5c\theta - 2B_N^2 - 2B_G^2)}{2c} \\
&= \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(2c\theta - B_G^2 - B_N^2 + B_N^2 - B_G^2)} + (3c\theta - B_N^2 - B_G^2)\sqrt{1 + \frac{(B_G^2 - B_N^2)}{(2c\theta - B_G^2)}} - (5c\theta - 2B_N^2 - 2B_G^2)}{2c} \\
&= \frac{(2c\theta - B_N^2 - B_G^2)\sqrt{1 - \frac{(B_G^2 - B_N^2)}{(2c\theta - B_N^2 - B_G^2)}} + (3c\theta - B_N^2 - B_G^2)\sqrt{1 + \frac{(B_G^2 - B_N^2)}{(2c\theta - B_G^2)}} - (5c\theta - 2B_N^2 - 2B_G^2)}{2c} \\
&= \frac{(2c\theta - B_N^2 - B_G^2)\left(\sqrt{1 - \frac{(B_G^2 - B_N^2)}{(2c\theta - B_N^2 - B_G^2)}} - 1\right) + (3c\theta - B_N^2 - B_G^2)\left(\sqrt{1 + \frac{(B_G^2 - B_N^2)}{(2c\theta - B_G^2)}} - 1\right)}{2c} \\
&= \frac{(2c\theta - B_N^2 - B_G^2)\left(1 - \frac{(B_G^2 - B_N^2)}{2(2c\theta - B_N^2 - B_G^2)} - 1\right) + (3c\theta - B_N^2 - B_G^2)\left(1 + \frac{(B_G^2 - B_N^2)}{2(2c\theta - B_G^2)} - 1\right)}{2c} + o\left((B_G^2 - B_N^2)^2\right) \\
&= \frac{-\frac{(B_G^2 - B_N^2)}{2} + \frac{(3c\theta - B_N^2 - B_G^2)(B_G^2 - B_N^2)}{2(2c\theta - B_G^2)}}{2c} + o\left((B_G^2 - B_N^2)^2\right) \\
&\ge 0.
\end{aligned}
$$

In the above, the first equality follows from plugging in the expressions for k_1 and k_c, the second through the sixth equalities follows from simplification and reorganization, the seventh equality follows from Taylor expansion, noting that the Taylor expansion of $\sqrt{1+x}$ is $\sqrt{1+x} = 1 + \frac{x}{2} + o(x^2)$, and the Taylor expansion of $\sqrt{1-x}$ is $\sqrt{1-x} = 1 - \frac{x}{2} + o(x^2)$, the eighth equality follows from simplification, and the final inequality follows from $B_G^2 - B_N^2 \ge 0$, $(3c\theta - B_N^2 - B_G^2)/(2c\theta - B_G^2) = (2c\theta - B_G^2 + c\theta - B_N^2)/(2c\theta - B_G^2) \ge 1$, and $o\left((B_G^2 - B_N^2)^2\right)$ is negligible when B_N and B_G are close to each other. Thus, when the parameters satisfy $B_N^2 \le c\theta$ and $B_G^2 \le c\theta$, the resulting market share of the green product is always higher when flexible producers cooperate than when they compete.

Next, we will prove dominance for the total CSR investment when producers cooperate. We will follow a similar path as for green market share. Recall in Propositions 1 and 2 that the total CSR investment of purely green production in the cooperative market is the same as the equilibrium total CSR investment in the competitive market, i.e.,

$$S_G := \frac{B_G}{c}.$$

Similarly, the total CSR investment of purely non-green production in the cooperative market is the same as the equilibrium total CSR investment in the competitive market, i.e.,

$$S_N := \frac{B_N}{c}.$$

Finally, the total CSR investment of mixed green and non-green production in the cooperative market is

$$S_{NG} := \frac{B_N\left(c(k+\theta) - B_G^2\right)}{c(2c\theta - B_N^2 - B_G^2)} + \frac{B_G\left(c(k+\theta) - B_N^2\right)}{c(2c\theta - B_N^2 - B_G^2)},$$

which is larger than the purely non-green total CSR investment before switching. Thus by the dominance of tipping point (i.e. $k_1 \geq k_c$) established above, the total CSR investment of flexible producers in the cooperative market is always higher than the equilibrium total CSR investment in the competitive market.

□

A.3. Omitted Proofs from Section 5

For this section, the relevant Mathematica codes where the computations are conducted are `Balanced_Monopoly.nb` (Proposition 5), `Balanced_Competitive.nb` (Proposition 6), and `Flexible_General.nb` (Theorem 4).

Proof of Proposition 5 Since all segments between two producers are symmetric by assumption, we will analyze the optimal policy and profit of a non-green and green producers in one segment, then to get the total market share and CSR investment we simply multiply by $2n$. Now let x^* be the indifference point between the non-green producer and green producer in one segment, as depicted in Fig. 7. As in the Proposition 1, since the customer at x^* is indifferent between the nearest non-green and green product and since the producers are non-competitive (and can always raise the price) the utility at the indifferent point is zero. Thus:

$$U_N(x^*) = v + B_N s_N - \theta x^* - p_N = U_G(x^*) = v + B_G s_G - \theta\left(\frac{1}{2n} - x^*\right) - p_G = 0.$$

Solving the equation above, we get equations for the indifference point and the price of the green product in terms of p_N, s_N, and s_G:

$$x^* = \frac{v + B_N s_N - p_N}{\theta}, \quad p_G = 2v + B_N s_N + B_G s_G - p_N - \frac{\theta}{2n}.$$

Now, each producer is part of two market segments, the market share of one non-green producer is $2x^*$, and the market share of one green producer is $2\left(\frac{1}{2n} - x^*\right)$. Therefore, the total profit of the non-competitive green and non-green producers is:

$$\mathcal{R}\left(p_G, s_G, p_N, s_N\right) := \sum_{i=1}^{2n} \mathcal{R}_i\left(p_i, s_i\right)$$

$$
\begin{aligned}
&= n\left(2x^* p_N - \frac{cs_N^2}{2} + 2\left(\frac{1}{2n} - x^*\right)(p_G - k) - \frac{cs_G^2}{2}\right) \\
&= n\left(2\left(\frac{1}{2n} - \frac{v + B_N s_N - p_N}{\theta}\right)\left(2v + B_N s_N + B_G s_G - p_N - \frac{\theta}{2n} - k\right) - \frac{cs_G^2}{2}\right) \\
&\quad + n\left(\frac{2(v + B_N s_N - p_N)p_N}{\theta} - \frac{cs_N^2}{2}\right).
\end{aligned} \tag{EC.2}
$$

To maximize total profit, we check the first-order conditions for the three remaining independent variables:

$$
\begin{aligned}
\frac{\partial \mathcal{R}(p_G, s_G, p_N, s_N)}{\partial s_N} &= n\left(\frac{2B_N(k + 3p_N - B_G s_G + \theta - 3v) - 4B_N^2 s_N}{\theta} - cs_N\right) = 0 \\
\frac{\partial \mathcal{R}(p_G, s_G, p_N, s_N)}{\partial s_G} &= n\left(B_G\left(\frac{1}{n} - \frac{2(v + B_N s_N - p_N)}{\theta}\right) - cs_G\right) = 0 \\
\frac{\partial \mathcal{R}(p_G, s_G, p_N, s_N)}{\partial p_N} &= n\left(-\frac{2(kn + \theta + n(4p_N - 3B_N s_N - B_G s_G - 4v))}{n\theta}\right) = 0.
\end{aligned}
$$

Solving the system of first-order conditions, we get the profit-maximizing price and investment for the green and non-green product:

$$
\begin{aligned}
p_N &= v - \frac{(2B_N^2 - c\theta)(c(\theta + kn) - B_G^2)}{2cn(2c\theta - B_N^2 - B_G^2)}, \quad p_G = v - \frac{(2B_G^2 - c\theta)(c(\theta - kn) - B_N^2)}{2cn(2c\theta - B_N^2 - B_G^2)}, \\
s_N &= \frac{B_N(c(\theta + kn) - B_G^2)}{cn(2c\theta - B_N^2 - B_G^2)}, \quad s_G = \frac{B_G(cn(\theta - kn) - B_N^2)}{c(2c\theta - B_N^2 - B_G^2)}.
\end{aligned}
$$

Plugging back into our equation for the indifference point and multiplying by $2n$, the total market share for the green and non-green products under profit-maximizing price and investment will be:

$$
\mathcal{M}_N = \frac{c(\theta + kn) - B_G^2}{2c\theta - B_N^2 - B_G^2}, \quad \mathcal{M}_G = \frac{c(\theta - kn) - B_N^2}{2c\theta - B_N^2 - B_G^2}.
$$

Note that both $\mathcal{M}_N$ and $\mathcal{M}_G$ are positive due to the condition $B_N^2 \le c(\theta - kn)$ and $B_G^2 \le c(\theta + kn)$ and thus represents an interior solution for the marketplace. For more discussion of the feasible region when producers cooperate, please see Section B.1.

□

Proof of Proposition 6 Again by symmetry, we will analyze one segment of the circle and at the end multiply by $2n$ to get the total green market share and CSR investment. Again, let x^* be the indifference point of non-green product in one segment. By definition, the customer at x^* is indifferent between green and non-green product, i.e.:

$$
U_N(x^*) = v + B_N s_N - \theta x^* - p_N = U_G(x^*) = v + B_G s_G - \theta\left(\frac{1}{2n} - x^*\right) - p_G.
$$

Note as in Proposition 2, we no longer assume the customer utility at the indifference point is equal to 0 since the producers are in competition. Solving the equation above, we get the indifference point in one segment is:

$$
x^* = \frac{1}{4n} + \frac{(B_N s_N - p_N) - (B_G s_G - p_G)}{2\theta}.
$$

As in Proposition 5, each producer is part of two market segments and thus the market share of one non-green producer is $2x^*$, and the market share of one green producer is $2\left(\frac{1}{2n} - x^*\right)$. Therefore, the profit of one non-green producer and one green producer is:

$$
\begin{aligned}
\mathcal{R}_N(p_N, s_N) &= 2x^* p_N - \frac{cs_N^2}{2} = \left(\frac{1}{2n} + \frac{(B_N s_N - p_N) - (B_G s_G - p_G)}{\theta}\right) p_N - \frac{cs_N^2}{2}, \\
\mathcal{R}_G(p_G, s_G) &= 2\left(\frac{1}{2n} - x^*\right)(p_G - k) - \frac{cs_G^2}{2} = \left(\frac{1}{2n} + \frac{(B_G s_G - p_G) - (B_N s_N - p_N)}{\theta}\right) p_G - \frac{cs_G^2}{2}.
\end{aligned}
$$

Now we will solve for the Nash equilibrium price and CSR investment by solving the linear system of first-order conditions:

$$\begin{aligned}
\frac{\partial \mathcal{R}_N(p_N, s_N)}{\partial s_N} &= \frac{B_N p_N}{\theta} - c s_N = 0, \\
\frac{\partial \mathcal{R}_G(p_G, s_G)}{\partial s_G} &= \frac{B_G p_G}{\theta} - c s_G = 0, \\
\frac{\partial \mathcal{R}_N(p_N, s_N)}{\partial p_N} &= \frac{1}{2n} + \frac{(B_N s_N - 2p_N) - (B_G s_G - p_G)}{\theta} = 0, \\
\frac{\partial \mathcal{R}_G(p_G, s_G)}{\partial p_G} &= \frac{1}{2n} + \frac{(B_G s_G - 2p_G) - (B_N s_N - p_N)}{\theta} = 0.
\end{aligned}$$

Solving the linear system of first-order conditions, we obtain the equilibrium price and investment for the green and non-green producers as:

$$\begin{aligned}
p_N &= \frac{\theta\left(c(1.5\theta + kn) - B_G^2\right)}{n\left(3c\theta - B_N^2 - B_G^2\right)}, \quad p_G = \frac{c\theta(2kn + 1.5\theta) - B_G^2 kn - B_N^2(kn + \theta)}{n\left(3c\theta - B_N^2 - B_G^2\right)}, \\
s_N &= \frac{B_N\left(c(1.5\theta + kn) - B_G^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)}, \quad s_G = \frac{B_G\left(c(1.5\theta - kn) - B_N^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)}.
\end{aligned}$$

Plugging back into our initial equation for the indifference point and multiplying by n, the competitive market share for the green and non-green producer under equilibrium price and investment will be

$$\mathcal{M}_N = \frac{c(1.5\theta + kn) - B_G^2}{3c\theta - B_N^2 - B_G^2}, \quad \mathcal{M}_G = \frac{c(1.5\theta - kn) - B_N^2}{3c\theta - B_N^2 - B_G^2}.$$

Note that both $\mathcal{M}_N$ and $\mathcal{M}_G$ are positive due to the condition $B_N^2 \leq c(1.5\theta - kn)$ and $B_G^2 \leq c(1.5\theta + kn)$ and thus represents an interior solution for the marketplace. For more discussion of the feasible region when producers compete, please see Section B.2.

□

Proof of Theorem 3 From Propositions 5 and 6 we have closed-form expressions for the total green market share and total CSR investment in both cooperative and competitive markets. As a function of the cost of green production, the total green market share and CSR investment can be written as:

$$\begin{aligned}
\mathcal{M}_G^M(k) &= \frac{c(\theta - kn) - B_N^2}{2c\theta - B_N^2 - B_G^2}, \\
\mathcal{M}_G^D(k) &= \frac{c(1.5\theta - kn) - B_N^2}{3c\theta - B_N^2 - B_G^2}, \\
S^M(k) &= \frac{B_N\left(c(\theta + kn) - B_G^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)} + \frac{B_G\left(c(\theta - kn) - B_N^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)}, \\
S^D(k) &= \frac{B_N\left(c(1.5\theta + kn) - B_G^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)} + \frac{B_G\left(c(1.5\theta - kn) - B_N^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)}.
\end{aligned}$$

where recall, the superscript M and D denotes the cooperative and competitive solutions, respectively. In the following parts, we will compare these functions as k varies.

Part a) First when $k = 0$, the green market share when the market is cooperative is:

$$\begin{aligned}
\mathcal{M}_G^M(0) &= \frac{c\theta - B_N^2}{2c\theta - B_N^2 - B_G^2} \\
&= \frac{c\theta - 0.5B_N^2 - 0.5B_G^2 - 0.5B_N^2 + 0.5B_G^2}{2c\theta - B_N^2 - B_G^2} \\
&= \frac{1}{2} + \frac{0.5\left(B_G^2 - B_N^2\right)}{2c\theta - B_N^2 - B_G^2}.
\end{aligned}$$

While the green market share under competition is:

$$\begin{aligned}\mathcal{M}_G^D(0) &= \frac{1.5c\theta - B_N^2}{3c\theta - B_N^2 - B_G^2} \\ &= \frac{1.5c\theta - 0.5B_N^2 - 0.5B_G^2 - 0.5B_N^2 + 0.5B_G^2}{3c\theta - B_N^2 - B_G^2} \\ &= \frac{1}{2} + \frac{0.5\left(B_G^2 - B_N^2\right)}{3c\theta - B_N^2 - B_G^2}.\end{aligned}$$

Therefore:

$$\mathcal{M}_G^M(0) - \mathcal{M}_G^D(0) = \frac{0.5\left(B_G^2 - B_N^2\right)}{2c\theta - B_N^2 - B_G^2} - \frac{0.5\left(B_G^2 - B_N^2\right)}{3c\theta - B_N^2 - B_G^2} \geq 0,$$

where the inequality follows from the fact that $B_G^2 - B_N^2 \geq 0$ by assumption, and $3c\theta - B_N^2 - B_G^2 \geq 2c\theta - B_N^2 - B_G^2 > 0$, by the conditions in Propositions 5 and 6.

Now we will take the derivative of the green market share with respect to k:

$$\begin{aligned}\frac{\partial \mathcal{M}_G^M(k)}{\partial k} &= \frac{-cn}{2c\theta - B_N^2 - B_G^2}, \\ \frac{\partial \mathcal{M}_G^D(k)}{\partial k} &= \frac{-cn}{3c\theta - B_N^2 - B_G^2}.\end{aligned}$$

Again we have $3c\theta - B_N^2 - B_G^2 \geq 2c\theta - B_N^2 - B_G^2 > 0$ by the conditions in Propositions 5 and 6, thus we conclude that:

$$\frac{\partial \mathcal{M}_G^M(k)}{\partial k} \leq \frac{\partial \mathcal{M}_G^D(k)}{\partial k} < 0.$$

Part b) Similarly when $k = 0$, the total CSR investment when the market is cooperative is:

$$\begin{aligned}S^M(0) &= \frac{B_N\left(c(\theta+0) - B_G^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)} + \frac{B_G\left(c(\theta-0) - B_N^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)} \\ &= \frac{B_N\left(c\theta - 0.5B_N^2 - 0.5B_G^2 - 0.5B_G^2 + 0.5B_N^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)} + \frac{B_G\left(c\theta - 0.5B_N^2 - 0.5B_G^2 - 0.5B_N^2 + 0.5B_G^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)} \\ &= B_N\left(\frac{1}{2cn} - \frac{0.5B_G^2 - 0.5B_N^2}{cn\left(2c\theta - B_N^2 - B_G^2\right)}\right) + B_G\left(\frac{1}{2cn} + \frac{0.5B_G^2 - 0.5B_N^2}{cn\left(2c\theta - B_N^2 - B_G^2\right)}\right) \\ &= \frac{B_N + B_G}{2cn} + \frac{0.5\left(B_G - B_N\right)\left(B_G^2 - B_N^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)},\end{aligned}$$

where the final equality follows from the fact that $-B_N\left(\frac{0.5B_G^2 - 0.5B_N^2}{cn\left(2c\theta - B_N^2 - B_G^2\right)}\right) + B_G\left(\frac{0.5B_G^2 - 0.5B_N^2}{cn\left(2c\theta - B_N^2 - B_G^2\right)}\right) = \frac{0.5\left(B_G - B_N\right)\left(B_G^2 - B_N^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)}$. Similarly, when $k = 0$, the total CSR investment under competition is:

$$\begin{aligned}S^D(0) &= \frac{B_N\left(c(1.5\theta+0) - B_G^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)} + \frac{B_G\left(c(1.5\theta-0) - B_N^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)} \\ &= \frac{B_N + B_G}{2cn} + \frac{0.5\left(B_G - B_N\right)\left(B_G^2 - B_N^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)}.\end{aligned}$$

Therefore:

$$S^M(0) - S^D(0) = \frac{0.5\left(B_G - B_N\right)\left(B_G^2 - B_N^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)} - \frac{0.5\left(B_G - B_N\right)\left(B_G^2 - B_N^2\right)}{cn\left(3c\theta - B_N^2 - B_G^2\right)} \geq 0,$$

where the inequality follows from $B_G - B_N \geq 0$ and $3c\theta - B_N^2 - B_G^2 \geq 2c\theta - B_N^2 - B_G^2 \geq 0$.

The derivatives of $S^M(k)$ and $S^D(k)$ with respect to k are:

$$\frac{\partial S^M(k)}{\partial k} = \frac{cnB_N}{c\,(2c\theta - B_N^2 - B_G^2)} - \frac{cnB_G}{c\,(2c\theta - B_N^2 - B_G^2)} = \frac{-cn(B_G - B_N)}{c\,(2c\theta - B_N^2 + B_G^2)},$$

$$\frac{\partial S^D(k)}{\partial k} = \frac{cnB_N}{c\,(3c\theta - B_N^2 - B_G^2)} - \frac{cnB_G}{c\,(3c\theta - B_N^2 - B_G^2)} = \frac{-cn(B_G - B_N)}{c\,(3c\theta - B_N^2 + B_G^2)}.$$

Thus, by the condition of Proposition 5 and Proposition 6, $3c\theta - B_N^2 - B_G^2 \geq 2c\theta - B_N^2 - B_G^2 \geq 0$, we obtain:

$$\frac{\partial S^M(k)}{\partial k} \leq \frac{\partial S^D(k)}{\partial k} < 0.$$

Part c) If the condition of Proposition 5 is satisfied while the condition of Proposition 6 is not, i.e., $B_N^2 + B_G^2 - 3c\theta < 0 \leq B_N^2 + B_G^2 - 2c\theta$, we will get a corner solution for the cooperative case, namely, $\mathcal{M}_G^M = 0$. However, the green market share for the competitive case is still positive, $\mathcal{M}_G^D = \frac{c(1.5\theta - kn) - B_N^2}{3c\theta - B_N^2 - B_G^2} > 0$. For more details see Section B.

Part d) By Proposition 5, when the producers cooperate and the market parameters satisfy the conditions, the total green market share for some fixed k, B_N, B_G, θ and c is:

$$\mathcal{M}_G^M(k) = \frac{1}{2} + \frac{B_G^2 - B_N^2}{2\,(2c\theta - B_N^2 - B_G^2)} - \frac{kn}{2c\theta - B_N^2 - B_G^2}.$$

When B_N and B_G satisfy the conditions of Proposition 5, they ensure that last term above is negative, and thus $\mathcal{M}_G^M(k)$ is decreasing in n, and when n is large enough $\mathcal{M}_G^M(k)$ will be 0.

Now, for the competitive market, when the parameters satisfy the condition in Proposition 6, the total green market share is,

$$\mathcal{M}_G^D(k) = \frac{c(1.5\theta - kn) - B_N^2}{3c\theta - B_N^2 - B_G^2},$$

which is decreasing in n. When n goes to infinity, the condition of Proposition 6 that $B_N^2 \leq c(1.5\theta - kn)$ will be violated as long as $k > 0$. From Section B, we know this violation results in a market of purely non-green producers. □

Proof of Theorem 4 We will prove the two parts of Theorem 4 separately. First, for part a), we will prove an analog of Theorem 2. Then, combining the dominance result in part a) and Theorem 3, we show the green market share is non-increasing as the number of producers increases.

Part a) To prove an analog of Theorem 2, first will characterize the tipping points for balanced, flexible producers in cooperation/competition. Then we will show dominance of the tipping points which will imply dominance of the green market share and total CSR investment.

To that end, first we will give the optimal profit functions for cooperative markets of balanced green and non-green production, purely green production, and purely non-green production, parameterized by the cost of green production k. Let $\mathcal{R}_{GN}(p_G, s_G, p_N, s_N)$ be the *total* profit for $2n$ balanced, flexible, cooperating producers who opt for a mixed policy of green and non-green production, using prices and CSR investment p_G, s_G, p_N, and s_N. According to Proposition 5, the optimal total profit of $2n$ balanced, flexible producers can be obtained by plugging in the optimal prices and CSR investment, which, suppressing the computation of these prices and investment levels, is given by,

$$\mathcal{R}_{GN}(k) := \max_{p_G, s_G, p_N, s_N} \mathcal{R}_{GN}(p_G, s_G, p_N, s_N) = v - \frac{\theta}{2n} - \frac{c^2(kn-\theta)^2 - B_N^2(B_G^2 - 2ckn)}{2cn(B_N^2 + B_G^2 - 2c\theta)}.$$

Let $\mathcal{R}_{GG}(p_G, s_G)$ be the total profit of purely green production. By the same type of calculation, the optimal total profit of purely green production is given by,

$$\mathcal{R}_{GG}(k) := \max_{p_G, s_G} \mathcal{R}_{GG}(p_G, s_G) = v - \frac{\theta}{4n} - k + \frac{B_G^2}{4cn}.$$

In this proof, we focus on the first tipping point in the balanced, flexible cooperative market, which we denote by k_1. Following the same type of calculation in Proposition 3, we obtain the closed expression for k_1,

$$k_1 = \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)\,(c\theta - B_G^2)}}{\sqrt{2}cn} - \frac{c\theta - B_G^2}{cn}.$$

Now to obtain the balanced, flexible tipping point in the competitive case we will give the profit of the green producer in the mixed competitive equilibrium of green and non-green production, denoted $\mathcal{R}_{GN}^G$. Plugging the equilibrium solution in from Proposition 6, the equilibrium profit of the green producer under balanced mixed production is given by,

$$\mathcal{R}_{GN}^G = \frac{\left(2B_N^2 + 2ckn - 3c\theta\right)^2 (2c\theta - B_G^2)}{8cn^2\left(B_N^2 + B_G^2 - 3c\theta\right)^2}.$$

Let $\mathcal{R}_{NN}^N$ be the equilibrium profit of one green producer under purely green production. Like before, the equilibrium profit of one non-green producer in the purely non-green production equilibria is given by,

$$\mathcal{R}_{NN}^N = \frac{2c\theta - B_N^2}{8cn^2}.$$

Now solving the condition in a similar manner as in Proposition 4, the unique tipping point in the balanced, flexible, competitive market is,

$$k_c = \frac{3c\theta - 2B_N^2 - \sqrt{\left(3c\theta - B_N^2 - B_G^2\right)^2 (2c\theta - B_N^2)\,/\,(2c\theta - B_G^2)}}{2cn}.$$

Note, both k_1 and k_c depend linearly $\frac{1}{n}$, but otherwise are the same as before. Thus, the dominance of tipping points in Theorem 2 directly implies the dominance of tipping points for multiple balanced, flexible producers. Moreover, by the same analysis, the resulting green market share is always higher when balanced, flexible cooperate versus when they compete.

Finally, note by Propositions 5 and 6, the total CSR investment of purely green production in the balanced cooperative market is the same as the equilibrium total CSR investment in the balanced competitive market, which is,

$$S_G := \frac{B_G}{cn}.$$

Similarly, the total CSR investment of purely non-green production in the balanced cooperative market is the same as the equilibrium total CSR investment in the balanced competitive market, which is,

$$S_N := \frac{B_N}{cn}.$$

Further, the total CSR investment of mixed green and non-green production in the balanced cooperative market is,

$$S_{NG} := \frac{B_N\left(c(kn+\theta) - B_G^2\right)}{cn(2c\theta - B_N^2 - B_G^2)} + \frac{B_G\left(c(kn+\theta) - B_N^2\right)}{cn(2c\theta - B_N^2 - B_G^2)},$$

which is larger than the purely non-green total CSR investment before switching. By the dominance of the tipping point (i.e. $k_1 \geq k_c$), the total CSR investment of balanced, flexible producers in the cooperative market is always higher than the equilibrium total CSR investment in the competitive market.

Part b) Note that the second tipping point in cooperative market is,

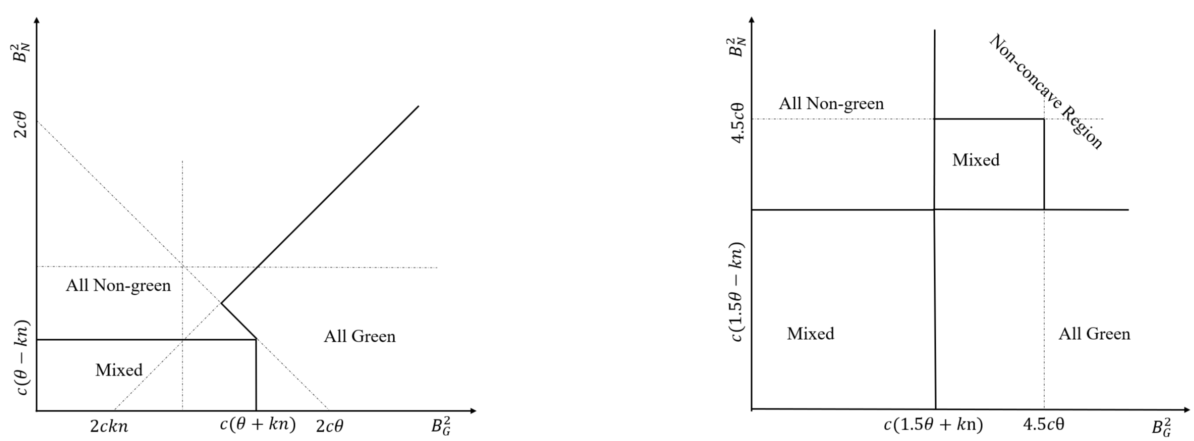
$$k_2 = \frac{c\theta - B_N^2}{cn} - \frac{\sqrt{(2c\theta - B_N^2 - B_G^2)(c\theta - B_N^2)}}{\sqrt{2}cn}.$$

Thus we see all tipping points decrease in n, the number of producers on the Salop's circle. First, we consider the cooperative market, for any given $k > 0$, when k is less than the first tipping point k_1, the green market share is 1. As n increases, k_1 goes 0, then k will be less than k_1, but still larger than k_2, then as stated in Theorem 3, the green market share will decrease as the number of producers increases. Finally, when $k \le k_2$, the green market share will be 0. Similarly in the competitive market, as n increases, the tipping point decreases to 0. For any given k, when $k \le k_c$, the green market share is 1, when $k > k_c$, the green market share is 0. Therefore, the green market share is non-increasing as n increases in both cooperative and competitive market. □

Appendix B: Feasible Region for Models Studied

In this section, we characterize the parameter regions in the optimized market where either only a green product is sold, only a non-green product, or there is a mix of the two products. As emphasized in Section 3, we are particularly interested in conditions that guarantee the production of both green and non-green products, as these parameter ranges represent markets where these products compete for market share and thus can be tipped one way or the other. In particular, we will focus on the balanced case when there are $2n$ producers as presented in Section 5 as it generalizes the model in Section 3. In Section B.1 we will describe the feasible space for the cooperative balanced market. In Section B.2 we will describe the feasible space in the competitive market.

Figure EC.1 Feasible region for cooperative and competitive balanced market.



Note. Depicted is the feasible region for the balanced cooperative (left) and competitive (right) market with $2n$ producers, under the assumptions described in Section 5. In the both figures the x-axis is B_G^2 and y-axis is B_N^2. The dashed lines are the conditions for cases. 1 Non-green (Green) means there is only one non-green (green) producer in the resulting market. Mixed means a mixture of green and non-green products are sold in the resulting market. In the rightmost figure, the Non-concave region corresponds to boundary solutions where either only a green product or only a non-green product is sold, but the boundary between those two cases is complicated.

B.1. Feasible Space for the Cooperative Balanced Market

In this subsection we analyze the profit function derived in the proof of Proposition 5, and examine when the optimal profit comes from a market with a mix of sold products or else when it is dominated by solely the green or non-green.

First, recall the total optimal profit for $2n$ balanced cooperative green and non-green producers from Eq. (EC.2) is:

$$\begin{aligned}\mathcal{R}(p_G,s_G,p_N,s_N) &= n\left(2x^*p_N - \frac{cs_N^2}{2} + 2\left(\frac{1}{2n} - x^*\right)(p_G - k) - \frac{cs_G^2}{2}\right)\\ &= n\left(2\left(\frac{1}{2n} - \frac{v + B_N s_N - p_N}{\theta}\right)\left(2v + B_N s_N + B_G s_G - p_N - \frac{\theta}{2n} - k\right) - \frac{cs_G^2}{2}\right)\\ &\quad + n\left(\frac{2(v + B_N s_N - p_N)p_N}{\theta} - \frac{cs_N^2}{2}\right).\end{aligned}$$

To maximize total profit, we check the first order condition for p_N:

$$\frac{\partial \mathcal{R}(p_G,s_G,p_N,s_N)}{\partial p_N} = n\left(-\frac{2\left(kn + \theta + n\left(4p_N - 3B_N s_N - B_G s_G - 4v\right)\right)}{n\theta}\right) = 0.$$

Solving the first order condition for p_N, we obtain the profit-maximizing price p_N in terms of s_N and s_G:

$$p_N = v + \frac{3nB_N s_N + nB_G s_G - kn - \theta}{4n}.$$

Plugging in the total profit can be written and simplified as:

$$\begin{aligned}\mathcal{R}(p_G,s_G,p_N,s_N) &= n\left(\left(\frac{B_N^2}{2\theta} - c\right)\left(\frac{s_N^2}{2}\right) + \left(\frac{B_G^2}{2\theta} - c\right)\left(\frac{s_G^2}{2}\right) - \left(\frac{B_N B_G}{2\theta}\right)(s_N s_G) + \frac{k^2}{\theta}\right)\\ &\quad + \frac{2kn\left(nB_N s_N - nB_G s_G - \theta\right)}{4n\theta} + \frac{\theta\left(2nB_N s_N + 2nB_G s_G - \theta + 4nv\right)}{4n\theta}.\end{aligned}$$

Now to maximize the total profit as a function of s_N and s_G, we need to check the Hessian matrix of the profit function, which is:

$$\mathcal{H} = n\begin{bmatrix} \frac{B_N^2}{2\theta} - c & -\frac{B_N B_G}{2\theta} \\ -\frac{B_N B_G}{2\theta} & \frac{B_G^2}{2\theta} - c \end{bmatrix}.$$

The total profit function is concave if and only if this Hessian matrix is negative semi-definite. Note that a symmetric matrix is positive definite if and only if its leading principal minors are positive. Therefore, the Hessian matrix $\mathcal{H}$ is negative semi-definite if and only if:

$$c - \frac{B_N^2}{2\theta} \geq 0, \quad c - \frac{B_G^2}{2\theta} \geq 0, \quad \text{and } \left(\frac{B_N^2}{2\theta} - c\right)\left(\frac{B_G^2}{2\theta} - c\right) - \left(\frac{B_N B_G}{2\theta}\right)^2 \geq 0.$$

Simplifying the above inequalities, we obtain the condition for the total profit function to be concave is:

$$B_N^2 + B_G^2 \leq 2c\theta.$$

If the condition $B_N^2 + B_G^2 \leq 2c\theta$ is violated, we will get a boundary solution, i.e., a solution resulting in purely non-green market share or purely green market share, depending on which one will give the producers a higher profit.

Suppose the condition $B_N^2 + B_G^2 \leq 2c\theta$ is satisfied, solving the system of first-order conditions for the total profit, we get the profit-maximizing price and investment for the green and non-green product:

$$p_N = v - \frac{(2B_N^2 - c\theta)\left(c(\theta+kn) - B_G^2\right)}{2cn\left(2c\theta - B_N^2 - B_G^2\right)}, \quad p_G = v - \frac{(2B_G^2 - c\theta)\left(c(\theta-kn) - B_N^2\right)}{2cn\left(2c\theta - B_N^2 - B_G^2\right)},$$
$$s_N = \frac{B_N\left(c(\theta+kn) - B_G^2\right)}{cn\left(2c\theta - B_N^2 - B_G^2\right)}, \quad s_G = \frac{B_G\left(cn(\theta-kn) - B_N^2\right)}{c\left(2c\theta - B_N^2 - B_G^2\right)}.$$

Plugging back into our equation for the indifference point Eq. (EC.1) and multiplying by $2n$, the total market share for the green and non-green products under profit-maximizing price and investment will be:

$$\mathcal{M}_N = \frac{c(\theta+kn) - B_G^2}{2c\theta - B_N^2 - B_G^2}, \quad \mathcal{M}_G = \frac{c(\theta-kn) - B_N^2}{2c\theta - B_N^2 - B_G^2}.$$

Note that by definition, the market share of non-green and green producers should be non-negative (i.e., an interior solution), which as noted in the proof of Proposition 6 requires $B_N^2 \leq c(\theta - kn)$ and $B_G^2 \leq c(\theta + kn)$. If $B_N^2 \geq c(\theta - kn)$ and $B_G^2 \leq c(\theta + kn)$, the market share of the green producer $\mathcal{M}_G$ will be 0 and vice versa. Thus the square in the bottom left corner of Fig. EC.1 represents these conditions and, in turn, the region of interior (i.e. mixed) solutions.

Now, if $B_N^2 + B_G^2 \geq 2c\theta$, the total profit function will be convex, and thus will be maximized for purely green or pure non-green producers. Suppose all producers are green, and let x^* be the indifference point between two green producers in one segment as in Fig. 7. Since all the green producers are going to use the same price and CSR investment, the indifference point will be $x^* = \frac{1}{2n}$. As noted in the proof of Proposition 6, in the cooperative market the producers can always raise the price such that the utility at the indifference point is zero. Thus:

$$U_G(x^*) = v + B_G s_G - \theta x^* - p_G = 0.$$

Solving the equation above, we obtain the expression for the price of the green product in terms of s_G:

$$p_G = v + B_G s_G - \frac{\theta}{2n}.$$

Therefore, the total profit of all the green producers is:

$$\mathcal{R}_G(p_G, s_G) = n\left(2x^*(p_G - k) - \frac{cs_G^2}{2}\right).$$

Solving the first-order condition of the total profit function, we obtain the profit-maximizing price and CSR investment:

$$p_G = v + \frac{B_G^2}{cn} - \frac{\theta}{2n}, \quad s_G = \frac{B_G}{cn}.$$

The maximized total profit is:

$$\mathcal{R}_G(p_G, s_G) = v - k + \frac{B_G^2 - c\theta}{2cn}.$$

Similarly, if the producers are all non-green, the profit-maximizing price and CSR investment will be:

$$p_N = v + \frac{B_N^2}{cn} - \frac{\theta}{2n}, \quad s_N = \frac{B_N}{cn}.$$

The corresponding maximized total profit is:

$$\mathcal{R}_N(p_N, s_N) = v + \frac{B_N^2 - c\theta}{2cn}.$$

Therefore, when $B_N^2 + B_G^2 \geq 2c\theta$, the green producer dominates if $\mathcal{R}_G(p_G, s_G) - \mathcal{R}_N(p_N, s_N) \geq 0$, i.e.,

$$v - k + \frac{B_G^2 - c\theta}{2cn} \geq v + \frac{B_N^2 - c\theta}{2cn},$$

which is equivalent to $B_G^2 - B_N^2 \geq 2ckn$. Otherwise, the non-green producer dominates. The above two cases covers the convex region of the cooperative market in Fig. EC.1 left panel.

B.2. Feasible Space for the Competitive Balanced Market

In this subsection, we analyze the profit functions derived in the proof of Proposition 6 and examine when the equilibrium profit comes from a market with a mix of sold products or when it is dominated by solely the green or non-green.

Recall from the proof of Proposition 6, the resulting profits of the non-green producer and the green producer in the competitive market are:

$$\mathcal{R}_N(p_N, s_N) = 2xp_N - \frac{cs_N^2}{2} = \left(\frac{1}{2n} + \frac{(B_N s_N - p_N) - (B_G s_G - p_G)}{\theta}\right) p_N - \frac{cs_N^2}{2},$$
$$\mathcal{R}_G(p_G, s_G) = 2\left(\frac{1}{2n} - x\right)(p_G - k) - \frac{cs_G^2}{2} = \left(\frac{1}{2n} + \frac{(B_G s_G - p_G) - (B_N s_N - p_N)}{\theta}\right) p_G - \frac{cs_G^2}{2}.$$

Notice that the second-order derivative of the non-green and green profit with respect to p_G (p_N) is always negative, i.e.:

$$\frac{\partial^2 \mathcal{R}_N(p_G, s_G, p_N, s_N)}{\partial p_N^2} = \frac{\partial^2 \mathcal{R}_G(p_G, s_G)}{\partial p_G^2} = -\frac{2}{\theta} < 0.$$

Thus the profit functions are always concave with respect to p_G (p_N). To maximize the profit, both p_N and p_G should satisfy the first-order optimality condition, namely:

$$\frac{\partial \mathcal{R}_N(p_N, s_N)}{\partial p_N} = \frac{1}{2n} + \frac{(B_N s_N - 2p_N) - (B_G s_G - p_G)}{\theta} = 0,$$
$$\frac{\partial \mathcal{R}_G(p_G, s_G)}{\partial p_G} = \frac{1}{2n} + \frac{(B_G s_G - 2p_G) - (B_N s_N - p_N)}{\theta} = 0.$$

Solving the first order condition of p_N and p_G, the optimal price p_G and p_G in terms of s_N and s_G are:

$$p_N = \frac{2kn + 2nB_N s_N - 2nB_G s_G + 3\theta}{6n},$$
$$p_G = \frac{4kn - 2nB_N s_N + 2nB_G s_G + 3\theta}{6n}.$$

Further, the market share of the non-green and green producers in terms of s_N and s_G are:

$$x^* = \frac{2kn + 2nB_N s_N - 2nB_G s_G + 3\theta}{12n\theta},$$
$$\frac{1}{2n} - x = \frac{-2kn - 2nB_N s_N + 2nB_G s_G + 3\theta}{12n\theta}.$$

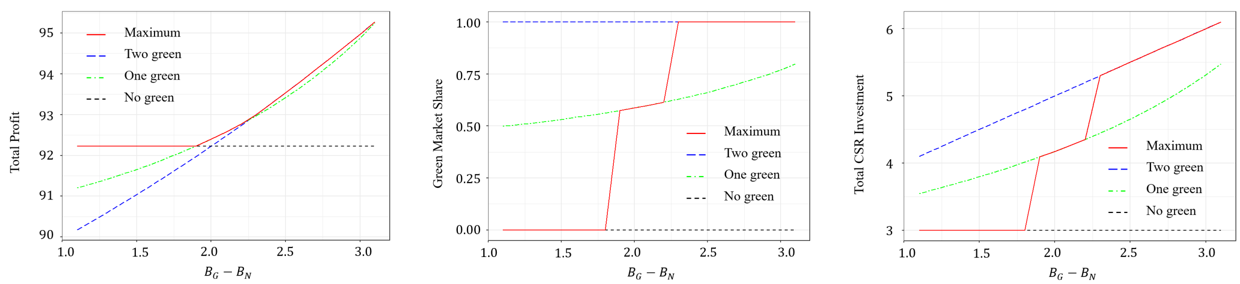
Then, we can calculate the second-order derivative of the profit for the non-green producer and green producer with respect to s_N and s_G, which are:

$$\frac{\partial^2 \mathcal{R}_N(p_N, s_N)}{\partial s_N^2} = -c + \frac{2B_N^2}{9\theta}$$
$$\frac{\partial^2 \mathcal{R}_G(p_G, s_G)}{\partial s_G^2} = -c + \frac{2B_G^2}{9\theta}$$

Thus, when $B_N^2 \leq 4.5c\theta$ and $B_G^2 \leq 4.5c\theta$, both the profit of non-green producer and green producer are concave. We can find the Nash Equilibrium of CSR investment s_N and s_G by looking at the first-order condition of s_N and s_G, which corresponds to the dotted square in the right panel of Fig. EC.1. However, when $B_N^2 > 4.5c\theta$, or $B_G^2 > 4.5c\theta$, the profit function will not be concave. We have to check the boundary condition to find the equilibrium CSR investment. In this paper, we focus on the concave region.

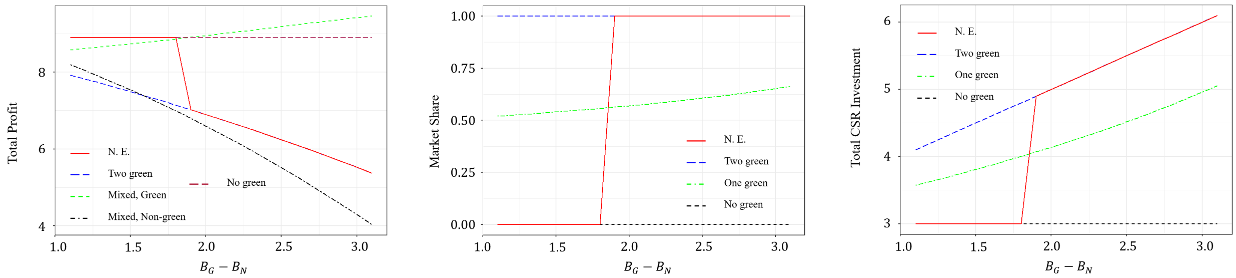
Appendix C: Omitted Figures

Figure EC.2 Flexible cooperative market composition as $B_G - B_N$ varies.



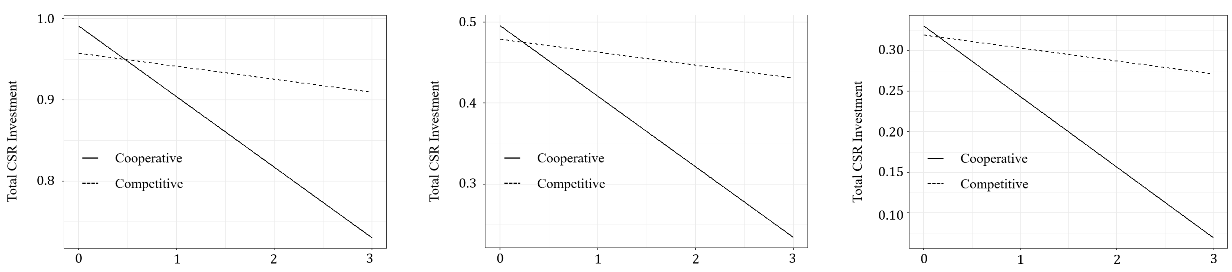
Note. Consider a market with two cooperating producers who can flexibly produce either the green or non-green product, with market parameters $v = 100$, $c = 1$, $\theta = 40.1$, $B_N = 3$, $k = 4$. Depicted is the change in profit (left), green market share (center), and total CSR investment (right) in the market as the effectiveness of green CSR investment, B_G, varies from 4 to 6.

Figure EC.3 Flexible competitive market composition as $B_G - B_N$ varies.



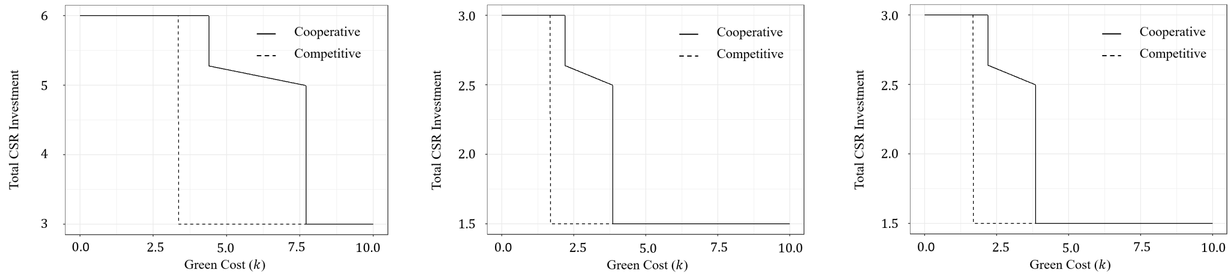
Note. Consider a market with two cooperating producers who can flexibly produce either the green or non-green product, with market parameters $v = 100$, $c = 1$, $\theta = 40.1$, $B_N = 3$, $k = 2$. Depicted is the change in profit (left), green market share (center), and total CSR investment (right) in the market as the effectiveness of green CSR investment, B_G, varies from 4 to 6. *N.E.* is the market outcomes in the profit-maximizing Nash equilibrium, *Two-green* is the outcomes of either producer when they both choose to produce the green product, *Mixed-Green* and *Mixed Non-Green* are the profit of the green and non-green producer under mixed production in the left panel, respectively, and are combined into *One green* in the middle and right panel, and *No-green* is the outcomes of either producer when they both choose to produce the non-green product.

Figure EC.4 Total CSR investment of $2n$ producers as k varies.



Note. Depicted is the change in total CSR investment for $2n$ producers when $n = 1$ (left), $n = 2$ (middle), and $n = 3$ (right), as the cost of green production k varies. The remaining market parameters are set to $B_N = 4.5$, $B_G = 5$, $c = 5$, $\theta = 5.1$. In the left panel, we observe total CSR investment are higher in the cooperative case when k small, and they decreases when k increases for both cooperative and competitive markets.

Figure EC.5 Total CSR investment of $2n$ balanced flexible producers as k varies.



Note. Depicted is the change in total CSR investment for $2n$ flexible producers when $n = 1$ (left), $n = 2$ (middle), and $n = 3$ (right), as the cost of green production k varies. The remaining market parameters are set to $v = 100$, $c = 1$, $\theta = 40.1$, $B_N = 3$, $B_G = 6$. From the left to the right panel, we observe the tipping points decrease for both cooperative and competitive market.