Carbon Footprinting and Pricing Under Climate Concerns*

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Abstract

This paper studies how firms should design a product by choosing the carbon footprint and price when facing climate concerns. The authors first show how the cost and demand effects of reducing the carbon footprint determine the profit-maximizing carbon footprint and price, and examine how firms should adjust the product design in the face of stronger climate concerns. Paradoxically, they find that stronger climate concerns may increase the firm's climate impact. Second, the authors establish that offsetting carbon emissions to reach a net zero climate impact may create a win-win outcome for the firm and the climate, even if the product's carbon footprint before offsetting is larger. Third, the authors show how government regulation in the form of a cap-and-trade scheme or a carbon tax affects product design, firm profitability, and the adoption of green technologies. Finally, the authors study profit-maximizing product design and carbon offsetting under competition. These results are meant to help marketers understand the consequences of voicing climate concerns with an organization.

Keywords: Product design, climate impact, corporate social responsibility, carbon regulation, carbon offsetting, net zero emissions.

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1 Introduction

The consequences of climate change have become apparent and touch every corner of our society. Although 197 nations formally committed to reducing greenhouse gas emissions at the Rio de Janeiro Earth Summit in 1992, 50 percent of the carbon dioxide humankind has released into the atmosphere since the industrial revolution was added after 1990 (*The Economist* 2019). As the planet warms up, the debate about climate change and the need to find a solution is also increasingly heated. Greta Thunberg, a teenage climate activist and *2019 Time Person of the Year*, condemned world leaders gathered at the 2019 U.N. Action Summit held in New York: "How dare you continue to look away!"

Public opinion has also reached a point where "business as usual" is hard to justify. In December 2019, the *The Guardian* (2019) accused fossil fuel companies of "dither and denial." For airlines, "flight-shaming" (*Forbes* 2019) and the European Commission's Green Deal, which challenges tax exemptions on kerosene and free carbon allowances under Europe's emissions trading system (*Bloomberg* 2019), create turbulence and pose a threat to the business model. Amid much fanfare, several airlines have responded by adopting approaches that are broadly in line with the three-step process "Measure, Reduce, Offset" outlined in the U.N. Climate Neutral Now initiative. *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." *British Airways* made a similar move and communicated that "from January 2020, we'll become the first UK airline to offset carbon emissions on domestic flights." *JetBlue* goes net zero as of July 2020, making it the first major US airline to do so.

The recent experience of airlines, which generalizes to a vast array of organizations in manufacturing and service industries, raises the question of how firms should adjust products and prices in response to climate concerns in the market. Marketing professionals play a critical role here because they represent the voice of consumers among internal stakeholders—they sense changes in preferences and champion them within their firms. According to a recent article, "CMOs 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), yet they consistently rate themselves poorly on a variety of metrics related to societal and environmental impact (CMO Survey 2019).

Against this backdrop, the goal of our research is to develop an understanding of the consequences of championing climate concerns within an organization. A powerful metric to capture climate concerns are *carbon footprints*, which measure the climate impact of products (or services) in carbon dioxide equivalent (CO_2eq) emissions. Calculating carbon footprints has become standard (Meinrenken et al. 2012; Vandenbergh, Dietz, and Stern 2011) and they can be certified by consulting firms based on international accounting standards (GHG Protocol 2011; ISO 2006).[1] Accordingly, we develop a model of carbon footprinting and pricing under climate concerns to address several issues.[2] First, we study the impact of consumers' climate concerns on carbon footprinting and pricing decisions, and how they determine the *climate impact* of the firm, obtained by multiplying the carbon footprint by demand. These climate concerns are well documented (Whitmarsh and Capstick 2018; Wicker and Becken 2013), and media coverage of climate change, especially the need to reduce the carbon footprint, is shown to motivate consumers to make more sustainable consumption decisions (Chen et al. 2019; Holt and Barkemeyer 2102).

Second, we consider the profitability of *carbon offsetting*, a nascent strategy that recently gained popularity (*The Economist* 2019). Third, we look at the consequences of these managerial decisions for social welfare, which reflects on a firm's corporate social responsibility (CSR). Fourth, we study impact of regulation on product design and green technology adoption. Finally, we study the impact of competition.

The starting point of our analysis is a monopoly setting in which a firm designs a product (or service) by choosing the carbon footprint and price, henceforth referred to as

[1]Carbon footprinting plays not only a role in firm-to-consumer markets, but also in business-to-business markets to understand the climate impact of the supply chain (Diabat and Simchi-Levi 2010).

[2]Using terminology from the Greenhouse Gas Protocol (2011), we define the 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).

product design. Importantly, changes in the carbon footprint not only have a cost effect, but also a demand effect. 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 climate impact, which may cause a market externality (depending on the strength of the consumers' climate concerns). In addition, a regulator may want to curb the firm's climate impact. Product design and the climate impact are therefore endogenously determined by the interplay of the choices made by the firm, consumers, and the regulator. Figure 1 summarizes the main components of the analytical framework and highlights the relationship between product design, the firm's climate impact and the climate externality.

We derive three key results for this basic analytical framework. First, we show how the profit-maximizing carbon footprint depends on the size of the cost effect relative to the demand effect of reducing the carbon footprint.[3] This result reflects the familiar "return on quality" logic (Rust, Moorman, and Dickson 2002; Rust and Zahorik 1993; Rust, Zahorik, and Keiningham 1995), but considers consumers' climate concerns. Second, we analyze how firms should respond to stronger climate concerns. It turns out that the impact of stronger climate concerns on profit-maximizing product design is generally ambiguous, and we identify the conditions under which it is optimal for firms to decrease the carbon footprint and increase the price. In addition, we note that, depending on the shape of the demand curve, stronger climate concerns may induce the firm to increase (rather than decrease) its carbon footprint. Third, we show that the firm's climate impact may increase with stronger climate concerns even when it reduces the product's 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 carbon footprint outweighs the reduction in the carbon footprint (i.e., the firm falls victim to its success in reducing the carbon footprint at the product level).

[3]In particular, it is optimal to offer the product with the lowest cost and highest carbon footprint if the demand effect is zero (i.e., in the standard setting where consumers have no climate concerns).

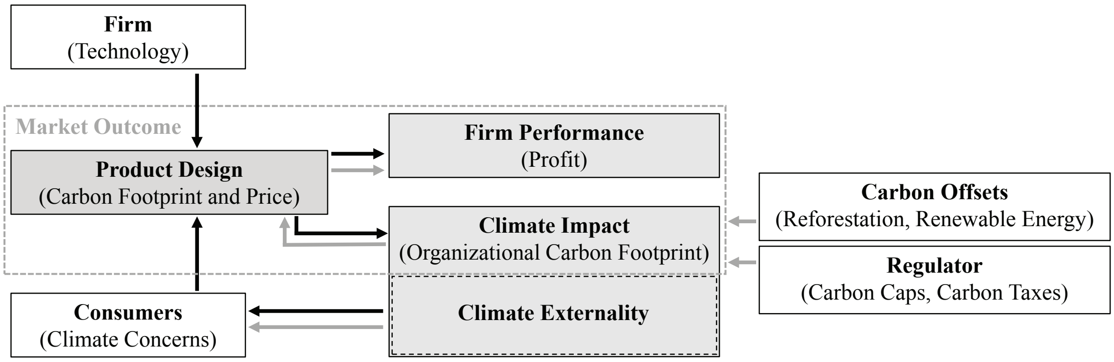

Figure 1: Components of the analytical framework.

We then extend the analysis in several directions. First, we allow for the possibility that the firm purchases carbon offsets to attain a net zero climate impact ("go net zero"). As a result, a firm may be able to offer a climate-neutral product (after offsetting) even if its carbon footprint (before offsetting) is large. 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 carbon footprint to net zero. In this case, going net zero is a "win-win" strategy in the sense that the climate impact decreases while the firm's profit increases relative to the case without offsetting.

Second, we examine the profit-maximizing product design from a welfare perspective that accounts for the triple bottom line of profit, planet and people. More specifically, we explore the conditions under which the firm's decisions are consistent with corporate social responsibility (CSR). We show that the profit-maximizing carbon footprint generally deviates from the socially optimal level in the absence of offsetting. A net zero carbon footprint, in turn, is economically efficient if the cost of offsetting is sufficiently low compared to the social cost of the climate impact. These results support the view that a focus on profit may be inconsistent with corporate social responsibility.

Third, we analyze how carbon regulation affects a firm's product design and climate impact. We study three popular regulatory market interventions (The World Bank 2015): carbon caps, cap-and-trade systems, and carbon taxes. We find that these instruments typically reduce firm profit. In addition, we show that while a carbon cap is well-suited to curbing the firm's climate impact, it may increase (rather than decrease) the carbon footprint, whereas a carbon tax may reduce the carbon footprint but has an ambiguous impact on the climate impact. We also consider the impact of carbon regulation on the adoption of a green technology.

Finally, we show how our results on the profit-maximizing product design and carbon offsetting generalize to settings with competition. Considering a setting with two firms and both horizontal and vertical product differentiation, we show that going net zero is a "win-win" strategy for both firms under reasonable assumptions: Specifically, while the decision of the competitor to go net zero reduces the competitive advantage of adopting an offset strategy, it remains the strictly dominant strategy for both firms if the cost of offsetting the emissions is sufficiently low. 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 results and highlights the key insights for marketers. With respect to the literature, we 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 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 help managers understand the climate impact of product design decisions, 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) by providing a formal analysis of the triple bottom line approach. 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.

Topic	Insight
Product Design (Propositions 1 and 2)	Reducing a product's carbon footprint impacts not only the cost of production, but also demand. Surprisingly, stronger climate concerns do not necessarily reduce the carbon footprint—what matters is the net effect of these countervailing forces.
Climate Impact (Proposition 3)	Paradoxically, offering a greener product in response to stronger climate concerns can increase the firm's overall climate impact due to the higher sales volume.
Carbon Offsetting (Proposition 4)	Offsetting carbon emissions can create a win-win for the firm and climate if the demand effect of reducing the firm's climate impact to net zero is sufficiently large compared to the cost of carbon removal.
Corporate Social Responsibility (Proposition 5)	Offsetting carbon emissions can create a triple-win for the firm, climate, and society if the cost of carbon removal is sufficiently low compared to the social cost of the climate impact.
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's carbon footprint, but also the climate impact of each firm. If the offset technology is sufficiently effective, going net zero can create a triple-win outcome.

Table 1: Overview of results.

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 profit-maximizing product design. We also extend classic work by Spence (1975) by showing how climate concerns affect price and quality decisions. 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 carbon footprint $\kappa \in [0, \overline{\kappa}]$, the emissions generated by producing a single unit of the product measured in carbon dioxide equivalents (CO_2eq), for given intrinsic features of the product.[4] The set $[0, \overline{\kappa}]$ indicates the technologically feasible 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 gives rise to the unit cost function $c(\kappa)$ defined on $[0, \overline{\kappa}]$.

There is a unit measure of consumers who have climate concerns and evaluate the product based not only on intrinsic features and price p, but also on the carbon footprint κ. Specifically, a buyer derives utility

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

where v is the valuation of the intrinsic features, $z(\kappa; \lambda)$ measures the disutility from purchasing a product with carbon footprint κ, with $\lambda \geq 0$ capturing the strength of climate concerns, and where $E \geq 0$ 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 same irrespective of whether or not the consumer purchases the product. Normalizing the intrinsic utility of the outside option to zero, a consumer therefore 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 increasing and convex in κ, that is, $z_\kappa(\kappa; \lambda) > 0$ and $z_{\kappa\kappa}(\kappa; \lambda) \geq 0$, and can be interpreted as the guilt

[4]Chen (2001) assumes a tradeoff between traditional and environmental attributes, a technological constraint that could be added to our analysis.

or "cold prickle" (Andreoni 1995) of creating a carbon footprint. We set the disutility to zero if consumers do not have climate concerns or if the product is green, that is, $z(\kappa;0) = z(0;\lambda) = 0$.[5] 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 their 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 carbon footprint and price. Interpreting the carbon footprint as an inverse measure for product quality, a lower κ means higher quality and therefore higher demand. Lowering the carbon footprint implies *demand neutrality* when consumers do not care about creating a carbon footprint ($D_\kappa = 0$) and *demand expansion* when consumers have climate concerns ($D_\kappa < 0$). The novel aspect here is that "product quality" not only affects demand, but also has a climate impact.

The climate impact of the firm is calculated by multiplying the carbon footprint by demand and is thus given by $\Phi = \kappa D(\kappa, p;\lambda)$. Note that if buyers do not fully 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 climate impact if consumers do not care about creating a carbon footprint ($z(\kappa;0) = 0$). Note that the climate impact has distributional consequences if consumers do not fully internalize the climate externality.

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

3 Managing Carbon Footprint and Price

This section first derives the profit-maximizing carbon footprint and price, and then studies the impact of stronger climate concerns on product design. Next, we consider the impact of product-level decisions on the firm's climate impact. We assume throughout that the profit function is strictly concave and thus has a unique constrained global maximizer.

3.1 Profit-Maximizing Carbon Footprint and Price

The firm chooses the 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 both the carbon footprint and price have a dual impact on markup and demand. Our first result characterizes the profit-maximizing product design with carbon footprint κ^* and price $p^*(\kappa^*)$. To facilitate exposition, all proofs are relegated to the Appendix.

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

Proposition 1 mirrors the familiar "return on quality" logic (Rust, Moorman, and Dickson 2002; Rust and Zahorik 1993; Rust, Zahorik, and Keiningham 1995) and has two important managerial implications. First, if lowering the carbon footprint reduces unit cost, then it is optimal to increase efficiency (e.g., by eliminating waste) and thereby increase "process quality" (Deming 1986; Crosby 1979). Such green cost cutting is more attractive when lowering the carbon footprint not only reduces cost, but also increases demand because of higher perceived "product quality" (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 carbon footprint increases unit cost, there may be a tradeoff between the cost effect and the demand effect. Absent a demand effect, lowering the carbon footprint only results in higher unit cost and is therefore suboptimal under profit maximization. However, when the increase in demand outweighs the profit impact of higher unit cost, firms should reduce the 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 as a function of the cost and demand effects.

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 for product design.

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

Proposition 2 has two managerial implications. First, it shows that stronger climate concerns may increase (rather than decrease) the profit-maximizing carbon footprint. Intuitively, a lower carbon footprint may lead to a large cost effect and thereby create upward pressure on the price that outweighs the demand effect of the lower carbon footprint. Interpreting the carbon footprint as an inverse measure of product quality, Proposition 2 implies an ambiguous relationship between product quality and price and

	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: Cost and demand effects of lowering the carbon footprint, and profit-maximizing product design.

thereby adds to the literature on price-quality relationships (Gerstner 1985; Parasuraman, Zeithaml and Berry 1985).

Second, Proposition 2 implies that firms have a motive to downplay climate concerns due to their negative impact on profit. This suggests an intuitive explanation for climate change denial by polluting firms (Krugman 2018; Mann and Toles 2016). This result also points to a potential tension between product managers 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 adopting a triple bottom line.

3.3 Climate Impact

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

Proposition 3. *The climate impact of a profit-maximizing firm is* $\Phi^* = \kappa^* D(\kappa^*, p^*; \lambda)$. *Stronger climate concerns may increase the climate impact* Φ^* *even when it is optimal for firms to reduce the carbon footprint* κ^*.

Proposition 3 shows that reducing the carbon footprint in response to stronger climate concerns does not necessarily reduce a firm's climate impact. This occurs because the demand effect may result in higher sales and thus a greater climate impact—a situation where a firm that offers a product with a lower 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 climate impact of the firm. This is reminiscent of the rebound effect from technological progress (Alcott 2005): higher efficiency leads to an initial reduction in demand 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

Since climate change is a global environmental phenomenon, firms can achieve climate neutrality either by offering a green product ($\Phi^* = 0$), or by adopting an offset strategy where the firm's climate impact ($\Phi^* > 0$) is fully compensated for elsewhere (by funding projects that achieve an equivalent level of carbon dioxide saving), thereby creating a net zero carbon footprint. While carbon offsetting is arguably not the solution to climate change, it may allow firms to achieve climate neutrality even if the available production technology does not (yet) allow for a zero carbon footprint. In principle, any company can go net zero by buying offset services (investing in projects that provide for the planting of trees, renewable energy, etc.) from providers such as *Carbon Footprint Ltd*, *Gold Standard*, or *myclimate*.

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

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

where $\omega\kappa D(0, p)$ is total cost of compensating for the emissions to the firm to achieve a net zero carbon footprint. Importantly, with carbon offsets, demand depends on the net zero carbon footprint rather than the carbon footprint κ. The next result points to the possibility of a win-win outcome for the firm and the 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 climate impact to net zero. Surprisingly, using an offset strategy motivates a firm to increase the 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* do good for the climate. The key driver for this result is that relieving consumers from guilt by offering a product with a net zero carbon footprint has a demand-enhancing effect that directly translates into higher profit. Intuitively, the increase in demand comes from the ability of the firm to monetize guilt by bundling the product with carbon removal in a cost-efficient way to achieve a net zero carbon footprint. This profit effect may be reinforced by the lower unit cost that results from a higher carbon footprint (before compensation). In exchange, a firm must cover offsetting costs that are otherwise absent.

Our analysis shows that a firm is more prone to adopting 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 climate impact even when the standard tools of carbon regulation are not effective.

5 Corporate Social Responsibility

Sustainability is generally viewed as the triple bottom line of economic profitability, respect for the environment, and social justice (Boyd 2001; Huang and Rust 2011; Johnson 2009). To integrate these pillars of sustainability 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 triple-win outcome.

Proposition 5. *The carbon footprint under a no-offset strategy is positive and generally different from the socially optimal level. Adopting an offset strategy that results in net zero emissions is economically efficient if the cost of carbon removal is sufficiently low compared to the social cost of the climate impact.*

Proposition 5 confirms the notion that an exclusive focus 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 carbon footprint to exploit pricing power, which leads to an economically inefficient carbon footprint (Spence 1975). Interestingly, under an offset strategy, profit-maximization may result in a net zero 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 triple-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 compensation stems from the fact that emissions are compensated for 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 a firm's climate impact is to impose a binding carbon cap $R \geq 0$. An example of such a carbon cap is the European Unions's fleet-wide binding emissions target for new cars imposed on manufacturers.[6] In such a business environment, the firm solves the following problem:

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

The next result summarizes the impact of a binding carbon cap.

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

A binding carbon cap has the obvious effect of reducing the firm's climate impact and profit. More interestingly, a binding carbon cap may have the unintended consequence of increasing the carbon footprint. The intuition for this result is driven by the demand effect

[6] For details, see `https://bit.ly/37hLavC`.

of lowering κ: If $\Phi_\kappa < 0$, then lowering the carbon footprint translates into a higher climate impact even though κ is smaller. Consequently, the firm has an incentive to increase κ and thereby purposely reduce sales to meet the carbon target (demarketing). Instead, if $\Phi_\kappa > 0$, lowering κ relaxes the carbon constraint and thus provides an incentive to lower the carbon footprint. The impact on price is ambiguous because of the simultaneous cost and demand effects of a change in κ. In reality, 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). We next address how a firm can proactively deal with the uncertain introduction of a cap-and-trade system.

To capture regulatory uncertainty, we assume that a regulator is expected to implement a cap-and-trade system with probability $\rho \in [0,1]$, with carbon cap $R \geq 0$. In this case, the firm can choose among two options: adjust the product design to meet the 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 an emissions market.

Proposition 7. *The expected cost of a cap-and-trade regulation 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 cost of regulation 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 Taxation

In December 2019, the International Monetary Fund issued a report suggesting that a global average carbon price of $75 a ton could hit the Paris accord (IMF 2019). While a carbon cap directly limits the climate impact, such a price alters the cost structure of the firm with the goal of reducing the climate impact 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 carbon footprint if the demand effect is sufficiently strong compared to the cost effect, but has an ambiguous effect on the climate impact. 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 the tax rate t.*

Proposition 8 shows that while a higher tax rate may reduce the profit-maximizing carbon footprint, the effect on the climate impact is ambiguous because the product's lower carbon footprint may increase sales and therefore overall emissions (a rebound effect). The result also shows that the uncertain introduction of a carbon tax reduces expected profit: The carbon tax increases unit cost and thereby reduces firm profitability, as the increase in cost can only be partially passed on to consumers in the form of higher prices, similar to the imperfect pass-through of trade deals in the channel literature (Nijs, Misra, Anderson and Hansen 2010; Moorthy 2005).

The results show 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 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, Vernon and Harrington 2005). On the other hand, the results show why an offsetting strategy is an interesting option: a net zero carbon footprint makes regulation unnecessary and has an immediate positive impact on the climate. In contrast, a carbon tax affects the 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 while new technologies are developed.

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 new green technology $c_1(\kappa)$ at a fixed cost $f > 0$, where $c_0(\kappa) \geq c_1(\kappa)$ for all κ and $\overline{\kappa}_0 \geq \overline{\kappa}_1$. Letting π_0^* and π_1^* denote the profits in the absence of carbon regulation with the brown and the green technology, respectively, and letting CR_0^* and CR_1^* denote the corresponding costs of complying with regulation, the following result holds.

Proposition 9. *A firm facing the risk of regulation adopts the green technology if* $\pi_1^* - f \geq \pi_0^* - (CR_0^* - CR_1^*)$.

Proposition 9 shows that regulatory risk may provide an incentive for the firm to adopt the green technology. In particular, the uncertainty about the likelihood of carbon regulation relaxes the standard adoption condition $\pi_1^* - f \geq \pi_0^*$ if the green technology reduces the cost of regulation ($CR_1^* < CR_0^*$). Thus, the mere threat of carbon regulation may lead to the adoption of a green technology, greener product design, and a lower climate impact. Regulatory pressure can thus provide incentives for firms to do good for the climate by offering greener products, the standard link from regulation to promoting innovation (Porter and van der Linde 1995). More broadly, from a policy perspective, the threat of regulation puts the burden of technology adoption on the shoulders of the firm. In contrast, the R&D costs to develop carbon removal technologies are often government funded and carried by society. To make rapid progress in limiting the climate impact, one could therefore expect that governments will rely on both regulation and carbon removal technologies.

7 Competitive Strategy

To this point, we have explored a monopoly setting. In this section, we extend this baseline case to include competition. We first describe the interaction between the 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 compete on the 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 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 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 uniform distribution over the interval $[0,1]$. Demand of firm i as a function of the 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 where each firm can either choose a no-offset strategy or an offset strategy, there are four possible competitive interactions: both firms adopt a no-offset strategy, both firms adopt an offset strategy, or one firm adopts an offset strategy while the

Firm 2

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

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

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 can unilaterally increase its profit by adopting an offset strategy. Whereas the initial competitive advantage of an offset strategy is eroded by the reaction of the rival, each firm's choice of strategy is consistent with corporate social responsibility.*

To understand what governs the optimal choice of strategy, consider a situation where both firms choose to not offset their carbon emissions initially (the top-left cell in Figure 3). Once offsetting emissions becomes sufficiently cheap, each firm can 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 for its profit bottom line 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 the firm not exploited the profit opportunity, its profit would have been lower because the rival would have attained a competitive advantage.

In contrast to a monopoly market, stronger climate concerns reduce not only the carbon footprint, but also each firm's climate impact in a competitive market. 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 triple-win outcome for the firm, the climate, and consumers. 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 carbon footprint.

8 General Discussion

This paper has explored how marketers can champion climate concerns of consumers and regulators within their organization. Specifically, the paper provides guidance on how marketers can channel climate concerns back to the firm, and how they affect product design, the climate impact of the firm, the profitability of carbon offsetting, corporate social responsibility, and green technology adoption.

Our analysis first showed that if reducing carbon emissions increases cost, the optimal carbon footprint and price are not only driven by the cost effect, but also by the demand effect which results from reducing the climate impact of the product. Second, we showed that greener product design may actually increase the firm's climate impact, a situation where a firm falls victim to its success due to higher demand. Third, we established that offsetting the carbon emissions to reach a net zero carbon footprint may create a win-win outcome for the firm and the climate, even if the product's carbon footprint is higher than without offsetting. Fourth, we showed how product design, firm profitability, and green technology adoption are affected by carbon regulation in the form of binding carbon caps, cap-and-trade systems, and carbon taxes. Finally, we established that going net zero is a competitive equilibrium strategy that is consistent with corporate social responsibility under some conditions.

The results confirm the intuition that climate concerns of consumers and regulators tend to reduce the carbon footprint of products and organizations. However, in a monopoly market, the climate impact of the firm can increase due to the increase in demand for products with a lower carbon footprint. Importantly, the logic here applies beyond carbon emissions, including water or plastic footprints and ecological footprints more broadly, which all play a key role in managing corporate social responsibility.

8.1 Managerial Implications

Our analysis provides new insights into how marketing managers can represent the voice of consumers and regulators within an organization. This allows firms to respond to changing climate concerns by adjusting product design and better manage their climate strategy. Consumers with climate concerns have a lower willingness to pay for the product for a given carbon footprint and price, which provides an incentive for the firm to adjust product design. In some cases, this can lead to a firm offering two products: A green product to appeal to consumers who are concerned with the environment and a brown product targeted to consumers who are not. In contrast, climate concerns of the government that lead to carbon regulation force the firm to adjust its product design to account for the specific type of regulation. These insights inform managers under what conditions their decisions contribute to a better world by reducing the climate impact of the firm. Designing greener products is not sufficient to reduce the firm's climate impact. More broadly, our results can also be used to help understand how firms can contribute to reducing anthropogenic greenhouse gas emissions.

Based on our analysis, climate concerns reduce firm profitability. The best a firm can do with a given technology is to adjust the product design. However, climate concerns may provide an opportunity to invest in green technologies, which allow the firm to reduce the cost of compliance with regulation and to earn additional revenue by selling the technology they develop. Interestingly, climate regulation can motivate managers to push for a greener technology that reduces the carbon footprint of the product. Hence, taking a proactive approach to deal with climate concerns can mitigate the impact of more stringent regulation on firm profitability.

Our analysis can also help managers to set an internal carbon price—a shadow price used within an organization to reflect the external cost of carbon emissions. An internal carbon price affects product design and the climate impact in the same way as a carbon tax set by a regulator. The *United Nations Global Compact* calls for companies to set an internal price at a minimum of $100 per metric ton by 2020 to put climate change at the heart of strategy and decision-making.[7] *Microsoft* took a leadership role in this by introducing an internal carbon fee in 2012 to achieve carbon neutrality and "maximizing the impact for our company on the three Ps (people, planet, and profit)" (*Microsoft* 2015).

Furthermore, our analysis highlights that marketing greener products may be in conflict with the goal of reducing the climate impact of the firm. This points to a possible tension between internal stakeholders, such as product managers, and managers who are responsible for carbon management at the organizational level. Resolving the tension between "green products" and "green organizations" is important for positioning products and brands.

8.2 Limitations and Avenues for Future Research

Our analysis suggests several directions for future research. First, future research could examine how climate concerns are being shaped. One approach is to assume that climate concerns are influenced by the firm's climate impact. Another approach is to assume that the firm or regulators can influence climate concerns via persuasive advertising. We predict that regulators will become more concerned over time and hence implement either stricter regulations or provide stronger incentives to reduce carbon emissions. These could either occur gradually or be influenced by a major event (e.g., Three-Mile Island, Chernobyl, and Exxon-Valdez incidents), i.e., have a discontinuity. Such regulatory changes can alter the market structure in the long run and lead to unpredictable substitution patterns.

[7] See `https://www.unglobalcompact.org/take-action/action/carbon` for details.

However, because dealing with climate concerns typically increases cost, the incentives for a firm to produce and advertise less polluting products must come from either altruism or the demand-enhancing effect of having a greener brand image. In that regard, one could explore the relative impact of different appeals (e.g., fear, currently used extensively, vs. social). Interestingly, the health communication literature suggests fear appeals are not very effective as are general appeals to society while implications for individuals or in-group members have more impact (Keller and Lehmann 2008).

Second, while our model provides a basis for thinking about the interplay between firm behavior and carbon emissions, the "real world" is more nuanced. Individuals differ in both their price sensitivity and the weight they put on carbon emissions (and these may not be independent of each other). One can extend the model to the case of a bimodal distribution of preferences (or the special case of a single mode plus a spike at zero for those who do not pay attention to the carbon footprint in their purchase decisions). Another interesting extension is to assume firms altruistically care about carbon *per se*, in addition to profits. This would imply expanding the firms' objective function, as advocated by the triple bottom line approach (Cronin et al. 2011, Huang and Rust 2011). One could also assume the weight consumers place on carbon footprints will increase the more consumers "adopt" products with lower carbon emissions in a diffusion/contagion process.

In our model, we assume the firm is focused on a single product. To the extent that reducing carbon output of one product causes the sales mix to change, the firm's total carbon output may change (go up if it switches consumers from less-polluting options in its product line, down if they switch from more-polluting options). Similarly, if the product draws consumers from products outside the industry, their relative carbon output levels determine the impact on total carbon output. Another extension of the model is to consider not only production emissions, but also emissions that occur in the consumption stage. This would allow managers 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, one could study the role of competition in a more nuanced way. For example, competition is often asymmetric in terms of brand equity, resources, technical capabilities, and even objective functions (e.g., across countries). Technological breakthroughs that improve the ability to produce products and services with lower carbon footprints and lead to higher demand (e.g., by adding new features) will also affect markets. Similarly, government regulations are likely to depend both on industry and country level emissions, and may include both caps and taxes. The strategic behavior of competitors can also affect both demand and the likelihood and severity of governmental regulations (Moorman, Du, and Mela 2005). Relatedly, if regulators punished carbon reduction overstatement, this could lead companies to produce a higher level carbon product, similar to the result regarding regulating advertised quality in Kopalle and Lehmann (2015).

Our paper also suggests several avenues for empirical research such as measuring the strength of climate concerns, quantifying the impact of these climate concerns for product design (e.g., using conjoint analysis) and the climate impact of the firm, and understanding what managers or consumers would (as opposed to should) do in response to changing climate concerns. Taking a broader perspective, one could compare the carbon-sensitivity at the country level based on the average energy efficiency of appliances purchased, per capita electricity or gasoline consumption, or reliance on fossil fuels, and where the distribution of purchases falls on a price-carbon consequences line.

Finally, prescriptive research and suggestions is another potentially important focus. For example, one way for managers to the reduce carbon footprint is to convert interactions with the consumer to being more digital, for example purchasing (if search costs in fact are reduced) and service (e.g., by making self-service easier). Given the importance of the topic, further empirical, analytical, and simulation work is definitely called for.

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Appendix

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

$$\begin{aligned} -c'(\kappa^*)D(\kappa^*,p^*;\lambda)+[p^*-c(\kappa^*)]D_\kappa(\kappa^*,p^*;\lambda)+\mu_1-\mu_2 &= 0 \qquad \text{(A.1)} \\ D(\kappa^*,p^*;\lambda)+[p^*-c(\kappa^*)]D_p(\kappa^*,p^*;\lambda) &= 0 \qquad \text{(A.2)} \\ \mu_1\kappa^*=0 \text{ and } \mu_2(\kappa^*-\overline{\kappa}) &= 0. \end{aligned}$$

Depending on the slope of the cost function, there are two cases. First consider the case where $c'(\kappa) > 0$. Suppose that $D_\kappa = 0$ and that $\kappa^* > 0$. Then, (A.1) leads to a contradiction as $\mu_1 = 0$, so that $\kappa^* = 0$. This result holds a fortiori if $D_\kappa < 0$. Second, assume that $c'(\kappa) < 0$. If $D_\kappa = 0$, then a solution that involves $\kappa^* < \overline{\kappa}$ leads to a contradiction in (A.1), so that $\kappa^* = \overline{\kappa}$. Next, if $D_\kappa < 0$, then the choice of the carbon footprint is governed by the relative strength of the cost effect and the demand effect: 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, the firm sets $\kappa^* = 0$ and $p^*(0)$ under cost-decreasing sustainability. Since $D(0,p^*(0);0) = D(0,p^*(0);\lambda)$ for $\lambda > 0$, stronger climate concerns leave profit unchanged.

Second, under cost-increasing sustainability, 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

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

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 (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 and pricing, consider a green product strategy where $\kappa^* \in (0, \overline{\kappa})$ and where the first-order conditions (A.1) and (A.2) hold with equality. 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 (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 carbon footprint and price is ambiguous. Clearly, the 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 climate impact of the firm is obtained by multiplying the carbon footprint per unit of product by the corresponding demand:

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

Differentiating (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 cannot be signed unambiguously. Therefore, under some conditions, stronger climate concerns may increase the climate impact even if it is optimal for the firm to lower the carbon footprint. □

Proof of Proposition 4. Consider the case of cost-increasing sustainability. Adopting an offset strategy yields the optimal profit

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

Applying the envelope theorem implies

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

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. We follow the convention and define welfare as the sum of consumer surplus and profit. Consumer surplus is obtained by adding up the utilities from buyers and non-buyers:

$$\begin{aligned} S(\kappa, p; \lambda) &= \int_{p+z(\kappa;\lambda)}^{\infty} [v - p - z(\kappa;\lambda) - E] dF(v) + \int_{0}^{p+z(\kappa;\lambda)} [-E] dF(v) \\ &= \int_{p+z(\kappa;\lambda)}^{\infty} [v - p - z(\kappa;\lambda)] dF(v) - E \\ &= \int_{p+z(\kappa;\lambda)}^{\infty} v dF(v) - pD(\kappa, p; \lambda) - \Phi(\kappa), \end{aligned} \tag{A.9}$$

where the third equality uses the definition of demand in Equation (2), the definition of the market externality in Equation (3), and where $\Phi(\kappa) \equiv \kappa D(\kappa, p; \lambda)$ denotes the firm's overall level of emissions. Adding the consumer surplus in Equation (A.9) and the profit in Equation (4) yields welfare:

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

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

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

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 choice of the carbon footprint. By definition, $\overline{\pi}'(\kappa^*) = 0$, so that

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

Thus, the carbon footprint exceeds the socially optimal level if $\beta'(\kappa^*) > 0$ and conversely, which implies that the firm's choice of the 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 simply a transfer from the firm to the offset provider and cancels out in the welfare calculation. Clearly, a climate neutral strategy is economically efficient if the cost of carbon removal $\phi\omega\kappa^o D(p^o) + F$ is sufficiently low compared to the climate damage that results from the climate impact under a no-offset strategy, given by $\Phi(\kappa^*)$. □

Proof of Proposition 6. The firm maximizes profit if and only if its carbon footprint and price selections satisfy the following Kuhn-Tucker conditions (the multipliers $\mu_i \geq 0$ are associated with the inequality constraints):

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

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

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

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 the carbon regulation if $\Phi_\kappa(p, \kappa) < 0$. Instead, if $\Phi_\kappa(p, \kappa) > 0$, it is optimal for the firm to lower the carbon footprint in response to the regulatory intervention. □

Proof of Proposition 7. If a firms meets the carbon cap, the expect cost of regulation is given by the difference between the actual profit and the expected profit under the carbon regulation: $\pi^* - [\rho \pi^r + (1-\rho)\pi^*] = \rho(\pi^* - \pi^r)$. Instead, if the firm does not meet the carbon cap and purchases carbon allowances, the expected cost of regulation is given by the difference between the actual profit and the expected profit net of the cost of the carbon allowances: $\pi^* - [\rho(\pi^* - \varpi(\Phi(p^*, \kappa^*) - R)) + (1-\rho)\pi^*] = \rho \varpi(\Phi(p^*, \kappa^*) - R)$. Clearly, the firm chooses the option that yields the higher expected profit. Therefore, the expected cost of regulation 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

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

and

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

The expression in the denominators of (A.14) and (A.15) is the determinant of the Hessian matrix of $\pi(p,\kappa)$, which is positive under the concavity assumption. Assuming that π_{pp}, $\pi_{\kappa p}$, and π_{pt} are negative, the 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 t if $\pi_{\kappa\lambda} > \frac{\pi_{\kappa\kappa}\pi_{pt}}{\pi_{p\kappa}}$, a condition that is assumed to hold.

Using Proposition 3, the climate impact for a given tax t rate is given by

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

Differentiating (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 (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 is ambiguous. Therefore, the impact of a carbon tax on the climate impact is ambiguous.

The expected cost of carbon taxation is the difference between the actual profit and the expected profit under the carbon tax: $\pi^*(0) - [\rho\pi^*(t) + (1-\rho)\pi^*(0)] = \rho\{\pi^*(0) - \pi^*(t)\}$, where $\pi^*(0) \equiv \pi^*$ is the profit under a zero tax rate. Note that $\Delta\pi$ is positive as

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

is positive, where the last equality follows from the application of the envelope theorem and the definition of the climate impact. □

Proof of Proposition 9. If the firm adopts the green technology, the actual profit is given by $\pi_1^* - f$. Using the CR defined in Proposition 7, the expected profit to accommodate the carbon regulation with the green technology can be derived as $\pi_1^* - f - CR_1$. Similarly, the expected profit to accommodate the carbon regulation with the existing technology is $\pi_0^* - CR_0$. Clearly, if $\pi_1^* - f - CR_1 \geq \pi_0^* - CR_0$, then the firm will adopt the green technology to increase the expected profit. □

Proof of Proposition 10. Demand for each firm i 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 1. 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 $\lambda = 1$.[8] First, we analyze the setting in which both firms adopt a no-offset strategy. Firm i then solves

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

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, $\hat{x} = \frac{1}{2}$, $\pi_i^* = \frac{1}{4}$ (indicated in top-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, (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

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

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

where w denote 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 $\hat{\pi}_1 = \frac{1}{144}(w(w-4)+9)^2 \equiv A$ and $\hat{\pi}_2 = \frac{1}{144}(w(w-4)-3)^2 \equiv B$ (indicated in bottom-left cell in Figure 3). Since $\hat{\pi}_1 > \frac{1}{4}$ and $\hat{\pi}_2 < \frac{1}{4}$ for all $w < 1$, adopting an offset strategy is a dominant strategy for firm 1. Note that the other asymmetric outcome in which firm 1 uses a no-offset strategy and firm 2 uses an offset strategy can be obtained by reversing the payoffs (indicated in top-right cell in Figure 3).

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

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

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

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

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

Carbon offsets improve welfare over the case absent offsets if and only if $\overline{W}^* \geq W^*$. 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. □