

Carbon Footprinting and Pricing Under Climate Concerns

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Abstract

This article studies how organizations should design a product by choosing the carbon footprint and price in a market with climate concerns. The authors develop a model and first show how the cost and demand effects of reducing the product carbon footprint determine the profit-maximizing product design. They find that stronger climate concerns reduce the product carbon footprint, demand, the overall corporate carbon footprint and profit, but have an ambiguous impact on price. Next, the authors establish that offsetting carbon emissions can create a win-win outcome for the firm and the climate if the cost of compensation is sufficiently low. Going net zero leads to a win for society if the cost of offsetting is sufficiently low compared to the social cost of pollution created by the corporate carbon footprint. 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 and show that going net zero creates a win-win-win outcome for the firm, the climate, and society if the offset technology is sufficiently effective.

Keywords

carbon footprint, carbon offsetting, climate impact, net-zero emissions, pricing

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 (Bryant 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 run. 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” (Cavanaugh 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 article develops a model that helps marketers address climate concerns by optimizing carbon footprinting and pricing. 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

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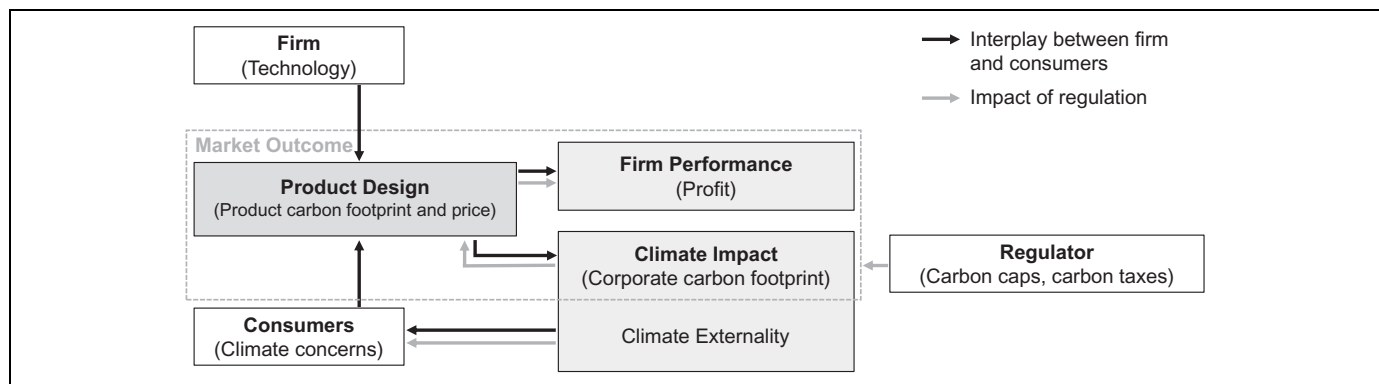


Figure 1. The interplay between firm, consumers, and regulator and the resulting market outcome under climate concerns.

monopoly setting in which the firm designs a product by choosing its product carbon footprint and price, hereinafter referred to simply as product design. Calculating product carbon footprints—the climate impact per unit of product in carbon dioxide equivalent (CO₂ eq) emissions—is now common practice (Meinrenken et al. 2012; Vandenbergh, Dietz, and Stern 2011), and these footprints are routinely certified based on international accounting standards (Greenhouse Gas Protocol 2011; ISO 2018). 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).¹ Importantly, reducing the product carbon footprint has both a cost effect due to the change in the unit cost to produce a greener product and a demand effect due to consumers’ climate concerns.

The key difference from a standard model where the firm chooses price and (environmental) quality is that the total number of purchases made by consumers determines not only 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 the interplay between firm and consumers drives the market outcome (comprising product design, firm performance, and climate impact) and climate externality, and the role played by the regulator intervening to limit corporate carbon footprints.

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. We demonstrate that it is

optimal for a firm to decrease the product carbon footprint, and analyze the impact on price. In addition, we show that stronger climate concerns reduce firm profit.

Finally, we show that stronger climate concerns reduce the overall corporate carbon footprint. This result occurs because stronger climate concerns reduce both the product carbon footprint and demand, which leads to a reduction in overall emissions. In other words, the greener product design further contributes to the reduction in overall emissions that results from the lower sales volume. Listening to the voice of consumers who demand greener products therefore helps organizations to reduce their corporate 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 is 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 prior to offsetting 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 the 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

¹ The model abstracts from consumption emissions (Scope 3) because they are difficult to measure in practice (Meinrenken et al. 2012).

Table 1. Key Results and Insights for Marketers.

Topic	Insight
Product design (Propositions 1 and 2)	Climate concerns affect the product carbon footprint and price, and thereby profit. Stronger climate concerns reduce the product carbon footprint and profit, but have an ambiguous impact on price.
Climate impact (Proposition 3)	Stronger climate concerns reduce demand and the corporate carbon footprint.
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 with 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 with the social cost created by the corporate carbon footprint.
Regulation (Propositions 6–9)	Carbon regulation in the form of binding carbon caps, cap-and-trade systems, and carbon taxation reduces firm profitability, stimulates green technology adoption, and typically leads to the design of greener products.
Competitive strategy (Proposition 10)	Stronger climate concerns reduce the product carbon footprint and 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, the climate, and society.

cost of offsetting is sufficiently low compared with 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 these instruments are generally effective in curbing both the product carbon footprint and the corporate carbon footprint when taking the profit-maximizing price response into account. 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 consumers' climate concerns (Kotler 2011), firm technology, and market regulation (Porter and Van der Linde 1995). By endogenizing product design, this article 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 (Chandy et al. 2021; 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).

The Model

Consider a firm that designs a product (or service) by choosing the price $p \geq 0$ and product carbon footprint $\kappa \in [0, \bar{\kappa}]$. The set $[0, \bar{\kappa}]$ 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 $\kappa = \bar{\kappa}$. The technology of the firm results in the unit cost function $c(\kappa)$ defined on $[0, \bar{\kappa}]$, 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

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

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

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

no impact on the climate externality, E is the 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 affects the climate. Formally, letting subscripts denote first and second partial derivatives, the convexity assumption $z(\kappa; \lambda)$ 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 $\lim_{\lambda \rightarrow \infty} z(\kappa; \lambda) = \kappa$. We further assume that stronger climate concerns increase the disutility from a given carbon footprint, that is, $z_{\lambda}(\kappa; \lambda) > 0$. Finally, we assume that stronger climate concerns increase the marginal disutility of increasing κ , that is, $z_{\kappa\lambda}(\kappa; \lambda) > 0$.

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

$$D(\kappa, p; \lambda) = 1 - F[p + z(\kappa; \lambda)]. \quad (2)$$

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” affects not only demand but also the corporate carbon footprint (i.e., 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 account for their carbon emissions, they create a climate externality—“the biggest market failure the world has seen” (Stern 2008, p. 1). The climate externality results from adding up the noninternalized carbon emissions across buyers:

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

This climate externality is reduced to zero when consumers have strong climate concerns ($z(\kappa; \lambda) = \kappa$) and equals the corporate carbon footprint if consumers do not care about purchasing a product that affects 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.

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.

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

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

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 $\kappa^* = \bar{\kappa}$ at price $p^*(\bar{\kappa})$. Finally, if the demand effect is sufficiently strong compared with the cost effect, then it is optimal to offer a product with $\kappa^* \in (0, \bar{\kappa})$ 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” (Crosby 1979; Deming 1986). 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 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 trade-off 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

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. 1993; Tse and Wilton 1988) of a green product.

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

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).

marketing practices may come from consumers themselves" (Kotler 2011, p. 133) 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.

Impact of Climate Concerns on Product Design

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

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, and leave profit unchanged. Instead, if reducing the product carbon footprint increases unit cost, stronger climate concerns decrease the product carbon footprint, have an ambiguous impact on price, and reduce profit.

Proposition 2 has two important implications. First, it shows how climate concerns affect the profit-maximizing product design. Stronger climate concerns increase the consumers' marginal disutility of raising κ , which motivates the firm to reduce the product carbon footprint to make the product more attractive to consumers. The impact on the price is ambiguous because stronger climate concerns not only increase the unit cost due to the lower product carbon footprint, but also compress the price-cost margin.⁴ Note that 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" (Watts et al. 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 show next, one way firms can resolve this tension is by broadening the scope of performance measurement beyond profit to include climate and societal impact.

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 changes in climate concerns affect the climate impact of the firm.

Proposition 3: Stronger climate concerns reduce demand and the corporate carbon footprint $\Phi^* = \kappa^* D(\kappa^*, p^*; \lambda)$.

Proposition 3 shows that stronger climate concerns necessarily reduce the corporate carbon footprint. The reason is that stronger climate concerns reduce both the product carbon footprint and demand, which leads to a reduction in overall emissions. This is a strong result, because the positive demand effect of offering a greener product could be expected to compensate for the lower product carbon footprint—similar to the rebound effect from technological progress (Alcott 2005), which suggests that higher efficiency leads to an initial reduction in demand for a resource that is outweighed by a corresponding increase in demand due to relatively lower resource cost ("Jevons paradox"). In our setting, the rebound effect cannot occur because stronger climate concerns increase the disutility from a given carbon footprint ($z_\lambda(\kappa; \lambda) > 0$), which translates into an overall reduction in demand. In contrast, in a setting where $z_\lambda(\kappa; \lambda) < 0$, stronger climate concerns may lead to a rebound effect because of the resulting increase in demand, an outcome that is conceivable if consumers use the brown product (rather than the green product) as a reference point.⁵ In sum, whenever listening to the voice of consumers leads to greener product design and lower demand, the consumer pressure for greener products motivates profit-maximizing organizations to become greener, even though the impact on profit is negative. Proposition 3 thus suggests that consumers play an important role in making both products and organizations greener.

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 whereby the corporate carbon footprint is fully compensated for (by funding

⁴ To see the ambiguous price effect, consider the example where v is uniformly distributed on $[0, 1]$, $c(\kappa) = (\bar{\kappa} - \kappa)^2$, and $z(\kappa; \lambda) = \lambda\kappa$, with $\lambda \in (0, 1]$ and $\bar{\kappa} = 1$. The impact of stronger climate concerns on the profit-maximizing price is $\frac{dp^*}{d\lambda} = \frac{1}{4}(3\lambda - 2)$, which is positive if $\lambda > \frac{2}{3}$ and negative if $\lambda < \frac{2}{3}$.

⁵ To illustrate the possibility of a rebound effect outside of our model, consider the example where v is uniformly distributed on $[0, 1]$, $c(\kappa) = (\bar{\kappa} - \kappa)^2$, and $z(\kappa; \lambda) = 1 + \lambda(\kappa - \bar{\kappa})$, with $\lambda \in (0, 1]$ and $\bar{\kappa} = 1$. The impact of stronger climate concerns on the corporate carbon footprint is $\frac{d\Phi^*}{d\lambda} = \frac{\lambda}{16}(4 - 3\lambda)$, which is strictly positive.

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

$$\max_{\kappa, p} \pi(\kappa, p; \omega) = [p - c(\kappa) - \omega\kappa]D(0, p) \quad (5)$$

$$\text{s.t.} \quad 0 \leq \kappa \leq \bar{\kappa},$$

where $\omega\kappa D(0, p)$ is the total offsetting cost of reaching a net-zero corporate carbon footprint if the product carbon footprint prior to offsetting is κ . That is, with carbon offsetting purchase decisions and demand depend on the net-zero product 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 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 with the additional profit from the demand-enhancing effect of reducing the product carbon footprint to net zero. Stronger climate concerns make the adoption of an offset strategy more attractive. The downside of an offset strategy is that it motivates a firm to increase the product carbon footprint before offsetting if the price per unit of carbon offset is sufficiently low.

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 disutility resulting from consuming a product with a positive 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.

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 with 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).

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, which 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.

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 Union'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:

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

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, and translates into a lower product carbon footprint if the sales expansion that results from offering a greener product is sufficiently small.

A binding carbon cap has the obvious effect of reducing the corporate carbon footprint and profit. More interestingly, restricting overall emissions forces the firm to adjust the profit-maximizing product design by lowering the product carbon footprint because this helps to relax the carbon constraint if the sales expansion from offering a greener product is sufficiently small compared with the direct reduction in overall emissions. In real-world markets, 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.

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 (McGee and Campbell 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 $R \geq 0$. Under regulation, the firm can choose between two options: (1) adjust the product design to meet the potential regulatory constraint at the firm level (profit π^r) or (2) 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 uncertain cap-and-trade regulation reduces the expected profit of the firm. Furthermore, 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.

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

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

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 proportional carbon tax reduces not only the profit-maximizing product carbon footprint but also 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 a higher carbon tax effectively reduces the corporate carbon footprint via its impact on the profit-maximizing product carbon footprint and price in response to higher cost, which leads to an overall reduction in sales. The result also shows that the uncertain introduction of a carbon tax reduces expected profit: The increase in 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 (Moorthy 2005; Nijs et al. 2010). The

adverse impact on profit helps explain why firms lobby against regulation (Viscusi, Harrington, and Sappington 2018).

That said, 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.

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 $f_1 > 0$. This green technology enables 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.

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.

Setup

We 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 between two strategies: a no-offset strategy where the product is marketed with carbon

		Firm 2	
		No Offset	Offset
Firm 1	No Offset	$\frac{1}{4}$ $\frac{1}{4}$	$B < \frac{1}{4}$ $A > \frac{1}{4}$
	Offset	$A > \frac{1}{4}$ $B < \frac{1}{4}$	$\frac{1}{4}$ $\frac{1}{4}$

Figure 3. Possible outcomes and corresponding profits for $c_1^0 = c_2^0 = 1$ and $\lambda = 1$, where the top left number is the profit of Firm 1 and the bottom right number the profit of Firm 2.

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

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

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 for the product of firm i as a function of the product carbon footprints $\kappa = (\kappa_1, \kappa_2)$ and prices $\mathbf{p} = (p_1, p_2)$ can be derived as

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

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.

Competitive Carbon Offsetting

In a setting with two firms and two strategic options per firm, there are a total of four possible outcomes: 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. To illustrate the emergence of competitive carbon offsetting, we consider symmetric firms with $c_1^0 = c_2^0 = 1$ and let $\lambda = 1$ represent strong climate concerns. The following result holds.

Proposition 10: Suppose that firms are symmetric and consumers have strong climate concerns. Then, if 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 the intuition for this result, consider the profits that each firm can earn in the four possible outcomes represented in Figure 3. From firm 1's point of view, it is always more profitable to adopt an offset strategy than a no-offset strategy, no matter whether firm 2 chooses a no-offset strategy (which yields profit $A > \frac{1}{4}$) or an offset strategy (which yields profit $\frac{1}{4} > B$). Because the firms are symmetric, the same logic applies to firm 2, no matter whether firm 1 chooses a no-offset strategy or an offset strategy. In other words, 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. Therefore, the offset strategy is strictly dominant for each firm, and competitive carbon offsetting emerges in equilibrium.

Interestingly, Proposition 10 further shows that if the offset technology is sufficiently cost effective, competitive forces can create a win-win-win outcome for each firm, the 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.

Discussion

This article 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. Furthermore, 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 how climate concerns translate into optimal carbon footprinting and pricing decisions. 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.

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 trade-off with demand (via, e.g., market research). They can then advise their 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. Because marketers lower the product carbon footprint and adjust price in response to stronger climate concerns, the changes in product design lead to a lower corporate carbon footprint as both the product carbon footprint and demand are reduced. Therefore, greener products lead to greener organizations. At the same time, the consumer pressure for greener products reduces profit. To save the cost of making the product greener, organizations may decide to go net zero by offsetting the carbon emissions. 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 2020). 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.

Implications for Policy Makers

While carbon regulation effectively limits the organization's overall climate impact, it imposes a cost of regulation on organizations. This is arguably the reason why policy makers hesitate to implement effective carbon regulation. 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 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).

Implications for Consumers

Our research suggests that organizations should act on consumers' climate concerns even if it reduces their profit, because not doing so would result in even lower profit. Voicing stronger climate concerns in our model necessarily reduces the corporate carbon footprint. However, in pressuring organizations into offering greener products, consumers may end up paying higher prices.

In addition, our research shows that consumers with stronger climate concerns cause a smaller climate externality and thereby reduce the burden they impose on society. Stronger climate concerns also increase the profitability of carbon off-setting, which may stimulate the transition to a net-zero carbon economy. More broadly, our analysis suggests that "green consumerism" has a real impact on market outcomes.

Limitations and Future Research

Future research could study how climate concerns are shaped and how they affect the consumers' utility function. Exploring preferences is key to understanding the impact of stronger climate concerns on product design and the overall corporate carbon footprint. One approach is to assume that climate concerns are influenced by opinion leaders. Another option is to assume that the organization can influence climate concerns via persuasive advertising. Yet another issue for future research is whether changes in climate concerns monotonically affect purchase decisions.

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, including the determination of offset prices. 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 or at least, absent that, better understanding of the trade-offs being made among the three parties.

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):

$$-c'(\kappa^*)D(\kappa^*, p^*; \lambda) + [p^* - c(\kappa^*)]D_\kappa(\kappa^*, p^*; \lambda) + \mu_1 - \mu_2 = 0, \quad (A1)$$

$$D(\kappa^*, p^*; \lambda) + [p^* - c(\kappa^*)]D_p(\kappa^*, p^*; \lambda) = 0, \quad (A2)$$

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

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 A1 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 $\kappa^* < \bar{\kappa}$ leads to a contradiction in Equation A1, so that $\kappa^* = \bar{\kappa}$. 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 $-c'(\bar{\kappa})D + [p^* - c(\bar{\kappa})]D_\kappa \geq 0$, then $\kappa^* = \bar{\kappa}$; otherwise, there is an interior solution with $\kappa^* \in (0, \bar{\kappa})$. $\square$

Proof of Proposition 2. First, from Proposition 1, $\kappa^* = 0$ and $p^*(0)$ if $c'(\kappa) > 0$. Because $D(0, p^*[0]; 0) = D(0, p^*[0]; \lambda)$ 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 $\bar{\kappa}$ is given by $\pi(\bar{\kappa}, p; 0) = [p - c(\bar{\kappa})]D(\bar{\kappa}, p; 0)$. Instead, when consumers have climate concerns ($\lambda > 0$), profit at $\kappa^* \leq \bar{\kappa}$ is given by $\pi(\kappa^*, p; \lambda) = [p - c(\kappa^*)]D(\kappa^*, p; \lambda)$. Because the emergence of climate concerns reduces demand and (weakly) increases unit cost, this implies that

$$\pi(\kappa^*, p^*; \lambda) < \pi(\bar{\kappa}, p^0; 0), \quad (A3)$$

where $p^* = \arg \max_p \pi(\kappa^*, p; \lambda)$ and $p^0 = \arg \max_p \pi(\bar{\kappa}, p; 0)$, which means that the emergence of climate concerns reduces profit. Instead, when climate concerns are reinforced, applying the envelope theorem yields

$$\frac{\pi(\kappa^*, p^*; \lambda)}{d\lambda} = [p^* - c(\kappa^*)]D_\lambda(\kappa^*, p^*; \lambda) < 0, \quad (A4)$$

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 $\kappa^* \in (0, \bar{\kappa})$, so that the multipliers μ_1 and μ_2 are zero in Equations A1 and A2. Substituting Equation A2 into Equation A1 yields $-c'(\kappa^*) - D_\kappa/D_p = 0$, which can be expressed in model primitives as

$$-c'(\kappa^*) = z_\kappa(\kappa^*; \lambda) \quad (\text{A5})$$

by using that $D_\kappa = -f(p + z(\kappa; \lambda))z_\kappa(\kappa; \lambda)$ and $D_p = -f(p + z(\kappa; \lambda))$. Applying the implicit function theorem to Equation A5 yields

$$\frac{d\kappa^*}{d\lambda} = -\frac{z_{\kappa\lambda}(\kappa^*; \lambda)}{c''(\kappa^*) + z_{\kappa\kappa}(\kappa^*; \lambda)} < 0, \quad (\text{A6})$$

because the denominator is positive by the concavity assumption and $z_{\kappa\lambda}(\kappa^*; \lambda) > 0$ by assumption. To see the impact of stronger climate concerns on price, note that Equation A2 can be expressed in model primitives as

$$p^* = c(\kappa^*) + \frac{1 - F(p^* + z(\kappa^*; \lambda))}{f(p^* + z(\kappa^*; \lambda))}. \quad (\text{A7})$$

From the implicit function theorem,

$$\frac{dp^*}{d\lambda} = -\frac{[f(\cdot) + (p^* - c(\kappa^*))f'(\cdot)]z_\lambda(\kappa^*; \lambda)}{2f(\cdot) + (p^* - c(\kappa^*))f'(\cdot)} + c'(\kappa^*) \frac{d\kappa^*}{d\lambda}. \quad (\text{A8})$$

The concavity assumption and $z_\lambda(\kappa^*; \lambda) > 0$ imply that the first term on the right-hand side of Equation A8 is negative, whereas the second term is positive by Equation A6 and the assumption that $c'(\kappa) < 0$. Therefore, the impact of stronger climate concerns on the profit-maximizing price is ambiguous.

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

$$\Phi^*(\lambda) = \kappa^*(\lambda)[1 - F(p^* + z(\kappa^*; \lambda))]. \quad (\text{A9})$$

Differentiating Equation A9 with respect to λ yields

$$\begin{aligned} \frac{d\Phi^*(\lambda)}{d\lambda} &= \frac{d\kappa^*}{d\lambda} [1 - F(\cdot)] - \kappa^* f(\cdot) \left[\frac{dp^*}{d\lambda} + z_\kappa \frac{d\kappa^*}{d\lambda} + z_\lambda \right] \\ &= \frac{d\kappa^*}{d\lambda} [1 - F(\cdot)] - \frac{\kappa^* [f(\cdot)]^2 z_\lambda(\kappa^*; \lambda)}{2f(\cdot) + (p^* - c(\kappa^*))f'(\cdot)}, \end{aligned} \quad (\text{A10})$$

where the second equality follows from substituting the expressions for $d\kappa^*/d\lambda$ and $dp^*/d\lambda$ in Equations A6 and A8, respectively, and using that $-c'(\kappa^*) = z_\kappa(\kappa^*; \lambda)$ from Equation A5. Because $z_\lambda(\kappa^*; \lambda) > 0$ and $2f(\cdot) + (p^* - c(\kappa^*))f'(\cdot) > 0$ by the concavity assumption, stronger climate concerns reduce demand and therefore the corporate carbon footprint because $\frac{d\kappa^*}{d\lambda} < 0$ by Proposition 2.

Proof of Proposition 4. Suppose that $c'(\kappa) < 0$. Under carbon offsetting, the product has a net-zero carbon footprint, which implies that $z(0, \lambda) = 0$ and thus that demand $D(0, p)$ is independent of λ . An offset strategy yields the profit

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

where κ^0 is the product carbon footprint prior to offsetting and p^0 is the corresponding price. Noting that $\pi(\bar{\kappa}, p^0; \omega = 0) = \pi(\bar{\kappa}, p^0; \lambda = 0)$, it follows from Equation A3 that $\pi(\bar{\kappa}, p^0; \omega = 0) > \pi(\kappa^*, p^*; \lambda)$. Applying the envelope theorem to the optimal profit under offsetting yields $d\pi(\kappa^0, p^0; \omega)/d\omega = -\kappa^0 D(0, p^0) < 0$. This implies there exists $\bar{\omega}$ such that $\pi(\kappa^0, p^0; \omega) > \pi(\kappa^*, p^*; \lambda)$ for $\omega \in (0, \bar{\omega})$, which means that the firm can benefit from adopting a climate neutral strategy when ω is sufficiently low. Next, stronger climate concerns reduce profit in the benchmark case absent carbon offsets by Equation A4 ($d\pi(\kappa^*, p^*; \lambda)/d\lambda < 0$), whereas they leave profit unaffected under an offset strategy ($d\pi(\kappa^0, p^0; \omega)/d\lambda = 0$) because demand is independent of λ . Consequently, stronger climate concerns make the adoption of an offset strategy more attractive to the firm.

Absent carbon offsets, the optimal product carbon footprint is determined by the condition $-c'(\kappa^*) = z_\kappa(\kappa^*; \lambda)$ from Equation A5. Under an offset strategy, the firm chooses κ^0 to maximize the markup $p - c(\kappa) - \omega\kappa$ because demand does not depend on the choice of κ . Therefore, at an interior solution, κ^0 is determined by the condition $-c'(\kappa^0) = \omega$. Clearly, $\kappa^0 > \kappa^*$ if $\omega < z_\kappa(\kappa^*; \lambda)$. Note that this result holds a fortiori at a corner solution where $\omega < -c'(\bar{\kappa})$. Thus, an offset strategy motivates a firm to increase the product carbon footprint before offsetting the emissions if ω is sufficiently low.

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 nonbuyers:

$$\begin{aligned} S(\kappa, p; \lambda) &= \int_{p+z(\kappa; \lambda)}^{\infty} [v - p - z(\kappa; \lambda) - E]dF(v) + \int_0^{p+z(\kappa; \lambda)} [-E]dF(v) \\ &= \int_{p+z(\kappa; \lambda)}^{\infty} [v - p - z(\kappa; \lambda)]dF(v) - E \\ &= \int_{p+z(\kappa; \lambda)}^{\infty} v dF(v) - pD(\kappa, p; \lambda) - \Phi(\kappa, p; \lambda), \end{aligned} \quad (\text{A11})$$

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. Summing consumer surplus in Equation A11 and profit in Equation 4 yields welfare:

$$W(\kappa, p; \lambda) = \int_{p+z(\kappa; \lambda)}^{\infty} v dF(v) - c(\kappa)D(\kappa, p; \lambda) - \Phi(\kappa, p; \lambda). \quad (\text{A12})$$

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

maximized welfare is defined as $\beta(\kappa) \equiv \bar{\pi}(\kappa)/\bar{W}(\kappa)$. Taking logs and differentiating, it follows that $\beta'(\kappa)/\beta(\kappa) = \bar{\pi}'(\kappa)/\bar{\pi}(\kappa) - \bar{W}'(\kappa)/\bar{W}(\kappa)$. Now let κ^* denote the profit-maximizing product carbon footprint. Because $\bar{\pi}'(\kappa^*) = 0$ by definition, it follows that $\beta'(\kappa^*)/\beta(\kappa^*) = -\bar{W}'(\kappa^*)/\bar{W}(\kappa^*)$.

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 with the no-offset strategy. To this end, consider an offset market in which an offset provider compensates emissions at variable cost $\phi\omega\kappa^0 D(p^0)$, 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:

$$W(\kappa^0, p^0; \omega) = \int_{p^0}^{\infty} v dF(v) - c(\kappa^0)D(0, p^0) - \phi\omega\kappa^0 D(0, p^0) - F. \quad (A13)$$

Because the offset cost $\omega\kappa^0 D(0, p^0)$ is a transfer from the firm to the offset provider, it cancels out in the welfare calculation. Using Equations A12 and A13, adopting a climate neutral strategy is economically efficient if $W(\kappa^0, p^0; \omega) \geq W(\kappa^*, p^*; \lambda)$. This condition is satisfied if the social cost of carbon offsetting $\phi\omega\kappa^0 D(0, p^0) + F$ is sufficiently low compared with 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:

$$-c'(\kappa^r)D(\kappa^r, p^r) + (p^r - c(\kappa^r))D_{\kappa}(\kappa^r, p^r) + \mu_1 - \mu_2 - \mu_3\Phi_{\kappa}(\kappa^r, p^r) = 0 \quad (A14)$$

$$D(\kappa^r, p^r) + (p^r - c(\kappa^r))D_p(\kappa^r, p^r) - \mu_3\Phi_p(\kappa^r, p^r) = 0, \quad (A15)$$

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

We denote the unique constrained profit-maximizing product design by (κ^r, p^r) and assume that the carbon constraint is binding so that $0 < \kappa^r < \bar{\kappa}$, which implies that $\mu_1 = \mu_2 = 0$. Substituting Equation A15 into Equation A14 and rearranging yields

$$-c'(\kappa^r) - z_{\kappa}(\kappa^r; \lambda) + \frac{\mu_3}{1 - F(\cdot)} [\Phi_p(\kappa^r, p^r)z_{\kappa}(\kappa^r; \lambda) - \Phi_{\kappa}(\kappa^r, p^r)] = 0. \quad (A16)$$

The third term on the left-hand side of Equation A16 is negative if $\Phi_{\kappa}(\kappa, p) > 0$, as $\Phi_p < 0$ and $z_{\kappa}(\kappa^r; \lambda) > 0$. Consequently, $\kappa^r < \kappa^*$ if $\Phi_{\kappa}(\kappa, p) > 0$, that is, if the sales expansion from offering a greener product is sufficiently small to not compensate for the direct reduction in overall emissions.

Proof of Proposition 7. Suppose that a firm with product design (κ^*, p^*) and profit π^* faces regulation that is implemented with probability ρ . If the firm decides to meet the carbon cap by adjusting the product design, the expected reduction in profit is given by $\pi^* - [\rho\pi^r + (1 - \rho)\pi^*] = \rho(\pi^* - \pi^r)$, where π^r is the constrained optimal profit. Instead, if the firm decides to leave the product design unchanged and to purchase carbon allowances, the expected reduction in profit 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 analyze the impact of a carbon tax, we use the same approach as in Proposition 2. Letting $C(\kappa) \equiv c(\kappa) + t\kappa$ denote the effective unit cost, the problem in Equation 7 is structurally equivalent to the problem in Equation 4. Therefore, using Equation A5, the profit-maximizing carbon footprint at an interior solution satisfies $-C'(\kappa^*) = z_{\kappa}(\kappa^*; \lambda)$, which can be rewritten as

$$-c'(\kappa^*) - t = z_{\kappa}(\kappa^*; \lambda). \quad (A17)$$

Applying the implicit function theorem to Equation A17 yields

$$\frac{d\kappa^*}{dt} = -\frac{1}{c''(\kappa^*) + z_{\kappa\kappa}(\kappa^*; \lambda)} < 0, \quad (A18)$$

where the inequality follows from the second-order condition. From Equation A7, the first-order condition for the profit-maximizing price reads $p^* = C(\kappa^*) + [1 - F(\cdot)]/f(\cdot)$. Implicit differentiation yields

$$\frac{dp^*}{dt} = \frac{\kappa^* f(\cdot)}{2f(\cdot) + (p - c(\kappa^*) - t\kappa^*)f'(\cdot)} - \frac{d\kappa^*}{dt} z_{\kappa}(\kappa^*; \lambda). \quad (A19)$$

The corporate carbon footprint can be written as

$$\Phi^*(t) = \kappa^*(t)[1 - F(p^*(t) + z(\kappa^*(t); \lambda))].$$

Differentiating $\Phi^*(t)$ with respect to the tax rate t and substituting for $d\kappa^*/dt$ and dp^*/dt given in Equations A18 and A19, respectively, yields

$$\begin{aligned} \Phi'(t) &= \frac{d\kappa^*}{dt} [1 - F(\cdot)] - \kappa^* f(\cdot) \left[\frac{dp^*}{dt} + z_{\kappa} \frac{d\kappa^*}{dt} \right] \\ &= \frac{d\kappa^*}{dt} [1 - F(\cdot)] - \frac{[\kappa^* f(\cdot)]^2}{2f(\cdot) + (p - c(\kappa^*) - t\kappa^*)f'(\cdot)} < 0. \end{aligned} \quad (A20)$$

Therefore, a proportional carbon reduces not only the profit-maximizing carbon footprint but also the corporate carbon footprint.

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. Because $d\pi^*(t)/dt = -\kappa^*D(\kappa^*, p^*; \lambda) = -\Phi^*(t)$ from the envelope theorem and using the definition of the corporate carbon footprint, we have that

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

which implies that uncertain taxation reduces profit.

Proof of Proposition 9. In the absence of carbon regulation, the firm adopts the green technology if $\pi_1^* - \pi_0^* \geq f_1$. With regulation, the firm adopts the green technology if $\rho(\pi_1^* - \pi_0^*) + (1 - \rho)(\pi_1^* - \pi_0^*) \geq f_1$. Therefore, if $\pi_1^* - \pi_0^* > \pi_1^* - \pi_0^*$, 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 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

$$D_i(\kappa, p; \lambda) = \frac{1}{2} - \lambda(\kappa_i - \kappa_j) - (p_i - p_j). \quad (A21)$$

To illustrate the emergence of competitive carbon offsetting, we focus on the case where $c_1^0 = c_2^0 \equiv 1$, $\lambda = 1$, and $\omega < 1$. Firm i then solves

$$\max_{\kappa_i, p_i} \pi_i(\kappa_i, p_i) = [p_i - (1 - \kappa_i)^2] D_i(\kappa, p). \quad (A22)$$

The (necessary and sufficient) first-order conditions are given by

$$\frac{\partial \pi_i}{\partial \kappa_i} = 2(1 - \kappa_i^*) D_i(\kappa^*, p^*) + [p_i^* - (1 - \kappa_i^*)^2] \frac{\partial D_i(\kappa^*, p^*)}{\partial \kappa_i} = 0 \quad (A23)$$

$$\frac{\partial \pi_i}{\partial p_i} = D_i(\kappa^*, p^*) + [p_i^* - (1 - \kappa_i^*)^2] \frac{\partial D_i(\kappa^*, p^*)}{\partial p_i} = 0. \quad (A24)$$

Simultaneously solving the first-order conditions of firm i by substituting Equation A24 into Equation A23 and using the properties of demand in Equation A21 (with $\lambda = 1$) yields $\kappa_i^* = \frac{1}{2}$. The optimal prices $p_i^* = \frac{3}{4}$ are then determined by solving for equilibrium in a standard Hotelling model with given unit costs $c_i(\kappa_i^*)$ and demand. The solution is indeed the profit maximum because π_i is concave in both κ_i and p_i and the determinant of the Hessian matrix H_i evaluated at (κ_i^*, p_i^*) is strictly positive (specifically, $\det(H_i) = 2$). 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

$$S_1(\kappa_1, p_1; 1) = \int_0^{\hat{x}} (v - p_1 - \kappa_1 - \frac{x}{2} - E) dx. \quad (A25)$$

Because consumers fully internalize their climate externality ($\lambda = 1$), it follows that $E = 0$. By substitution, Equation A25 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:

$$W^* = \sum_{i=1}^2 (S_i^* + \pi_i^* - \Phi_i^*) = v - \frac{11}{8}. \quad (A26)$$

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

$$\max_{\kappa_1, p_1} \pi_1(\kappa_1, p_1) = [p_1 - (1 - \kappa_1)^2 - \omega \kappa_1] \left(\frac{1}{2} + \kappa_2 - (p_1 - p_2) \right), \quad (A27)$$

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

$$\max_{\kappa_2, p_2} \pi_2(\kappa_2, p_2) = [p_2 - (1 - \kappa_2)^2] \left(\frac{1}{2} - \kappa_2 - (p_2 - p_1) \right). \quad (A28)$$

Using a similar approach as in the case where both firms adopt a no-offset strategy, simultaneously solving the first-order conditions and substituting the unique solutions back into the profit functions yields the optimal profits $\hat{\pi}_1 = \frac{1}{144}(\omega(\omega - 4) + 9)^2 \equiv A$ and $\hat{\pi}_2 = \frac{1}{144}(\omega(\omega - 4) - 3)^2 \equiv B$ (the lower-left cell in Figure 3). Note that these profits are reversed in a setting in which firm 1 uses a no-offset strategy and firm 2 uses an offset strategy (the upper-right cell in Figure 3).

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

$$\max_{\kappa_i, p_i} \pi_i(\kappa_i, p_i) = [p_i - (1 - \kappa_i)^2 - \omega \kappa_i] \left(\frac{1}{2} - (p_i - p_j) \right). \quad (A29)$$

Using a similar approach as in the previous cases, simultaneously solving the first-order conditions and substituting the unique solutions back into the profit functions yields the optimal profits $\bar{\pi}_i = \frac{1}{4}$ (the lower-right cell in Figure 3).

Inspection of Figure 3 shows that adopting an offset strategy is a strictly dominant strategy for each firm. The reason is that the offset strategy is more profitable than the no-offset strategy, no matter what the competitor may choose because $A > \frac{1}{4}$ and $B < \frac{1}{4}$ for all $\omega < 1$.

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

$$\begin{aligned}\bar{W}^* &= \sum_{i=1}^2 (S_i^* + \pi_i^*) + (\omega - \phi) \sum_{i=1}^2 \Phi_i^* - F \\ &= v - \frac{\omega^2}{4} - \frac{\phi}{2} (2 - \omega) - \frac{1}{8} - F,\end{aligned}\quad (\text{A30})$$

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 $\bar{W}^* > W^*$. 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.

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