Carbon Footprinting and Pricing Under Climate Concerns*

Marco Bertini, Stefan Buehler, Daniel Halbheer, and Donald R. Lehmann†

May 2020

Abstract

This paper studies how organizations should design a product by choosing the carbon footprint and price in a market with climate concerns. The authors first show how the cost and demand effects of reducing the product carbon footprint determine the profit-maximizing design. Paradoxically, they find that stronger climate concerns may increase the overall, corporate carbon footprint, even if the product itself is greener. Next, the authors establish that offsetting carbon emissions can create a win-win outcome for the firm and climate if the cost of compensation is sufficiently low. Third, the authors show how regulation in the form of a cap-and-trade scheme or a carbon tax affects product design, firm profitability, and green technology adoption. Finally, the authors extend the analysis to a competitive scenario. Overall, these results help marketing professionals understand the subtle consequences of voicing climate concerns within an organization.

Keywords: Carbon footprint, carbon offsetting, climate impact, net-zero emissions, pricing.

*The authors are grateful to co-editor Harald J. van Heerde, the associate editor, and three reviewers for their guidance. The authors further thank Samuel Haefner, Oded Koenigsberg, Vasiliki Kostami, and Armin Schmutzler for useful discussions and suggestions. Daniel Halbheer gratefully acknowledges the financial support of the HEC Foundation and Labex Ecodec (ANR-11-LABEX-0047).

†Marco Bertini (corresponding author): ESADE—Universitat Ramon Llull, Avinguda de la Torre Blanca, 59, 08172 Sant Cugat del Vallès, Spain (marco.bertini@esade.edu). Stefan Buehler: University of St. Gallen, Institute of Economics (FGN), Varnbüelstrasse 19, 9000 St. Gallen, Switzerland (stefan.buehler@unisg.ch); CESifo, Munich. Daniel Halbheer: HEC Paris, Marketing Department, 1 rue de la Libération, 78351 Jouy-en-Josas Cedex, France (halbheer@hec.fr); member of the CNRS unit GREGHEC, UMR CNRS 2959. Donald R. Lehmann: Columbia Business School, Uris Hall, 3022 Broadway, New York, NY 10027, United States (drl2@columbia.edu).

1 Introduction

The consequences of climate change have become apparent and touch every corner of our society. Public opinion has reached a point where "business as usual" is hard to justify and many organizations are pressed to find solutions. For instance, "flight-shaming" and the European Green Deal (European Commission 2019) pose a threat to the business model of airlines (Bloomberg 2019). Amid much fanfare, most major carriers are studying or already adopting approaches that are broadly in line with the three-step process "measure, reduce, compensate" outlined in the United Nations Climate Neutral Now initiative (United Nations 2020), essentially pledging to operate "net-zero" flights in the short term. Similarly, the automotive industry must urgently find ways to replace combustion engines to meet the increasing demand for low-emission vehicles and more stringent emission targets (Hannappel 2017). Car makers around the world are rushing to bring electric vehicles to the market at reasonable prices.

These recent developments, which generalize to organizations in logistics, fashion, retailing, and other sectors in the economy underscore the importance of understanding climate concerns and making the necessary adjustments to one's offerings and prices. Marketing professionals play a critical role here because they are often tasked with sensing changes in consumer preferences and channeling them within an organization. According to a recent article, "chief marketing officers should be involved in the development of the sustainability strategy based on what they can bring to the table: customer data, market analysis and audience insights" (Forbes 2018). At the same time, however, marketing officials may lack the confidence to contribute to the debate and provide meaningful guidance to internal stakeholders (CMO Survey 2019).

This paper develops a model that helps marketers better understand the consequences of voicing climate concerns. It is well documented that consumers have climate concerns (Whitmarsh and Capstick 2018; Wicker and Becken 2013), and that media coverage of climate change motivates consumers to make more sustainable consumption decisions (Chen et al. 2019; Holt and Barkemeyer 2012). The starting point of our analysis is a monopoly setting in which the firm designs a product by choosing its product carbon footprint and price, hereafter referred to simply as *product design*. Calculating *product carbon footprints*—the climate impact per unit of product in carbon dioxide equivalent (CO2eq) emissions—is now common practice (Meinrenken et al. 2012; Vandenbergh, Dietz, and Stern 2011), and they are routinely certified based on international accounting standards (GHG Protocol 2011; ISO 2018).[1] Importantly, reducing the product carbon footprint not only has a *cost effect* due to the change in the unit cost to produce a greener product, but also a *demand effect* due to consumers' climate concerns.

The key difference to a standard model where the firm chooses price and (environmental) quality is that the total number of purchases made by consumers not only determines the firm's profit, but also its *corporate carbon footprint* (Harangozo and Szigeti 2017)—the aggregate climate impact of the firm across all units sold. The corporate carbon footprint causes a market externality that depends on the strength of the climate concerns and that a regulator may want to control. Figure 1 illustrates how consumers' climate concerns and firm technology drive product design, profit, and the corporate carbon footprint, which together with the climate externality are affected by government regulation.

We derive three key results from this initial framework. First, we show how the profit-maximizing product carbon footprint depends on the relative size of the cost and demand effects of reducing the product carbon footprint. This insight reflects the familiar return-on-quality logic in the marketing literature (Rust, Moorman, and Dickson 2002; Rust and Zahorik 1993; Rust, Zahorik, and Keiningham 1995), but accounts for consumers' climate concerns.

Next, we show the impact of stronger climate concerns on the profit-maximizing product design, and identify conditions under which it is optimal for a firm to decrease the product carbon footprint and increase price. In addition, we note that, depending on the

[1]Using terminology from the Greenhouse Gas Protocol (2011), we define the product carbon footprint as "cradle-to-gate emissions," which include production emissions (Scope 1) and emissions from purchased energy (Scope 2). The model abstracts from consumption emissions (Scope 3) because they are hard to measure in practice (Meinrenken et al. 2012).

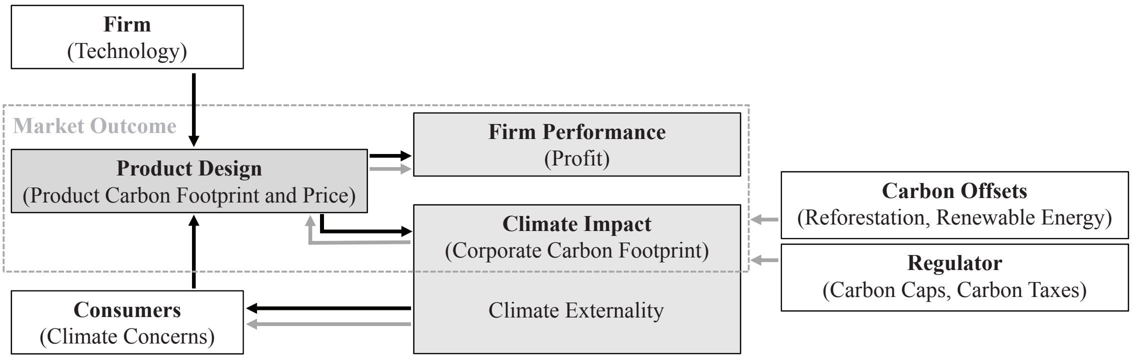

Figure 1: The interplay of the firm, the consumers, and the regulator, and the resulting market outcome under climate concerns.

shape of the demand curve, stronger climate concerns induce the firm to increase (rather than decrease) its product carbon footprint.

Finally, we show that the corporate carbon footprint may increase with stronger climate concerns even when they reduce the product carbon footprint. This result is reminiscent of the rebound effect from technological progress (Alcott 2005) and occurs if the demand-enhancing effect of lowering the product carbon footprint outweighs the reduction in the product carbon footprint (i.e., the firm falls victim to its success in reducing the product carbon footprint).

We then extend the analysis in several directions. First, we consider the profitability of *carbon offsetting*, which compensates for a carbon footprint by reducing, avoiding, or sequestering carbon emissions elsewhere on the planet (Goodward and Kelly 2010). Carbon offsetting if feasible because carbon emissions are a global (rather than local) environmental problem. Projects that result in carbon offsets tend to focus on renewable energy (such as building wind farms that replace coal-fired power plants) or carbon sequestration in soils or forests (such as agroforestry and tree-planting activities). Specifically, we allow the firm to purchase carbon offsets to attain a net-zero corporate carbon footprint. As a result, a firm may be able to offer a climate-neutral product even if its carbon footprint is positive. We show that it is optimal for firms to go net zero if the compensation cost is sufficiently low relative to the demand-enhancing effect of reducing the product carbon footprint to net zero. In this case, going net zero is a win-win strategy for the firm and climate.

Second, we examine the profit-maximizing product design from a welfare perspective, effectively complementing the profit motive of the firm with respect for the environment and social justice (Boyd 2001; Huang and Rust 2011; Johnson 2009)—often referred to as the triple bottom line of profit, planet, and people (Elkington 1999). We show that, in the absence of carbon offsetting, the profit-maximizing corporate carbon footprint generally deviates from the socially-optimal level. A net-zero corporate carbon footprint, in turn, is economically efficient if the cost of offsetting is sufficiently low compared to the social cost of the corporate carbon footprint.

Third, we analyze how carbon regulation affects product design and the corporate carbon footprint. We study three common market interventions (The World Bank 2015): carbon caps, cap-and-trade systems, and a carbon tax. We find that these interventions typically reduce firm profit. In addition, we show that while a carbon cap is effective at curbing the corporate carbon footprint, it may increase (rather than decrease) the product carbon footprint, whereas a carbon tax may reduce the product carbon footprint but has an ambiguous impact on the corporate carbon footprint. We also show how carbon regulation can accelerate green technology adoption.

Finally, we extend our analysis to competition and show that, under reasonable assumptions, adopting an offset strategy is optimal for both firms. From a policy perspective, this suggests that providing efficient carbon removal technologies can accelerate the transition to a low-carbon economy. Table 1 provides an overview of the key findings and highlights the insights for marketers.

Taken as a whole, our results contribute to research on green product development (Chen 2001) by showing how carbon footprinting and pricing are determined by the interplay of climate concerns of consumers (Kotler 2011), firm technology, and market regulation (Porter and van der Linde 1995). By endogenizing product design, this paper

Topic	Insight
Product Design (Propositions 1 and 2)	Climate concerns affect the product carbon footprint and price, and thereby product design. Surprisingly, stronger climate concerns do not necessarily reduce the product carbon footprint because of a tension between cost and demand effects.
Climate Impact (Proposition 3)	Paradoxically, offering a greener product in response to stronger climate concerns can increase the corporate carbon footprint due to the higher sales volume.
Carbon Offsetting (Proposition 4)	Offsetting carbon emissions can create a win-win outcome for the firm and climate if the demand effect of reducing the corporate carbon footprint to net zero is sufficiently large compared to the cost of carbon removal.
Corporate Social Responsibility (Proposition 5)	Offsetting carbon emissions can create a win-win-win outcome for the firm, climate, and society if the cost of carbon removal is sufficiently low compared to the social cost created by the corporate carbon footprint.
Regulation (Propositions 6 to 9)	Carbon regulation in the form of binding carbon caps, cap-and-trade systems, and carbon taxation reduces firm profitability, stimulates green technology adoption, but does not necessarily lead to the design of greener products.
Competitive Strategy (Proposition 10)	In a competitive environment, stronger climate concerns reduce not only the product carbon footprint, but also the corporate carbon footprint of each firm. If the offset technology is sufficiently effective, going net zero creates a win-win-win outcome for the firm, climate, and society.

Table 1: Key results and insights for marketers.

also adds to the return-on-quality literature (Rust, Moorman, and Dickson 2002; Rust and Zahorik 1993; Rust, Zahorik, and Keiningham 1995). Importantly, we provide a welfare analysis to understand the implications of product-design decisions for corporate social responsibility, and thereby add to the sustainability literature in marketing (Cronin et al. 2011; Huang and Rust 2011; Luo and Bhattacharya 2006; Papadas, Avlonitis, and Carrigan 2017). Finally, we extend Chen (2001) and related literature in supply chain management and engineering (Cheng and Zhang 2017; Diabat and Simchi-Levi 2010; He et al. 2019; Yalabik and Fairchild 2011) by accounting for the climate externality and providing the first analysis of carbon offsetting.

Our results also contribute to the literature on regulation in economics (Armstrong and Sappington 2007), by showing how carbon caps and carbon taxes (Cremer and Thisse 1999) affect product design. In addition, we show that climate regulation can trigger investments in green technologies, thereby adding to the insights of Porter and van der Linde (1995) on the dynamic impact of regulation and the economics of climate science more broadly (Hsiang and Kopp 2018; Nordhaus 2019; Stern 2008).

2 The Model

Consider a firm that designs a product (or service) by choosing the price $p \geq 0$ and product carbon footprint $\kappa \in [0, \overline{\kappa}]$. The set $[0, \overline{\kappa}]$ indicates the technologically-feasible product carbon footprints, where the firm offers a *green product* with zero emissions if $\kappa = 0$ and a maximally-polluting *brown product* if $\kappa = \overline{\kappa}$. The technology of the firm results in the unit cost function $c(\kappa)$ defined on $[0, \overline{\kappa}]$, where $c'(\kappa) \neq 0$ is the change in unit cost in response to a change in the product carbon footprint κ.[2] If $c'(\kappa) < 0$, reducing the product carbon footprint increases unit cost. The opposite is true if $c'(\kappa) > 0$.

We consider a market with consumers who have climate concerns and evaluate the product based on not only its intrinsic features and price p, but also its carbon footprint κ. Without loss of generality, the mass of consumers is normalized to unity. A buyer derives utility

$$u(\kappa, p; \lambda) = v - p - z(\kappa; \lambda) - E, \tag{1}$$

where $v \in [0, \infty)$ is the valuation of the intrinsic features, $z(\kappa; \lambda) \geq 0$ measures the disutility from purchasing a product with carbon footprint κ, with $\lambda \geq 0$ capturing the strength of climate concerns, and $E \geq 0$ is the disutility from the climate externality caused by other buyers. Because a single buyer has no impact on the climate externality, E is the

[2] To focus on the interesting cases where changes in κ affect unit cost, we abstract from $c'(\kappa) = 0$.

same irrespective of whether or not the consumer purchases the product. By normalizing the (intrinsic) utility of the outside option to zero, a consumer purchases the product if v exceeds the perceived price $p+z(\kappa;\lambda)$.

The unobserved valuation v is distributed independently across consumers according to the cumulative distribution function $F(v)$. The disutility $z(\kappa;\lambda)$ is assumed to increase at an increasing rate in the product carbon footprint κ, reflecting the increasing guilt or "cold prickle" (Andreoni 1995) of consumers from purchasing a product that impacts the climate. Formally, letting subscripts denote first and second partial derivatives, the convexity assumption of $z(\kappa;\lambda)$ can be restated as $z_\kappa(\kappa;\lambda) > 0$ and $z_{\kappa\kappa}(\kappa;\lambda) \geq 0$. We set the disutility to zero if consumers do not have climate concerns or if the product is green, that is, $z(\kappa;0) = z(0;\lambda) = 0$.[3] The other boundary case occurs if consumers have strong climate concerns, in which case we assume that $\lim_{\lambda\to\infty} z(\kappa;\lambda) = \kappa$. We further assume that stronger climate concerns increase the disutility from a given carbon footprint, that is, $z_\lambda(\kappa;\lambda) > 0$.

Consumers purchase if the utility from the product exceeds the utility from the outside option. Therefore, the demand for the product is derived as

$$D(\kappa, p;\lambda) = 1 - F(p + z(\kappa;\lambda)). \tag{2}$$

Demand is decreasing in the product carbon footprint and price. Interpreting the product carbon footprint as an inverse measure of product quality, a lower κ means higher quality and therefore higher demand. Lowering the product carbon footprint implies *demand neutrality* when consumers do not care about the climate impact of the product $(D_\kappa = 0)$ and *demand expansion* when consumers have climate concerns $(D_\kappa < 0)$. The novel aspect of our modeling approach is that "product quality" not only affects demand, but also the corporate carbon footprint (that is, the overall climate impact of the firm).

The corporate carbon footprint results from multiplying the product carbon footprint by demand, and is therefore given by $\Phi = \kappa D(\kappa, p;\lambda)$. Note that if buyers do not fully

[3] Alternatively, one can interpret the disutility $z(\kappa;\lambda)$ as the extent to which the product deviates from the "should expectation" (Boulding et al. 1994; Tse and Wilton 1988) of a green product, an assumption that can be relaxed to include an arbitrary reference point.

account for their carbon emissions, they create a climate externality—"the biggest market failure the world has seen" (Stern 2008, 1). The climate externality results from adding up the non-internalized carbon emissions across buyers:

$$E(\kappa, p; \lambda) = [\kappa - z(\kappa; \lambda)]D(\kappa, p; \lambda). \tag{3}$$

This climate externality is reduced to zero when consumers have strong climate concerns ($z(\kappa;\lambda) = \kappa$) and equals the product carbon footprint if consumers do not care about purchasing a product that impacts the climate ($z(\kappa;0) = 0$). Therefore, the corporate carbon footprint has an impact on all consumers if buyers do not fully account for the product carbon footprint when making their purchase decision.

3 Product Design

This section first derives the profit-maximizing product carbon footprint and price of a product. We then study the impact of stronger climate concerns on these variables. Finally, we consider the impact of product design on the corporate carbon footprint. We assume throughout that the profit function is strictly concave in κ and p and thus has a unique constrained global maximum.

3.1 Product Carbon Footprint and Price

The firm chooses the product carbon footprint κ and the price p of the product to maximize profit. More formally, the firm solves

$$\begin{aligned} \max_{\kappa, p} \quad & \pi(\kappa, p; \lambda) = [p - c(\kappa)]D(\kappa, p; \lambda) \\ \text{s.t.} \quad & 0 \leq \kappa \leq \overline{\kappa}. \end{aligned} \tag{4}$$

The profit function shows that the product carbon footprint and price have a dual impact on markup and demand. Proposition 1 characterizes the profit-maximizing product design with product carbon footprint κ^* and price $p^*(\kappa^*)$. To facilitate exposition, all proofs are relegated to the Appendix.

Proposition 1. *If reducing the product carbon footprint lowers unit cost, the firm should offer a green product with* $\kappa^* = 0$ *at price* $p^*(0)$*, irrespective of the demand effect. If reducing the product carbon footprint increases unit cost but not demand, then it is optimal to offer a brown product with* $\kappa^* = \overline{\kappa}$ *at price* $p^*(\overline{\kappa})$*. Finally, if the demand effect is sufficiently strong compared to the cost effect, then it is optimal to offer a product with* $\kappa^* \in (0, \overline{\kappa})$ *at price* $p^*(\kappa^*)$*.*

Proposition 1 mirrors the familiar return-on-quality logic in the marketing literature (Rust, Moorman, and Dickson 2002; Rust and Zahorik 1993; Rust, Zahorik, and Keiningham 1995) and has two important implications. First, if lowering the product carbon footprint reduces unit cost, then it is optimal to increase efficiency and thereby increase "process quality" (Deming 1986; Crosby 1979). Green cost cutting is more attractive when lowering the product carbon footprint not only reduces cost, but also increases demand (Parasuraman, Zeithaml, and Berry 1985). This result helps to explain why many sustainability efforts increase firm profit (Winston, Favaloro, and Healy 2017).

Second, if lowering the product carbon footprint increases unit cost, there may be a tradeoff between the cost effect and the demand effect. Absent a demand effect, reducing the product carbon footprint below that of the brown product only results in higher unit cost and is therefore suboptimal under profit maximization. However, when the increase in demand outweighs the impact of higher unit cost, firms should reduce the product carbon footprint relative to the brown product. In contrast to cost-cutting sustainability, cost-increasing sustainability reflects the idea that "major pressure for changing marketing practices may come from consumers themselves" (Kotler 2011) and can be viewed as one of the "sustainability programs worthy of the name" (*The Economist* 2014). Figure 2 summarizes the product design strategies derived in Proposition 1.

3.2 Impact of Climate Concerns on Product Design

Stronger climate concerns strengthen the negative demand effect and affect product design and firm profitability. The next result summarizes the implications.

	Demand Neutrality ($D_\kappa = 0$)	**Demand Expansion** ($D_\kappa < 0$)
Cost Reduction ($c' > 0$)	$\kappa^* = 0$ and $p^*(0)$ (Green Product)	
Cost Increase ($c' < 0$)	$\kappa^* = \overline{\kappa}$ and $p^*(\overline{\kappa})$ (Brown Product)	$\kappa^* \in (0, \overline{\kappa})$ and $p^*(\kappa^*)$

Figure 2: Profit-maximizing product design as a function of the cost effect (due to the change in unit cost) and the demand effect (due to consumers' climate concerns).

Proposition 2. *If reducing the product carbon footprint lowers unit cost, stronger climate concerns do not affect the profit-maximizing product carbon footprint and price. Instead, if reducing the product carbon footprint increases unit cost, stronger climate concerns reduce profit and have an ambiguous effect on product design. Lowering the product carbon footprint and increasing price is optimal if the demand effect is sufficiently strong compared to the cost effect.*

Proposition 2 has two important implications. First, it shows that stronger climate concerns may increase (rather than decrease) the profit-maximizing product carbon footprint. Intuitively, a lower product carbon footprint may lead to a large cost effect and, therefore, create sufficient upward pressure on price to outweigh the positive demand effect of offering a greener product. If we interpret the product carbon footprint as an inverse measure of product quality, then Proposition 2 implies an ambiguous relationship between product quality and price, which contributes to the literature on price-quality relationships (Gerstner 1985; Parasuraman, Zeithaml and Berry 1985).

Second, Proposition 2 implies that a monopoly firm has a motive to downplay climate concerns due to their negative impact on profit. This suggests an intuitive explanation for "dither and denial" (*Guardian* 2019) by polluting firms in the face of climate change (Krugman 2018; Mann and Toles 2016). This result also points to a potential tension between product managers who tend to focus on profit and managers who are in charge of corporate social responsibility. As we will show in Section 5, one way firms can resolve this tension is by broadening the scope of performance measurement beyond profit to include climate and societal impact.

3.3 Corporate Carbon Footprint

The first two propositions extend the logic of profit-maximizing product design to a setting where consumers have climate concerns. The goal of this subsection is to provide new insights on how product design affects the climate impact of the firm.

Proposition 3. *If the increase in demand in response to stronger climate concerns is sufficiently large, the corporate carbon footprint* $\Phi^* = \kappa^* D(\kappa^*, p^*; \lambda)$ *increases even when it is optimal to reduce the product carbon footprint* κ^*.

Proposition 3 shows that reducing the product carbon footprint in response to stronger climate concerns does not necessarily reduce the corporate carbon footprint. This occurs because the demand effect may result in higher sales and thus greater emissions by the firm as a whole—a situation where a firm that offers a product with a lower product carbon footprint falls victim to its own success. Said differently, by listening to the voice of consumers, the firm responds by bringing a greener product to the market, with the unintended consequence that the expansion of demand increases the corporate carbon footprint. This is reminiscent of the rebound effect from technological progress (Alcott 2005): higher efficiency leads to an initial reduction in demand for a resource that is outweighed by an increase in demand due to relatively lower resource cost ("Jevons paradox"). Proposition 3 thus suggests that, surprisingly, designing greener products may be in conflict with the objective of meeting climate targets mandated by law.

4 Carbon Offsetting

While producing a green product is perhaps the most obvious means for a firm to achieve climate neutrality, an increasingly popular alternative is to adopt an offset strategy where the corporate carbon footprint is fully compensated for (by funding projects that achieve an equivalent level of carbon dioxide saving), thereby creating a net-zero corporate carbon footprint. While carbon offsetting is arguably not the solution to climate change, it allows firms to achieve climate neutrality even if the available production technology does not yet allow it. In principle, any company can go net zero by buying offset services (that promote the planting of trees, renewable energy, etc.) from providers such as Carbon Footprint Ltd or Gold Standard.

Accordingly, the purpose of this section is to study under what conditions firms can benefit from adopting an offset strategy. Suppose that an offset provider charges a fixed price $\omega \geq 0$ per unit of carbon offset. The firm then chooses the product carbon footprint κ and the price p to

$$\begin{aligned} \max_{\kappa,p} \quad & \pi(\kappa,p;\omega) = [p - c(\kappa) - \omega\kappa]\,D(0,p) \\ \text{s.t.} \quad & 0 \leq \kappa \leq \overline{\kappa}, \end{aligned} \tag{5}$$

where $\omega\kappa D(0,p)$ is total cost of compensating for the emissions to the firm to achieve a net-zero corporate carbon footprint. Importantly, with carbon offsets purchase decisions and demand depend on the net-zero carbon footprint rather than the product carbon footprint prior to offsetting. The next result points to the possibility of a win-win outcome for the firm and climate, where the benchmark is provided by the no-offset strategy.

Proposition 4. *Adopting an offset strategy is optimal for a firm if the compensation cost is sufficiently low compared to the demand-enhancing effect of reducing the product carbon footprint to net zero. Surprisingly, adopting an offset strategy motivates a firm to increase the product carbon footprint before offsetting the emissions. Stronger climate concerns make the adoption of an offset strategy more attractive.*

Proposition 4 shows that offsetting carbon emissions can boost profit *and* fight climate change. The key driver of this result is that relieving consumers from guilt by offering a product with a net-zero product carbon footprint has a demand-enhancing effect that directly translates into higher profit. A firm is more likely to adopt an offset strategy if the price per unit of carbon offset is low. This suggests that providing low-cost carbon offset options to firms might curb their corporate carbon footprints even when the standard tools of carbon regulation have no bite.

5 Corporate Social Responsibility

Sustainability is an umbrella term generally viewed as comprising economic profitability, respect for the environment, and social justice (Boyd 2001; Huang and Rust 2011; Johnson 2009). To integrate these three ingredients into the analysis, we say that a firm behaves in a manner that is consistent with corporate social responsibility if it maximizes welfare. To do so, it must consider the triple bottom line of profit (firm and offset provider), planet (climate impact), and people (consumer surplus). Our next result shows that the adoption of an offset strategy can create a win-win-win outcome.

Proposition 5. *Without offsetting, the corporate carbon footprint is generally nonzero and different from the socially-optimal level. Adopting an offset strategy that leads to net-zero carbon emissions improves welfare if the cost of carbon offsetting is sufficiently low compared to the social cost created by the corporate carbon footprint.*

Proposition 5 confirms the notion that focusing exclusively on profit leads firms to make decisions that are generally inconsistent with corporate social responsibility. Intuitively, a firm has an incentive to strategically distort the product carbon footprint to exploit pricing power, which leads to an economically inefficient product carbon footprint (Spence 1975). Interestingly, under an offset strategy, profit-maximization may result in a net-zero corporate carbon footprint even if it is socially undesirable to fully compensate for the emissions because the firm does not factor in the social cost of carbon removal. However, if the carbon removal technology is sufficiently cost effective, the win-win outcome for the firm and the climate under an offset strategy translates into a win-win-win outcome and therefore produces benefits for society at large.

In addition, Proposition 5 sheds light on the controversial debate about carbon offsets that "have been used by polluters as a free pass for inaction" (United Nations Environment Programme 2019). The cost efficiency of carbon offsetting stems from the fact that emissions are compensated for in places where the cost of offsetting is low, typically in developing countries. While this makes sense from an economic perspective, managers have to bear in mind "whose mess this is" and that "some of these places would welcome investment in reforestation and afforestation, but they would also need to be able to integrate such endeavours into development plans which reflect their people's needs" (*The Economist* 2019).

6 Carbon Regulation

Regulators increasingly try to limit carbon emissions of firms to meet climate targets and address climate change. The most recent examples include the Green New Deal in the United States and the European Green Deal that address climate change by introducing various regulatory interventions. We show how a firm should respond to carbon caps, cap-and-trade systems, and carbon taxes, which are by far the most common regulatory market interventions today (The World Bank 2015), and study their impact on expected firm profitability. While the institutional details of these interventions vary across industries and legislations, we focus on their key characteristics and show that the risk of regulation accelerates investments in green technology.

6.1 Carbon Caps

The most direct approach to limit the corporate carbon footprint is to impose a binding carbon cap $R \geq 0$. An example is the European Unions's fleet-wide binding emissions target for new cars imposed on manufacturers (European Union 2020). In the face of such regulation, the firm solves the following problem:

$$\begin{aligned} \max_{\kappa,p} \quad & \pi(\kappa,p;\lambda) = [p - c(\kappa)]D(\kappa,p;\lambda) \\ \text{s.t.} \quad & 0 \leq \kappa \leq \overline{\kappa} \quad \text{and} \quad \Phi(\kappa,p;\lambda) \leq R, \end{aligned} \tag{6}$$

where $\Phi(\kappa, p; \lambda)$ is the corporate carbon footprint. The next result summarizes the impact of a binding carbon cap.

Proposition 6. *A binding carbon cap reduces the corporate carbon footprint and profit, but may induce the firm to increase the product carbon footprint and reduce sales to comply with the regulation.*

A binding carbon cap has the obvious effect of reducing corporate carbon footprint and profit. More interestingly, a binding carbon cap may have the unintended consequence of increasing the product carbon footprint. The intuition for this result is driven by the demand effect of lowering κ: If $\Phi_\kappa < 0$, then lowering the product carbon footprint translates into a higher corporate carbon footprint even though κ is smaller. Consequently, the firm has an incentive to increase κ to purposely reduce sales and, therefore, meet the legislated carbon target. Instead, if $\Phi_\kappa > 0$, lowering κ relaxes the carbon constraint and provides an incentive to lower the product carbon footprint. The impact on price is ambiguous because of the simultaneous cost and demand effects of a change in κ. In reality, however, carbon caps are often coupled with a carbon market, where firms can sell or purchase carbon allowances, which gives rise to cap-and-trade systems.

6.2 Cap-and-Trade Systems

The leading examples of cap-and-trade systems are California's Cap-and-Trade Program, the Chinese National Carbon Trading Scheme, and the European Union Emissions Trading System. Cap-and-trade systems have an important advantage over carbon caps: firms with low compliance costs can sell carbon allowances in the emissions market and turn them into a source of revenue. For example, Tesla generates significant revenues by selling zero emission vehicle credits in the United States (*Financial Times* 2019).

The society's need to tackle climate change creates considerable uncertainty for businesses regarding their regulatory environment. To address how a firm can proactively deal with the possible introduction of regulation, we assume that a regulator is expected to implement a cap-and-trade system with probability $\rho \in [0,1]$, with a given carbon cap $R \geq 0$. In this case, the firm can choose among two options: adjust the product design to meet the potential regulatory constraint at the firm level (profit π^r), or stick to the current product design and purchase carbon allowances at a market price $\varpi \geq 0$. The following result summarizes the impact of a binding carbon cap coupled with the possibility to buy carbon allowances in the emissions market.

Proposition 7. *The expected cost of a cap-and-trade system to the firm is given by* $\rho \min\{\pi^* - \pi^r, \varpi(\Phi^* - R)\}$*, where* $\rho(\pi^* - \pi^r)$ *is the expected reduction in profit if the firm complies with the carbon cap by adjusting product design, and* $\rho\varpi(\Phi^* - R)$ *is the expected reduction in profit if the firm purchases carbon allowances to offset the emissions. The expected cost increases when the implementation probability* ρ *is higher, when the carbon cap* R *is more severe, and when the carbon price* ϖ *is higher.*

Proposition 7 confirms the intuition that cap-and-trade regulation reduces the expected profit of the firm. Further, the cost of regulation to the firm is increasing in the probability of regulation and the market price for emissions. This is important because companies should anticipate changes in the regulatory environment and thus want to invest in the adoption of a greener technology to comply with expected regulation. Similar to a binding carbon cap, the impact of cap-and-trade systems on product design is generally ambiguous.

6.3 Carbon Tax

In December 2019, the International Monetary Fund issued a report suggesting that a global average carbon price of $70 a ton would be sufficient for many (but not all) countries to meet their Paris accord mitigation targets (IMF 2019). While a carbon cap directly limits the climate impact of the firm, such a price alters the cost structure of the firm with the goal of reducing the corporate carbon footprint to a socially desirable level. To reflect this, assume that $t \geq 0$ is the fixed (Pigouvian-style) tax rate on carbon emissions. Under such a proportional carbon tax, the firm solves

$$\begin{aligned} \max_{\kappa,p} \quad & \pi(\kappa,p;\lambda,t) = [p - c(\kappa) - t\kappa]D(\kappa,p;\lambda) \\ \text{s.t.} \quad & 0 \leq \kappa \leq \overline{\kappa}. \end{aligned} \tag{7}$$

The next result summarizes the impact on the product design and firm profit, where the optimized profit under a carbon tax is denoted by $\pi^*(t)$.

Proposition 8. *A carbon tax reduces the profit-maximizing product carbon footprint if the demand effect is sufficiently strong compared to the cost effect, but has an ambiguous effect on the corporate carbon footprint. The expected cost of taxation is given by* $\rho\{\pi^*(0) - \pi^*(t)\} > 0$*, which increases in the probability* ρ *that a tax will be implemented and in the tax rate* t*.*

Proposition 8 shows that, while a higher tax rate may reduce the profit-maximizing product carbon footprint, the effect on the corporate carbon footprint is ambiguous because the product's lower carbon footprint may increase sales and, therefore, overall emissions. The result also shows that the uncertain introduction of a carbon tax reduces expected profit: The carbon tax increases unit cost, but only part of this can be passed on to consumers in the form of higher prices—a result akin to the imperfect pass-through of trade deals documented in the channels literature (Nijs et al. 2010; Moorthy 2005).

The result shows that, similar to the climate concerns of consumers, regulatory constraints reduce profit but have an ambiguous impact on product design: the incentives to adjust the product carbon footprint and price depend on the relative size of the cost and demand effects. The profit impact may explain why firms lobby against regulation (Viscusi, Harrington, and Sappington 2018).

On the other hand, the result also shows why an offsetting strategy is an interesting option: a net-zero corporate carbon footprint makes regulation unnecessary and has an immediate positive impact on the climate. A carbon tax, in turn, affects the product carbon footprint and raises revenue for the government without offsetting the emissions. However, carbon offsets do not provide an incentive for firms to invest in green technologies and are therefore often considered an interim measure until new technologies become available.

6.4 Green Technology Adoption

The need to comply with carbon regulation may trigger investments in green technologies. To demonstrate this, we consider the case of a carbon cap and assume that an existing brown technology $c_0(\kappa)$ can be replaced with a green technology $c_1(\kappa)$ at a fixed cost $f > 0$. This green technology allows the firm to reach any product carbon footprint at a lower unit cost, that is, $c_0(\kappa) \geq c_1(\kappa)$ for all κ. Letting ρ denote the probability that carbon regulation becomes effective, we derive the following result.

Proposition 9. *The threat of carbon regulation stimulates green technology adoption if the anticipated carbon regulation reinforces the profit advantage of adopting the green technology.*

Proposition 9 shows that regulatory risk provides an incentive for the firm to adopt the green technology. In other words, the mere threat of carbon regulation can prompt a reduction of the corporate carbon footprint and lead to process innovation (Porter and van der Linde 1995). More broadly, from a policy perspective, the threat of effective regulation allows the government to put some of the burden of technology adoption on the shoulders of the firm.

7 Competitive Strategy

In this section, we extend this baseline case to include competition. We first describe the interaction between two firms and consumers, and then study conditions under which adopting an offset strategy is consistent with pursuing a triple bottom line.

7.1 Setup

We now consider a market with two single-product firms $i = 1,2$ that simultaneously choose the product carbon footprint κ_i and price p_i. The technology of firm i is represented by the unit cost function $c_i(\kappa_i) = c_i^0(1-\kappa_i)^2$, where $c_i^0 > 0$ is a firm-specific cost parameter. Carbon offsetting to achieve a net-zero product carbon footprint is provided by an independent provider at cost $\omega \geq 0$ per unit of carbon emissions. The carbon removal technology of the provider is represented by the unit cost $\phi \geq 0$ and fixed cost $F > 0$. Each firm can choose among two strategies: a no-offset strategy where the product is marketed with carbon footprint κ_i, or an offset strategy where the product is marketed with a net-zero carbon footprint.

The products are differentiated horizontally and vertically. Horizontal differentiation is à la Hotelling and reflects consumer heterogeneity with respect to intrinsic product features. We assume that the firms are located at the extremes of the characteristics space $[0,1]$, that is, $x_1 = 0$ and $x_2 = 1$. Vertical differentiation on the carbon footprint reflects the notion that a lower product carbon footprint enhances the worth of the product in the minds of consumers. Category demand is fixed, and the market consists of a unit mass of consumers. We assume that individual preferences are described by the conditional indirect utility function

$$u_i(\kappa_i, p_i; \lambda) = v - p_i - z_i(\kappa_i; \lambda) - \frac{1}{2}|x - x_i| - E, \tag{8}$$

where v is the valuation of the intrinsic product features, $z_i(\kappa_i; \lambda) = \lambda \kappa_i$ is the disutility from purchasing a product with carbon footprint κ_i, and $E \geq 0$ is the disutility from the climate externality caused by other buyers in the market. Following convention, we let $x \in [0,1]$ denote the consumer's preferred product characteristic and $|x - x_i|$ denote the horizontal distance to the product of firm i (Anderson, de Palma, and Thisse 1992). The preferred product characteristics are drawn independently across consumers from a

		Firm 2	
		No Offset	*Offset*
Firm 1	*No Offset*	$\frac{1}{4}$, $\frac{1}{4}$	B, A
	Offset	A, B	$\frac{1}{4}$, $\frac{1}{4}$

Figure 3: Possible competitive conditions and corresponding profits for $c_1^0 = c_2^0 = 1$ and $\lambda = 1$, where $A > \frac{1}{4}$ and $B < \frac{1}{4}$.

uniform distribution over the interval $[0,1]$. Demand for the product of firm i as a function of the product carbon footprints $\boldsymbol{\kappa} = (\kappa_1, \kappa_2)$ and prices $\mathbf{p} = (p_1, p_2)$ can be derived as

$$D_i(\boldsymbol{\kappa}, \mathbf{p}; \lambda) = \frac{1}{2} - \lambda(\kappa_i - \kappa_j) - (p_i - p_j). \tag{9}$$

Each firm can therefore obtain a competitive advantage over its rival by offering a product with a lower carbon footprint, by charging a lower price, or both.

7.2 Competitive Carbon Offsetting

In a setting with two firms and two strategic options per firm there are a total of four possible competitive conditions: both firms adopt a no-offset strategy, both firms adopt an offset strategy, or one firm adopts an offset strategy while the other firm adopts a no-offset strategy. Figure 3 represents these competitive interactions. The following result holds.

Proposition 10. *When consumers have strong climate concerns and the offset technology is sufficiently effective, each firm benefits from adopting an offset strategy irrespective of the rival's choice of strategy. This leads to a net-zero industry carbon footprint and improves welfare.*

To understand what governs the optimal choice of strategy, consider a situation where both firms at first decide not to offset their corporate carbon footprints (the upper-left cell of the payoff matrix in Figure 3). Once offsetting emissions becomes sufficiently cheap, each firm can unilaterally improve its profit due to the demand-enhancing effect of offering a product with a net-zero carbon footprint. Said differently, under some conditions each firm can create a win-win for itself and the climate by adopting the offset strategy—irrespective of the rival's choice of strategy. In the symmetric equilibrium, each firm chooses an offset strategy and ends up earning the same profit as in the initial situation. However, had either firm not adopted the offset strategy, its profit would have been lower because the rival would have attained a competitive advantage.

In contrast to a monopoly market, stronger climate concerns in a competitive market reduce not only the product carbon footprint, but also each firm's corporate carbon footprint. As a result, industry emissions are lower when consumers have stronger climate concerns. The reason for this is that offering a product with a lower carbon footprint does not create a market expansion effect when category demand is fixed. Interestingly, Proposition 10 further implies that, if the offset technology is sufficiently cost effective, competitive forces can create a win-win-win outcome for each firm, climate, and society. Therefore, choosing an offset strategy is consistent with pursuing corporate social responsibility. This has an important implication for policy makers: Providing efficient carbon removal technologies can accelerate the transition to a zero-carbon economy by providing incentives for firms to offer products and services with a net-zero product carbon footprint.

8 Discussion

This paper explored how organizations should design a product by choosing the carbon footprint and price in a market with climate concerns. We also analyzed how changes in product design affect profitability and the organization's overall climate impact—the corporate carbon footprint. Further, we analyzed how offset strategies and carbon regulation can be used to limit the corporate carbon footprint, and how they affect green technology adoption. Finally, we examined the role of competition for product-design decisions and carbon offsetting.

Throughout, the underlying objective was to help marketing professionals understand the consequences of voicing climate concerns with their organizations, as typically they are responsible for sensing changes in consumer preferences in a market. With this in mind, the current section elaborates on the implications of our results for organizations, policy makers, and consumers. We end by discussing some of the limitations of our work and avenues for future research.

8.1 Implications for Organizations

When confronted with climate concerns, the first response of an organization should be to assess the carbon footprint of its product and understand the impact on cost. If it is possible to reduce the product carbon footprint and reduce cost, eliminating waste (e.g., improving energy management) and adjusting price is the obvious consequence. However, if reducing the product carbon footprint is costly, it is imperative for marketers to understand the tradeoff with demand (via, for example, market research). They can then advise the organizations on how to adjust the product design in response to stronger climate concerns.

Another key consideration is how changes in product design affect the organization's overall climate impact. If the demand effect of manufacturing a greener product leads to a higher corporate carbon footprint, marketers face the unpalatable decision of making the product browner (which decreases its appeal) or raising its price (which decreases access). The option to offset carbon emissions eases the tension associated with this tradeoff, which explains why many organizations are going net zero. For example, UPS offers a carbon neutral shipping service with net-zero carbon emissions (UPS 2019), while Kering "will become carbon neutral within its own operations and across the entire supply chain" (Kering 2019). EasyJet announced its decision to go net zero and claims to be "the first major airline to offset the carbon emissions from the fuel used for every single flight" (EasyJet 2019). In theory, net-zero carbon footprints are consistent with corporate social responsibility if the social cost of carbon compensation is sufficiently low. However, in practice, carbon compensation remains an imperfect solution that falls short of green product development.

A third consideration is whether competition forces otherwise brown organizations to offset their carbon emissions. We showed that competition has the potential to prevent an industry from a race to the bottom where firms offer brown products. For instance, several European airlines offset their carbon emissions on domestic flights to compete for climate-concerned consumers.

8.2 Implications for Policy Makers

While carbon regulation effectively limits the organization's overall climate impact, it may have the unintended consequence of increasing the product carbon footprint. Carbon taxation, in turn, increases product cost, but does not necessarily reduce the corporate carbon footprint.

A second issue is the cost of regulation for firms and consumers. Our analysis shows that the mere threat of regulation negatively affects firm profitability. On the positive side, a well-designed market intervention benefits consumers and society at large, and stimulates green technology adoption.

More generally, our work suggests that society should put a price on carbon emissions. Carbon offsets and carbon taxes achieve this goal. However, carbon offsets do not provide an incentive for firms to invest in greener technologies and, therefore, should be considered as an interim measure until new technologies become available. The recent call by the United Nations Global Compact to set an internal price at a minimum of $100 per metric ton by 2020 is an attempt to price carbon emissions and put climate change at the heart of corporate strategy (United Nations 2019).

8.3 Implications for Consumers

Our research shows that organizations act on consumers' climate concerns. Yet, voicing stronger climate concerns does not necessarily induce organizations to offer greener products and reduce their corporate carbon footprint. Even if consumers succeed in pressuring organizations into offering greener products, they may end up paying higher prices because of cost pass-through.

More important, our analysis shows that stronger climate concerns reduce the climate externality, that is, the burden buyers impose on society. Stronger climate concerns also increase the profitability of carbon offsetting, which may stimulate the transition to a net-zero carbon economy.

8.4 Limitations and Future Research

Future research could study how climate concerns are shaped. For example, one approach is to assume that climate concerns are shaped by opinion leaders. Another option is to assume that the organization can influence climate concerns via persuasive advertising.

Second, future research could consider emissions that occur during the consumption stage (Scope 3). This would allow marketers to understand what drives the life-cycle carbon footprint of a product (a cradle-to-grave approach). The interesting aspect of such an extension is that the emissions in the consumption phase are driven by consumer behavior that cannot be easily influenced by the firm.

Third, it would be interesting to study the role of competition in a more nuanced way. A limitation of our approach is that it ignores the possibility of market expansion. Researchers could also study the impact of carbon regulation and taxation on industry dynamics and their potential to accelerate the transition to a zero carbon economy.

Overall, this article highlights some of the complexities and consequences of climate concerns on product design and corporate carbon emissions. Hopefully, this will spur further research into understanding the impact of climate-dependent preferences and exploring the system-wide effects of government actions. We also hope to see multiple approaches brought to bear in the area, including agent based simulations, data-based empirical analyses, and natural experiments. Ideally, this will lead to creative regulations and behaviors that result in win-win-win outcomes for consumers, organizations, and the environment and, absent that, better understanding of the tradeoffs being made among the three parties.

References

Alcott, Blake (2005), "Jevons' Paradox," *Ecological Economics*, 54(1), 9–21.

Anderson, Simon P., André de Palma, and Jacques-François Thisse (1992), *Discrete Choice Theory of Product Differentiation*, MIT Press.

Andreoni, James (1995), "Warm-Glow Versus Cold-Prickle: The Effects of Positive and Negative Framing on Cooperation in Experiments," *Quarterly Journal of Economics*, 110(1), 1–21.

Armstrong, Mark, and David E. M. Sappington (2007), "Recent Developments in the Theory of Regulation," in Mark Armstrong and Robert Porter (eds.), *Handbook of Industrial Organization, Volume 3* (pp. 1557–1700), Amsterdam: North-Holland.

Bloomberg (2019), "Business Class Flying Is Under Attack" (accessed January 6, 2020), `https://bloom.bg/2T0P9cff`.

Boulding, William, Ajay Kalra, Richard Staelin, and Valarie A. Zeithaml (1993), "Dynamic Process Model of Service Quality: From Expectations to Behavioral Intentions," *Journal of Marketing Research*, 30(1), 7–27.

Boyd, Chris (2001), "Sustainability is Good Business," *OECD Observer*, 228 (September).

Chen, Chialin (2001), "Design for the Environment: A Quality-Based Model for Green Product Development," *Management Science*, 47(2), 250–263.

Chen, Yubo, Mrinal Ghosh, Yong Liu, and Liang Zhao (2019), "Media Coverage of Climate Change and Sustainable Product Consumption: Evidence from the Hybrid Vehicle Market," *Journal of Marketing Research*, 56(6), 995–1011.

Cheng, Yonghong, and Pan Zhang (2017), "Optimal Pricing and Product Carbon Footprint Strategies with Different Carbon Policies and its Implications," IEE, *International Conference on Service Systems and Service Management*, 1–6.

Cremer, Helmuth, and Jacques-François Thisse (1999), "On the Taxation of Polluting Products in a Differentiated Industry," *European Economic Review*, 43(3), 575–594.

Cronin, Jr., J. Joseph, Jeffery S. Smith, Mark R. Gleim, Edward Ramirez, and Jennifer Dawn Martinez (2011), "Green Marketing Strategies: An Examination of Stakeholders and the Opportunities They Present," *Journal of the Academy of Marketing Science*, 39(1), 158–174.

Crosby, Philip B. (1979), *Quality is Free: The Art of Making Quality Certain*, McGraw-Hill.

Deming, W. Edwards (1986), *Out of the Crisis*, Boston: MIT Center for Advanced Engineering Study.

Diabat, Ali, and David Simchi-Levi (2010), "A Carbon-Capped Supply Chain Network Problem," IEEE International Conference on Industrial Engineering and Engineering Management, 2009 (Piscataway, N.J.: IEEE): 523–527.

EasyJet (2019). "Climate Change, Carbon Emissions and Carbon Offsetting" (accessed May 15, 2020), `https://bit.ly/2A8hk1v`.

Elkington, John (1999), "Triple Bottom-Line Reporting: Looking For Balance," *Australian CPA* 69, 18-21.

European Commission (2020), "Reducing CO2 emissions from passenger cars – before 2020" (accessed May 15, 2020), `https://bit.ly/37hLavC`.

European Commission (2019), "A European Green Deal" (accessed May 8, 2020), `https://bit.ly/2AdSpKd`.

Financial Times (2019), "Fiat Chrysler Pools Fleet With Tesla to Avoid EU Emissions Fines" (accessed June 12, 2019), on.ft.com/2G4Lp2r .

Forbes (2018), "The CMO's Role In Driving Sustainability" (accessed March 6, 2020), https://bit.ly/2wyzjfW.

Gerstner, Eitan (1985), "Do Higher Prices Signal Higher Quality?" *Journal of Marketing Research*, 22(2), 209–215.

GHG Protocol (2011), "Corporate Value Chain (Scope 3) Accounting and Reporting Standard" (accessed November 29, 2018), bit.ly/2SeYVDY.

Goodward, Jenna, and Alexia Kelly (2010), "Bottom Line on Offsets," *World Resources Institute*.

Hannappel, Ralf (2017), "The Impact of Global Warming on the Automotive Industry," *AIP Conference Proceedings* 1871, 060001.

Harangozo, Gabor, and Cecilia Szigeti (2017), "Corporate Carbon Footprint Analysis in Practice—With a Special Focus on Validity and Reliability Issues," *Journal of Cleaner Production*, 167, 1177–1183.

He, Bin, Yongjia Liu, Lingbin Zingbin, Shuai Wang, Dong Zhang, and Qianyi Yu (2019), "Product Carbon Footprint Across Sustainable Supply Chain," *Journal of Cleaner Production*, 241:118320.

Holt, Diane, and Ralf Barkemeyer (2012), "Media Coverage of Sustainable Development Issues-–Attention Cycles or Punctuated Equilibrium?" *Sustainable Development*, 20(1), 1–17.

Hsiang, Solomon, and Robert E. Kopp (2018), "An Economist's Guide to Climate Change Science," *Journal of Economic Perspectives*, 32(4), 3–32.

Huang, Ming-Hui, and Roland T. Rust (2011), "Sustainability and Consumption," *Journal of the Academy of Marketing Science*, 39(1), 40–54.

IMF—International Monetary Fund (2019), "Putting a Price on Pollution," *Finance & Development*, 56(4).

ISO—International Organization for Standardization (2006), "ISO 14064-1:2018 Greenhouse Gases – Part 1: Specification With Guidance at the Organization Level for Quantification and Reporting of Greenhouse Gas Emissions and Removals," Geneva, Switzerland.

Johnson, Robert L. (2009), "Organizational Motivations for Going Green or Profitability Versus Sustainability," *The Business Review*, 13(1), 22–28.

Kering (2020), "Soaring Toward a Carbon-Neutral Future" (accessed May 15, 2020), `https://bit.ly/2LpPS1u`.

Kotler, Philip (2011), "Reinventing Marketing to Manage the Environmental Imperative," *Journal of Marketing*, 75(4), 132–135.

Krugman, Paul (2018, November 26), "The Depravity of Climate-Change Denial: Risking Civilization for Profit, Ideology and Ego" (accessed November 29, 2018), *The New York Times*, `nyti.ms/2P2OdBX`.

Luo, Xueming, and C. B. Bhattacharya (2006), "Corporate Social Responsibility, Customer Satisfaction, and Market Value," *Journal of Marketing*, 70(4), 1–18.

Mann, Michael E., and Tom Toles (2016), *The Madhouse Effect: How Climate Change Denial is Threatening our Planet, Destroying our Politics, and Driving us Crazy*, Columbia University Press.

Meinrenken, Christoph J., Scott M. Kaufman, Siddharth Ramesh, and Klaus S. Lackner (2012), "Fast Carbon Footprinting for Large Product Portfolios," *Journal of Industrial Ecology*, 16(5), 669–679.

Moorthy, Sridhar (2005), "A General Theory of Pass-Through in Channels With Category Management and Retail Competition," *Marketing Science*, 24(1), 110–122.

Nijs, Vincent, Kanishka Misra, Eric T. Anderson, Karsten Hansen, and Lakshman Krishnamurthi (2010), "Channel Pass-Through of Trade Promotions," *Marketing Science*, 29(2), 250–267.

Nordhaus, William (2019), "Climate Change: The Ultimate Challenge for Economics," *American Economic Review*, 109(6), 1991–2014.

Papadas, Karolos-Konstantinos, George J. Avlonitis, Marylyn Carrigan (2017), "Green Marketing Orientation: Conceptualization, Scale Development and Validation," *Journal of Business Research*, 80, 236–246.

Parasuraman, A., Valarie A. Zeithaml, and Leonard L. Berry (1985), "A Conceptual Model of Service Quality and its Implications for Future Research," *Journal of Marketing*, 49(4), 41–50.

Porter, Michael E., and Class van der Linde (1995), "Toward a New Conception of the Environment-Competitiveness Relationship," *Journal of Economic Perspectives*, 9(4), 97–118.

Rust, Roland T., Christine Moorman, and Peter R. Dickson (2002), "Getting Return on Quality: Revenue Expansion, Cost Reduction, or Both?" *Journal of Marketing*, 66(4), 7–24.

Rust, Roland T., and Anthony J. Zahorik (1993), "Customer Satisfaction, Customer Retention, and Market Share," *Journal of Retailing*, 69(2), 193–215.

Rust, Roland T., Anthony J. Zahorik, and Timothy L. Keiningham (1995), "Return on Quality (ROQ): Making Service Quality Financially Accountable," *Journal of Marketing*, 59(2), 58–70.

Spence, A. Michael (1975), "Monopoly, Quality, and Regulation," *The Bell Journal of Economics*, 6(2), 417–429.

Stern, Nicholas (2008), "The Economics of Climate Change," *American Economic Review: Papers and Proceddings*, 98(2), 1–37.

The CMO Survey (2019), "Top Marketing Trends of the Decade" (accessed March 6, 2020), https://bit.ly/3axxFtx.

The Guardian (2019, October 9), "Half a Century of Dither and Denial—a Climate Crisis Timeline" (accessed December 27, 2019), http://bit.ly/2EVPVim .

The Economist (2019, December 7), "Climate Change—The Necessity of Pulling Carbon Dioxide out of the Air" (accessed December 10, 2019), econ.st/36nQopi.

The Economist (2014, August 30), "Schumpeter—The New Green Wave" (accessed June 12, 2019), econ.st/2vqKeEM.

The World Bank (2015), "State and Trends of Carbon Pricing 2015," Washington, DC.

Tse, David K., and Peter C. Wilton (1988), "Models of Consumer Satisfaction Formation: An Extension," *Journal of Marketing Research*, 25(2), 204–212.

United Nations (2020), "Climate Neutral Now" (accessed May 8, 2020), https://bit.ly/2SPcooV.

United Nations (2019), "Put a Price on Carbon" (accessed May 15, 2020), https://bit.ly/3cBLtom.

United Nations Environment Programme (2019), "Carbon Offsets Are Not Our Get-Out-Of-Jail Free Card" (accessed December 10, 2019), bit.ly/349DZ6M.

UPS (2019), "Receiving a UPS Carbon Neutral Shipment" (accessed May 15, 2020), https://bit.ly/2LyZ9EV.

Vandenbergh, Michael P., Thomas Dietz, and Paul C. Stern (2011), "Time to Try Carbon Labelling," *Nature Climate Change*, 1(1), p. 4.

Viscusi, W. Kip, Joseph E. Harrington, Jr., and David E. M. Sappington (2018), *Economics of Regulation and Antitrust* (5th ed.), MIT Press.

Whitmarsh, Lorraine, and Stuart Capstick (2018), "Perceptions of Climate Change," in S. Clayton and C. Manning (eds.), *Psychology and Climate Change* (pp. 13–33), Academic Press.

Wicker, Pamela, and Susanne Becken (2013), "Conscientious vs. Ambivalent Consumers: Do Concerns About Energy Availability and Climate Change Influence Consumer Behaviour?" *Ecological Economics*, 88, 41–48.

Winston, Andrew, George Favaloro, and Tim Healy (2017), "Energy Strategy for the C-Suite," *Harvard Business Review*, 95(1), 139–146.

Yalabik, Baris, and Richard J. Fairchild (2011), "Customer, Regulatory, and Competitive Pressure as Drivers of Environmental Innovation," *International Journal of Production Economics*, 131(2), 519–527.

Appendix

Proof of Proposition 1. Assuming that the profit function $\pi(\kappa, p; \lambda)$ is strictly concave in (κ, p), the profit-maximizing product carbon footprint κ^* and price p^* must satisfy the following necessary and sufficient Kuhn-Tucker conditions (the multipliers $\mu_1 \geq 0$ and $\mu_2 \geq 0$ are associated with the inequality constraints):

$$-c'(\kappa^*)D(\kappa^*, p^*; \lambda) + [p^* - c(\kappa^*)]D_\kappa(\kappa^*, p^*; \lambda) + \mu_1 - \mu_2 = 0 \quad \text{(A.1)}$$

$$D(\kappa^*, p^*; \lambda) + [p^* - c(\kappa^*)]D_p(\kappa^*, p^*; \lambda) = 0 \quad \text{(A.2)}$$

$$\mu_1 \kappa^* = 0 \text{ and } \mu_2(\kappa^* - \overline{\kappa}) = 0.$$

Depending on the slope of the unit cost function, we distinguish two cases. First, we consider the case where $c'(\kappa) > 0$. Suppose that $D_\kappa = 0$ and $\kappa^* > 0$. Then, Equation A.1 leads to a contradiction as $\mu_1 = 0$, so that $\kappa^* = 0$. This result holds a fortiori if $D_\kappa < 0$. Second, we assume that $c'(\kappa) < 0$. If $D_\kappa = 0$, then a solution that involves $\kappa^* < \overline{\kappa}$ leads to a contradiction in Equation A.1, so that $\kappa^* = \overline{\kappa}$. Next, if $D_\kappa < 0$, then the choice of the product carbon footprint is governed by the relative strength of the cost effect and the demand effect of increasing κ: If $-c'(0)D + [p^* - c(0)]D_\kappa \leq 0$, then $\kappa^* = 0$, whereas if $-c'(\overline{\kappa})D + [p^* - c(\overline{\kappa})]D_\kappa \geq 0$, then $\kappa^* = \overline{\kappa}$; otherwise there is an interior solution with $\kappa^* \in (0, \overline{\kappa})$. □

Proof of Proposition 2. First, from Proposition 1, $\kappa^* = 0$ and $p^*(0)$ if $c'(\kappa) > 0$. Since $D(0, p^*(0); 0) = D(0, p^*(0); \lambda)$ for $\lambda > 0$, stronger climate concerns leave profit unchanged.

Second, if $c'(\kappa) < 0$, there are two subcases: the emergence and the reinforcement of climate concerns. In the absence of climate concerns ($\lambda = 0$), profit at $\overline{\kappa}$ is given by $\pi(\overline{\kappa}, p; 0) = [p - c(\overline{\kappa})]D(\overline{\kappa}, p; 0)$. Instead, when consumers have climate concerns ($\lambda > 0$), profit at $\kappa^* \leq \overline{\kappa}$ is given by $\pi(\kappa^*, p; \lambda) = [p - c(\kappa^*)]D(\kappa^*, p; \lambda)$. Since the emergence of climate concerns reduces demand and (weakly) increases unit cost, this implies that

$$\pi(\kappa^*, p^*; \lambda) < \pi(\overline{\kappa}, p^0; 0), \tag{A.3}$$

where $p^* = \arg\max_p \pi(\kappa^*, p; \lambda)$ and $p^0 = \arg\max_p \pi(\overline{\kappa}, p; 0)$, which means that the emergence of climate concerns reduces profit. Note that, while $\kappa^* \leq \overline{\kappa}$, the impact on pricing is ambiguous due to the countervailing cost and demand effects.

Instead, when climate concerns are reinforced, applying the envelope theorem yields

$$\frac{\pi(\kappa^*, p^*; \lambda)}{d\lambda} = [p^* - c(\kappa^*)]D_\lambda(\kappa^*, p^*; \lambda) < 0, \tag{A.4}$$

where $D_\lambda = -f(p + z(\kappa; \lambda))z_\lambda(\kappa; \lambda)$ from Equation 2 and $z_\lambda(\kappa; \lambda) > 0$ by assumption, which means that the reinforcement of climate concerns reduces profit. To understand the impact of reinforced climate concerns on product design, suppose that $\kappa^* \in (0, \overline{\kappa})$, so that the multipliers μ_1 and μ_2 are zero in Equations A.1 and A.2. Applying Cramer's rule yields

$$\frac{d\kappa^*(\lambda)}{d\lambda} = -\frac{\pi_{pp}\pi_{\kappa\lambda} - \pi_{\kappa p}\pi_{p\lambda}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}} \tag{A.5}$$

and

$$\frac{dp^*(\lambda)}{d\lambda} = -\frac{\pi_{\kappa\kappa}\pi_{p\lambda} - \pi_{p\kappa}\pi_{\kappa\lambda}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}}. \tag{A.6}$$

The expression in the denominators of Equations A.5 and A.6 is the determinant of the Hessian matrix of $\pi(\kappa, p; \lambda)$, which is positive under the concavity assumption. Without additional restrictions on the profit function (and thus the demand function), the impact of stronger climate concerns on the profit-maximizing product carbon footprint and price is ambiguous. Clearly, the product carbon footprint is decreasing in λ if $\pi_{\kappa\lambda} > \frac{\pi_{\kappa p}\pi_{p\lambda}}{\pi_{pp}}$ and the price is increasing in λ if $\pi_{p\lambda} < \frac{\pi_{p\kappa}\pi_{\kappa\lambda}}{\pi_{\kappa\kappa}}$. □

Proof of Proposition 3. The corporate carbon footprint results from multiplying the product carbon footprint by demand, and can therefore be written as

$$\Phi^*(\lambda) = \kappa^*(\lambda) D(\kappa^*(\lambda), p^*(\lambda); \lambda). \tag{A.7}$$

Differentiating Equation A.7 with respect to λ yields

$$\frac{d\Phi^*(\lambda)}{d\lambda} = \frac{d\kappa^*(\lambda)}{d\lambda} D + \kappa^*(\lambda) \left(D_\kappa \frac{d\kappa^*(\lambda)}{d\lambda} + D_p \frac{dp^*(\lambda)}{d\lambda} + D_\lambda \right), \tag{A.8}$$

where the arguments of the demand function are suppressed for convenience. Proposition 2 implies that the terms on the right-hand side of Equation A.8 cannot be unambiguously signed without more restrictive assumptions on demand. However, if the increase in demand in response to stronger climate concerns is sufficiently large, stronger climate concerns increase the corporate carbon footprint even if it is optimal for the firm to lower the product carbon footprint. □

Proof of Proposition 4. Suppose that $c'(\kappa) < 0$. Adopting an offset strategy yields the profit

$$\pi(\kappa^o, p^o; \omega) = [p^o - c(\kappa^o) - \omega\kappa^o] D(0, p^o),$$

where (κ^o, p^o) is the profit-maximizing product design under offsetting. Applying the envelope theorem yields

$$\frac{d\pi(\kappa^o, p^o; \omega)}{d\omega} = -\kappa^o D(0, p^o) < 0.$$

Since $\pi(\bar{\kappa}, p^o; 0) > \pi(\kappa^*, p^*; \lambda)$ from Equation A.3 and $\pi(\kappa^o, p^o; \omega)$ decreases in ω, there exists $\bar{\omega}$ such that $\pi(\kappa^o, p^o; \omega) > \pi(\kappa^*, p^*; \lambda)$ for $\omega \in [0, \bar{\omega})$, which means that the firm can benefit from adopting a climate neutral strategy when the offsetting costs are sufficiently low.

From Proposition 3, we know that stronger climate concerns reduce profit in the benchmark case absent carbon offsets. Therefore, stronger climate concerns make the adoption of an offset strategy more attractive to the firm. □

Proof of Proposition 5. Following convention, we define welfare as the sum of consumer surplus and profit. Consumer surplus is obtained by adding up the utilities from buyers and non-buyers:

$$\begin{aligned} S(\kappa, p; \lambda) &= \int_{p+z(\kappa;\lambda)}^{\infty} [v - p - z(\kappa;\lambda) - E] dF(v) + \int_0^{p+z(\kappa;\lambda)} [-E] dF(v) \\ &= \int_{p+z(\kappa;\lambda)}^{\infty} [v - p - z(\kappa;\lambda)] dF(v) - E \\ &= \int_{p+z(\kappa;\lambda)}^{\infty} v dF(v) - pD(\kappa, p; \lambda) - \Phi(\kappa, p; \lambda), \end{aligned} \tag{A.9}$$

where the third equality uses the definition of demand in Equation 2, the definition of the market externality in Equation 3, and where $\Phi(\kappa, p; \lambda)$ denotes the corporate carbon footprint. Adding up consumer surplus in Equation A.9 and profit in Equation 4 yields welfare:

$$W(\kappa, p; \lambda) = \int_{p+z(\kappa;\lambda)}^{\infty} v dF(v) - c(\kappa)D(\kappa, p; \lambda) - \Phi(\kappa, p; \lambda). \tag{A.10}$$

Drawing on Spence (1975), let $\overline{\pi}(\kappa) \equiv \max_p \pi(\kappa, p; \lambda)$ and $\overline{W}(\kappa) \equiv \max_p W(\kappa, p; \lambda)$. The ratio of maximized profit to maximized welfare is defined as

$$\beta(\kappa) \equiv \frac{\overline{\pi}(\kappa)}{\overline{W}(\kappa)}.$$

Taking logs and differentiating, it follows that

$$\frac{\beta'(\kappa)}{\beta(\kappa)} = \frac{\overline{\pi}'(\kappa)}{\overline{\pi}(\kappa)} - \frac{\overline{W}'(\kappa)}{\overline{W}(\kappa)}.$$

Now let κ^* denote the profit-maximizing product carbon footprint. Since $\overline{\pi}'(\kappa^*) = 0$ by definition, it follows that

$$\frac{\beta'(\kappa^*)}{\beta(\kappa^*)} = -\frac{\overline{W}'(\kappa^*)}{\overline{W}(\kappa^*)}.$$

Thus, the product carbon footprint κ^* exceeds the socially-optimal level if $\beta'(\kappa^*) > 0$ and conversely, which implies that the firm's choice of the product carbon footprint is not necessarily consistent with corporate social responsibility.

Adopting an offset strategy is consistent with corporate social responsibility if it increases welfare compared to the no-offset strategy. To this end, consider an offset market in which an offset provider compensates emissions at variable cost $\phi \omega \kappa^o D(p^o)$, where $\phi \in [0,1]$ is an efficiency parameter, and fixed cost $F > 0$. In this scenario, welfare is obtained by adding up consumer surplus and the profits from the firm and the offset provider:

$$W(\kappa^o, p^o; \omega) = \int_{p^o}^{\infty} v dF(v) - c(\kappa^o) D(p^o) - \phi \omega \kappa^o D(p^o) - F. \tag{A.11}$$

Since the offset cost $\omega \kappa^o D(p^o)$ is a transfer from the firm to the offset provider, it cancels out in the welfare calculation. Clearly, a climate neutral strategy is economically efficient if the social cost of carbon offsetting $\phi \omega \kappa^o D(p^o) + F$ is sufficiently low compared to the climate damage that results from the corporate carbon footprint under a no-offset strategy, given by $\Phi(\kappa^*, p^*; \lambda)$. □

Proof of Proposition 6. The profit-maximizing product carbon footprint and price satisfy the following Kuhn-Tucker conditions (the multipliers $\mu_i \geq 0$, $i = 1,2,3$, are associated with the inequality constraints):

$$D(\kappa^r, p^r) + (p^r - c(\kappa^r)) D_p(\kappa^r, p^r) - \mu_3 \Phi_p(\kappa^r, p^r) = 0 \tag{A.12}$$

$$-c'(\kappa^r) D(\kappa^r, p^r) + (p^r - c(\kappa^r)) D_\kappa(\kappa^r, p^r) + \mu_1 - \mu_2 + \mu_3 \Phi_\kappa(\kappa^r, p^r) = 0 \tag{A.13}$$

$$\mu_1 \kappa^r = 0, \quad \mu_2(\kappa^r - \overline{\kappa}), \quad \text{and} \quad \mu_3(\Phi(\kappa^r, p^r) - R) = 0.$$

We denote the unique constrained profit-maximizing product design by (κ^r, p^r). Assuming that the carbon constraint is binding and that $0 < \kappa^r < \overline{\kappa}$, the firm raises κ above the level that would be optimal absent carbon regulation if $\Phi_\kappa(\kappa, p) < 0$. Instead, if $\Phi_\kappa(\kappa, p) > 0$, it is optimal for the firm to lower the product carbon footprint in response to the regulatory intervention. □

Proof of Proposition 7. If the firm meets the carbon cap by adjusting the product design, the profit impact of uncertain regulation is given $\pi^* - [\rho\pi^r + (1-\rho)\pi^*] = \rho(\pi^* - \pi^r)$, where π^r is the constrained optimal profit. Instead, if the firm does not meet the carbon cap and decides to purchases carbon allowances, the profit impact is given by $\pi^* - [\rho(\pi^* - \varpi(\Phi(p^*, \kappa^*) - R)) + (1-\rho)\pi^*] = \rho\varpi(\Phi(p^*, \kappa^*) - R)$. Clearly, the firm chooses the option that minimizes the negative profit impact. Therefore, the expected cost of a cap-and-trade regulation to the firm is given by $\rho \min\{\pi^* - \pi^r, \varpi(\Phi(p^*, \kappa^*) - R)\}$. □

Proof of Proposition 8. To understand the impact of a carbon tax, consider an interior solution and suppose that $\pi_{\kappa t} > \min\left\{\frac{\pi_{\kappa p}\pi_{pt}}{\pi_{pp}}, \frac{\pi_{\kappa\kappa}\pi_{pt}}{\pi_{p\kappa}}\right\}$. Totally differentiating the (necessary and sufficient) first-order conditions and applying Cramer's rule yields

$$\frac{d\kappa^*(t)}{dt} = -\frac{\pi_{pp}\pi_{\kappa t} - \pi_{\kappa p}\pi_{pt}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}} \tag{A.14}$$

and

$$\frac{dp^*(t)}{dt} = -\frac{\pi_{\kappa\kappa}\pi_{pt} - \pi_{p\kappa}\pi_{\kappa t}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}}. \tag{A.15}$$

The expression in the denominators of Equations A.14 and A.15 is the determinant of the Hessian matrix of $\pi(\kappa, p)$, which is positive under the concavity assumption. Assuming that π_{pp}, $\pi_{\kappa p}$, and π_{pt} are negative, the constrained profit-maximizing product carbon footprint is decreasing in the tax rate t if $\pi_{\kappa t} > \frac{\pi_{\kappa p}\pi_{pt}}{\pi_{pp}}$ (which is the case if $\pi_{\kappa t}$ is not too negative, as assumed). Further, assuming that $\pi_{\kappa\kappa} < 0$, the price is increasing in the tax rate if $\pi_{\kappa\lambda} > \frac{\pi_{\kappa\kappa}\pi_{pt}}{\pi_{p\kappa}}$, a condition that is assumed to hold.

Using Proposition 3, the corporate carbon footprint can be expressed as

$$\Phi^*(t) \equiv \kappa^*(t) D(p^*(t), \kappa^*(t), t). \tag{A.16}$$

Differentiating Equation A.16 with respect to the tax rate yields

$$\frac{d\Phi^*(t)}{dt} = \frac{d\kappa^*(t)}{dt} D + \kappa^*(t)\left(D_p \frac{dp^*(t)}{dt} + D_\kappa \frac{d\kappa^*(t)}{dt}\right), \tag{A.17}$$

where the arguments of the functions are suppressed for convenience. Since $\frac{d\kappa^*(t)}{dt} < 0$, the first term on the right-hand side of Equation A.17 is negative. This implies, since

$\frac{dp^*(t)}{dt} > 0$, $D_p < 0$, and $D_\kappa < 0$, that the sign of the second term of Equation A.17 is ambiguous. As a result, the overall impact of a carbon tax on the corporate carbon footprint is ambiguous.

The expected cost of carbon taxation is the difference between the actual profit and the expected profit under uncertain taxation, which can be expressed as $\pi^*(0) - [\rho\pi^*(t) + (1-\rho)\pi^*(0)] = \rho\{\pi^*(0) - \pi^*(t)\}$, where $\pi^*(0) \equiv \pi^*$ is the profit under a zero tax rate. Since

$$\pi^*(0) - \pi^*(t) \; = -\int_0^t \frac{d\pi^*(y)}{dy} dy = \int_0^t \Phi^*(y) dy$$

is positive, where the last equality follows from the application of the envelope theorem and the definition of the corporate carbon footprint, uncertain taxation reduces profit. □

Proof of Proposition 9. In the absence of carbon regulation, the firm adopts the green technology if $\pi_1^* - \pi_0^* \geq f$. With regulation, the firm adopts the green technology if $\rho(\pi_1^r - \pi_0^r) + (1-\rho)(\pi_1^* - \pi_0^*) \geq f$. Therefore, if $\pi_1^r - \pi_0^r > \pi_1^* - \pi_0^*$, the threat of carbon regulation captured by $\rho > 0$ relaxes the standard adoption constraint. □

Proof of Proposition 10. Demand for each firm i, $i = 1,2$, can be derived from the location of the consumer who is indifferent between buying from firm 1 and from firm 2, denoted $\hat{x}$. From the indirect utility function in Equation 8, this location solves the indifference condition $v_1(\hat{x}) = v_2(\hat{x})$. With linear mismatch, the consumer located at $\hat{x}$ segments the market, that is, consumers located to the left of $\hat{x}$ purchase from firm 1, while consumers located to the right of $\hat{x}$ purchase from firm 2. Demand of firm i can therefore be derived as

$$D_i(\boldsymbol{\kappa}, \mathbf{p}; \lambda) = \frac{1}{2} - \lambda(\kappa_i - \kappa_j) - (p_i - p_j). \tag{A.18}$$

To establish the claim, we first focus on the symmetric case where $c_1^0 = c_2^0 \equiv 1$ and set $\lambda = 1$.[4] First, we analyze the setting in which both firms adopt a no-offset strategy. Firm i then solves

$$\max_{\kappa_i, p_i} \quad \pi_i(\kappa_i, p_i) = \left[p_i - (1-\kappa_i)^2\right] D_i(\boldsymbol{\kappa}, \mathbf{p}; 1), \tag{A.19}$$

where demand follows by setting $\lambda = 1$ in Equation A.18. Simultaneously solving the (necessary and sufficient) first-order conditions yields $\kappa_i^* = \frac{1}{2}$ and $p_i^* = \frac{3}{4}$. By substitution, $\hat{x} = \frac{1}{2}$, $\pi_i^* = \frac{1}{4}$ (the upper-left cell in Figure 3), and $\Phi_i^* = \frac{1}{4}$. Consumer surplus for buyers of firm 1 is obtained as

$$S_1(\kappa_1, p_1; 1) = \int_0^{\hat{x}} (v - p_1 - \kappa_1 - \frac{x}{2} - E)dx. \tag{A.20}$$

Since consumers fully internalize their climate externality ($\lambda = 1$), it follows that $E = 0$. By substitution, Equation A.20 reduces to $S_1^* = \frac{8v-11}{16}$, and symmetry implies that $S_1^* = S_2^*$. Welfare is obtained by aggregating consumer surplus and profit net of the climate impact across firms:

$$W^* = \sum_{i=1}^{2}(S_i^* + \pi_i^* - \Phi_i^*) = v - \frac{11}{8}. \tag{A.21}$$

Second, we analyze the setting in which firm 1 uses an offset strategy and firm 2 uses a no-offset strategy. Firm 1 therefore solves

$$\max_{\kappa_1, p_1} \quad \pi_1(\kappa_1, p_1; \lambda) = \left[p_1 - (1-\kappa_1)^2 - \omega\right] \left(\frac{1}{2} + \kappa_2 - (p_1 - p_2)\right), \tag{A.22}$$

where ω denotes the offset cost per unit of carbon emissions. Instead, firm 2 solves

$$\max_{\kappa_2, p_2} \quad \pi_2(\kappa_2, p_2) = \left[p_2 - (1-\kappa_2)^2\right] \left(\frac{1}{2} - \kappa_2 - (p_2 - p_1)\right). \tag{A.23}$$

Simultaneously solving the first-order conditions and substituting back into the profit functions yields $\hat{\pi}_1 = \frac{1}{144}(\omega(\omega-4)+9)^2 \equiv A$ and $\hat{\pi}_2 = \frac{1}{144}(\omega(\omega-4)-3)^2 \equiv B$ (the lower-left cell in Figure 3). Since $\hat{\pi}_1 > \frac{1}{4}$ and $\hat{\pi}_2 < \frac{1}{4}$ for all $\omega < 1$, adopting an offset strategy is a dominant strategy for firm 1. Note that the other asymmetric outcome in

[4] The choice of parameter values simplifies the analysis without qualitatively affecting the results. The full proof is available from the authors upon request.

which firm 1 uses a no-offset strategy and firm 2 uses an offset strategy can be obtained by reversing the payoffs (the upper-right cell in Figure 3).

Third, we analyze the setting in which both firms adopt an offset strategy. Therefore, firm i solves

$$\max_{\kappa_i, p_i} \quad \pi_i(\kappa_i, p_i) = \left[p_i - (1-\kappa_i)^2 - \omega\right]\left(\frac{1}{2} - (p_i - p_j)\right). \tag{A.24}$$

Simultaneously solving the first-order conditions and substituting back into the profit functions yields $\overline{\pi}_i = \frac{1}{4}$. Since adopting an offset strategy is a strictly dominant strategy for each firm, equilibrium play involves that both firms use an offset strategy.

These equilibrium strategy choices are consistent with corporate social responsibility if welfare is improved over the benchmark case where both firm use a no offset strategy. Welfare under offset strategies can be derived as

$$\begin{aligned}\overline{W}^* &= \sum_{i=1}^{2}(S_i^* + \pi_i^*) + (\omega - \phi)\sum_{i=1}^{2}\Phi_i^* - F \\ &= v - \frac{\omega^2}{4} - \frac{\phi}{2}(2-\omega) - \frac{1}{8} - F,\end{aligned} \tag{A.25}$$

where $(\omega - \phi)\sum_{i=1}^{2}\Phi_i^* - F$ is the profit of the offset provider.

Carbon offsets improve welfare over the case absent offsets if $\overline{W}^* > W^*$. Clearly, this holds if the marginal cost ϕ and the fixed cost F are sufficiently small, that is, as long as the offset technology is sufficiently cost effective. □