Carbon Footprinting and Pricing Under Climate Concerns*

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Abstract

This paper studies how marketers should design and price a product in the face of climate concerns. We first derive the profit-maximizing carbon footprint and price, and examine how these respond to stronger climate concerns by consumers. Next, we consider the impact of product-level decisions on the carbon emissions of the firm as a whole. Interestingly, we find that a firm can become a victim of its own success, as a greener product may boost sales to the point that overall emissions also increase. Finally, we analyze how government regulation in the form of a cap-and-trade scheme or a carbon tax affects product design and pricing, firm profitability, and the adoption of green technologies.

Keywords: Green marketing, product design, organizational carbon footprint, carbon regulation.

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1 Introduction

"On climate change, we have to acknowledge that we have failed," the 16-year-old Swedish climate activist Greta Thunberg reminded the global leaders gathered at the 2019 Annual Meeting of the World Economic Forum in Davos.[1] And "I want you to act." The alarm had been sounded earlier in the 2018 report of the United Nations Intergovernmental Panel on Climate Change (IPCC 2018), which warns that humanity is less than 12 years away from the point of no return. Climate concerns are also shaped by the increasing number of climate marches that are organized around the world, the most recent example being the wave of Youth Climate Strikes, where children skipped school to demand action on climate change (*The New York Times* 2018).

Dealing with climate concerns is key to the survival of businesses in the marketplace. For example, "flight-shaming" over climate change poses an existential threat to airlines, which are forced to tackle their carbon emissions in response to consumer pressure (*Forbes* 2019). Calculating carbon footprints has become standard (Meinrenken et al. 2012; Vandenbergh, Dietz, and Stern 2011), and they are routinely reported by organizations according to international accounting standards (GHG Protocol 2011; ISO 2006) to allow consumers with climate concerns to make better-informed purchase decisions.[2] Marketing can play a leadership role in this by developing products and services that have a low carbon footprint—the climate impact measured in carbon dioxide equivalent (CO_2eq) emissions.

The objective of this paper is to understand how marketers should choose the carbon footprint and price of their products in markets where consumers and governments have climate concerns. Specifically, we develop a model to address the following questions: (i) What is the optimal carbon footprint and price of a product? (ii) How do stronger climate concerns affect optimal marketing activities, and the resulting organizational

[1]The video of the Special Address is available at `https://bit.ly/2G2HcNp`.

[2]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).

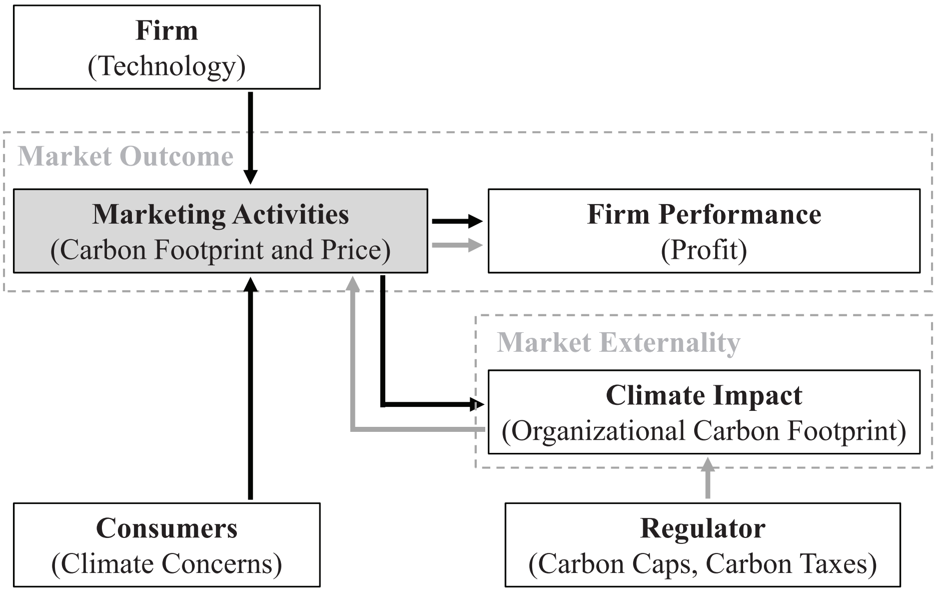

Figure 1: Model elements.

carbon footprint? (iii) How does carbon regulation that puts a price on the climate impact affect marketing activities, firm profitability, and green technology adoption?

To answer these questions, we develop a model in which a firm chooses the carbon footprint and price of a product that is marketed to consumers with climate concerns. Importantly, changes in the carbon footprint not only have a cost effect but also a demand effect (Rust, Moorman, and Dickson 2002; Rust, Zahorik, and Keiningham 1995). Consumers observe the firm's marketing activities and decide to purchase or choose an outside option. In addition, a regulator may impose a carbon cap or a carbon tax on the firm's overall level of emissions—the organizational carbon footprint. The marketing activities are therefore endogenously determined by the interplay of the choices made by the firm, the consumers, and the regulator. Figure 1 summarizes the main components of the analytical framework and the stakeholders, and highlights the fact that the climate impact resulting from the choice of the carbon footprint is a "market externality."

We derive several key results. First, we show that reducing the carbon footprint is obviously optimal if it eliminates waste—the case of cost-cutting sustainability. Under cost-increasing sustainability, the optimal carbon footprint and price are not only driven by the cost effect, but also by the demand effect. We identify the conditions under which stronger climate concerns lead to greener product design and a higher price. While these effects seem intuitive, they depend on the shape of the demand curve. Therefore, in some cases, stronger climate concerns may provide an incentive for the firm to increase (rather than decrease) the carbon footprint. In addition, we show that the profit-maximizing carbon footprint may be lower than the socially optimal level, which means that the firm can contribute to a "better world" by offering a product that is greener than socially optimal.

Second, we show how marketing activities translate into the organizational carbon footprint. We find that the overall emissions of the firm can be lower than the socially optimal carbon footprint, an effect that results because the firm does not consider the social cost of distorting product design and pricing. We also show that greener product design may actually increase the organizational carbon footprint when a firm that offers a green product becomes a victim of its own success due to higher sales. This means that marketing greener products may be in conflict with the goal of reducing the organizational carbon footprint.

Third, we show how marketing activities and firm profitability are affected by carbon regulation in the form of cap-and-trade systems and carbon taxes, the two most widely used instruments to reduce CO_2 emissions (The World Bank 2015). If regulation takes the form of a cap on the organizational carbon footprint, then it directly limits overall emission levels, but it also affects product design and may increase the product carbon footprint. However, if regulation imposes a proportional tax on carbon emissions, then it directly affects product design but may cause an increase of the organizational carbon footprint. Finally, we show that the mere threat of carbon regulation may lead to the adoption of a greener technology. The reason for this is that uncertainty about the likelihood of carbon regulation can relax the standard adoption condition by reducing the cost of complying with future carbon regulation.

Our results contribute to several streams of literature. First, we add to research on green marketing (Cheng and Zhang 2017; Cronin et al. 2011; Chen 2001) by showing how marketing activities are determined by the interplay of climate concerns (Kotler 2011), firm technology, and market regulation (Porter and van der Linde 1995). By endogenizing product design and pricing, this paper also adds to the "return on quality" literature (Rust, Moorman, and Dickson 2002; Rust, Zahorik, and Keiningham 1995; Rust and Zahorik 1993) and shows that offering a carbon neutral product is not necessarily optimal. This is in line with recent work that shows that there is an optimal level of service (Halbheer et al. 2018; Rust and Huang 2012) and that it may not be profitable to keep or redress all customers (Dukes and Zhu 2018; Ma, Sun, and Kekre 2015; Shin and Sudhir 2015). Importantly, we extend this line of research by establishing the link between marketing activities and the organizational carbon footprint. In contrast to previous research, the carbon footprint, which can be viewed as an inverse measure of product quality, not only affects demand and cost, but also creates a climate externality.

Second, this paper contributes to the literature on the link between corporate social responsibility (CSR) and firm market value (Luo and Bhattacharya 2006) by providing an explanation of the mixed evidence. It also contributes to the branding literature by showing how green product design and pricing affects the firm's overall level of emissions, and thereby its perceived brand attitude (Olsen, Slotegraaf, and Chandukala 2014; Keller 2003). This paper also adds to the regulation literature (Armstrong and Sappington 2007) by showing how carbon caps and carbon taxes affect profit-maximizing marketing activities. The novel insight is that product-level and firm-level regulatory intervention can be in conflict. Finally, 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 (Nordhaus 2019; Hsiang and Kopp 2018).

The remainder of the paper is organized as follows. Section 2 introduces the model. Section 3 focuses on profit-maximizing marketing activities, studies the impact of stronger climate concerns on the optimal carbon footprint and price, and compares the privately optimal decisions to the socially optimal levels. Section 4 identifies the link between the marketing activities and the organizational carbon footprint. Section 5 analyzes the impact of carbon regulation on marketing activities and firm profitability. Section 6 investigates how the prospect of carbon regulation triggers green technology adoption. Section 7 concludes by highlighting limitations of the research and offering directions for future work.

2 The Model

Consider a firm that conceives a product (or service) by choosing the carbon footprint $\kappa \in [0, \overline{\kappa}]$ and the price $p \geq 0$, the former indicating the emissions to produce a unit of the product in carbon dioxide equivalents (CO_2eq)—the climate externality.[3] The set $[0, \overline{\kappa}]$ indicates the technologically feasible carbon footprints: The firm offers a carbon neutral product if $\kappa = 0$ and a "brown product" if $\kappa = \overline{\kappa}$. The technology of the firm is represented by the unit cost function $c(\kappa)$ over the interval $[0, \overline{\kappa}]$.

There is a unit measure of consumers who may 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 consumer derives utility

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

from the product, where v is the valuation of the intrinsic product features and $z(\kappa; \lambda)$ is the disutility from purchasing a product with carbon footprint κ, with $\lambda \geq 0$ capturing the strength of the climate concerns. The unobserved valuation of the intrinsic features v is distributed across consumers according to the cumulative distribution function $F(v)$. The disutility $z(\kappa; \lambda)$ is increasing and convex in the carbon footprint κ; that is, $z_\kappa(\kappa; \lambda) > 0$

[3] 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).

and $z_{\kappa\kappa}(\kappa;\lambda) \geq 0$. We normalize disutility to zero if the product is carbon neutral or if consumers do not have climate concerns, so that $z(0;\lambda) = z(\kappa;0) = 0$.[4] We further assume that stronger climate concerns increase the disutility from a given carbon footprint, that is, $z_{\lambda}(\kappa;\lambda) > 0$. An intuitive way to interpret the disutility $z(\kappa;\lambda)$ is to view it as a negative transaction utility (Thaler 1985) or a "cold prickle" of producing a carbon externality in consumption (Andreoni 1995).

Consumers observe the carbon footprint κ and the price p and choose to purchase if the utility from the product exceeds their utility from the outside option, which is normalized to zero.[5] Therefore, the demand for the product can be derived as

$$\begin{aligned} D(\kappa, p; \lambda) &= Pr\{v \geq p + z(\kappa;\lambda)\} \\ &= 1 - F(p + z(\kappa;\lambda)). \end{aligned} \tag{2}$$

Demand is decreasing in the carbon footprint ($D_{\kappa} \leq 0$). Interpreting the carbon footprint as an inverse measure for product quality, a lower κ means higher quality and therefore (weakly) higher demand. The novel aspect is that "product quality" not only works as a demand shifter but also has a climate externality. Lowering the carbon footprint therefore implies "demand neutrality" when consumers do not care about the climate impact ($D_{\kappa} = 0$) and "demand expansion" when consumers have climate concerns ($D_{\kappa} < 0$). A simple example which illustrates the properties of demand arises if v is uniformly distributed on the interval $[0,1]$ and $z(\kappa;\lambda) = \lambda\kappa$. In this case $D(\kappa, p; \lambda) = 1 - p - \lambda\kappa$.

3 Carbon Footprint and Price

This section first derives the profit-maximizing product design and pricing decisions, and studies their relationship to climate concerns. Next, we compare the profit-maximizing

[4]Implicitly, the disutility $z(\kappa;\lambda)$ assumes that the "should expectation" (Boulding, Staelin, Kalra and Zeithaml 1994; Tse and Wilton 1988) is a carbon neutral product, an assumption that can be relaxed to include an arbitrary reference point.

[5]Our analysis assumes that the firm or an outside party truthfully reveals the carbon footprint, so that there is no uncertainty about environmental quality as in Harbaugh, Maxwell, and Roussillon (2011).

product design to the socially optimal product design that would result from welfare maximization.

3.1 Profit-Maximizing Carbon Footprint and Price

The firm chooses the carbon footprint κ and the price p to

$$\begin{aligned} \max_{\kappa,p} \quad & \pi(\kappa,p;\lambda) = [p - c(\kappa)]D(\kappa,p;\lambda) \\ \text{s.t.} \quad & 0 \leq \kappa \leq \overline{\kappa}. \end{aligned} \tag{3}$$

Assuming that the profit function $\pi(\kappa,p;\lambda)$ is strictly concave, standard optimization theory posits that there is a unique constrained profit-maximizing carbon footprint κ^* and price p^*.

Proposition 1 (Marketing Activities). *If reducing the carbon footprint lowers unit cost, the firm should offer a carbon neutral 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 the maximally polluting product with* $\kappa^* = \overline{\kappa}$ *at price* $p^*(\overline{\kappa})$*, whereas offering a product with a carbon footprint* $\kappa^* \in [0, \overline{\kappa}]$ *that depends on the relative size of the cost effect and the demand effect at price* $p^*(\kappa^*)$ *is optimal if lowering* κ *enhances demand.*

Proposition 1 mirrors the "return on quality" logic (Rust, Moorman, and Dickson 2002; Rust, Zahorik, and Keiningham 1995; Rust and Zahorik 1993) and has two important managerial implications. First, if lowering the carbon footprint reduces unit cost, then it is unsurprisingly optimal to increase efficiency by eliminating waste and thereby increase "process quality" (Deming 1986; Crosby 1979). When lowering the carbon footprint not only reduces cost but also increases demand because of higher perceived "product quality" (Parasuraman, Zeithaml, and Berry 1985), green cost cutting is even more attractive to the firm, as the firm benefits both from the cost effect and the demand effect. More broadly, this result helps to explain why many sustainability efforts tend to increase firm profit (Winston, Favaloro, and Healy 2017).

	Demand Neutrality ($D_\kappa = 0$)	**Demand Expansion** ($D_\kappa < 0$)
Cost Reduction ($c' > 0$)	$\kappa^* = 0$ (carbon neutral product)	
Cost Increase ($c' < 0$)	$\kappa^* = \overline{\kappa}$ (brown product)	$\kappa^* \in (0, \overline{\kappa})$ (green product) or $\kappa^* = 0$ or $\kappa^* = \overline{\kappa}$

Figure 2: Cost effect, demand effect, and optimal product design.

Second, if lowering the carbon footprint increases unit cost, there may be a tradeoff between the cost effect and the demand effect. Clearly, absent a demand effect, lowering the carbon footprint results in a cost to the firm and is therefore suboptimal under profit maximization. However, when lowering the carbon footprint increases both cost and demand, it may be optimal for the firm to adopt a "green product design" and set $\kappa^* \in (0, \overline{\kappa})$. 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 being part of the "sustainability programs worthy of the name" (*The Economist* 2014). Figure 2 summarizes the optimal product design strategies derived in Proposition 1.

3.2 Impact of Climate Concerns

Stronger climate concerns affect green product design only if lowering the carbon footprint leads to higher unit cost. In this interesting case, profit-maximization does not lead to a carbon neutral product that eliminates the climate externality.

Proposition 2 (Climate Concerns). *Under green product design, the firm should lower the carbon footprint and increase the price in response to stronger consumers' climate concerns if the profit function satisfies* $\pi_{\kappa\lambda} > \frac{\pi_{\kappa p}\pi_{p\lambda}}{\pi_{pp}}$ *and* $\pi_{p\lambda} < \frac{\pi_{p\kappa}\pi_{\kappa\lambda}}{\pi_{\kappa\kappa}}$.

Proposition 2 shows that stronger climate concerns have an ambiguous effect on the optimal carbon footprint and price, an unexpected result. To understand the result intuitively, note that stronger climate concerns affect the sensitivity of demand with respect to the carbon footprint and price, which drive the optimal product design and pricing. In addition, a change in the carbon footprint affects the cost structure of the firm. Taken together, these demand and supply side effects determine the curvature of the profit function and therefore the relative profitability of adjusting the carbon footprint and the price.

Specifically, Proposition 2 shows that stronger climate concerns lead to greener product design with a smaller carbon footprint if the impact on the profit increase resulting from a reduction in the carbon footprint is sufficiently large, while the price is higher if the impact on the profit decrease resulting from a higher price is sufficiently small. Finally, interpreting the carbon footprint as an inverse measure for product quality, Proposition 2 implies an ambiguous relationship between product quality and price and thereby adds to the literature on price-quality relationships (Gerstner 1985; Parasuraman, Zeithaml and Berry 1985).

3.3 Socially Optimal Carbon Footprint and Price

The profit-maximizing carbon footprint κ^* and price p^* typically differ from the socially optimal carbon footprint κ^w and price p^w that result from maximizing welfare, obtained by adding firm profit and consumer surplus. This difference is useful to evaluate the carbon impact of the product in the absence of climate regulation. The next result summarizes the two-dimensional comparison between the privately and socially optimal decisions.

Proposition 3 (**Market Outcome**). *Under a green product strategy, while the profit-maximizing carbon footprint differs from the socially optimal carbon footprint except when demand is linear in price, the profit-maximizing price exceeds the socially optimal price at any given carbon footprint.*

Proposition 3 shows that consumers' climate concerns can motivate a profit-maximizing firm to design a product with a carbon footprint that may be lower than the socially optimal level ($\kappa^* < \kappa^w$) and thereby contribute to a "better world" by offering a greener product than is socially optimal. However, the firm does not consider the social cost of providing "excessive quality." Generally, the extent to which the carbon footprint departs from the social optimum depends on the shape of the distribution function of consumer valuations of the intrinsic features, and hence the curvature of the demand (Spence 1975). A special case arises if demand is linear in price, in which case the firm then provides the product with socially optimal climate impact.

Proposition 3 also points to the possibility that the firm designs a product with a carbon footprint that exceeds the socially optimal level ($\kappa^* > \kappa^w$). Irrespective of the direction of the distortion, the profit-maximizing price exceeds the socially optimal price at any given carbon footprint κ ($p^*(\kappa) > p^w(\kappa)$). The reason for this is that the firm exploits its pricing power to raise price above unit cost—even in the case where the product has a higher carbon footprint than at the social optimum.

4 Organizational Carbon Footprint

This section shows how the choice of the profit-maximizing product design and pricing determines the overall climate impact of the firm—the organizational carbon footprint. The following result holds.

Proposition 4 (Organizational Footprint). *The organizational footprint of a profit-maximizing firm is given by $\Phi^* = \kappa^* D(\kappa^*, p^*; \lambda)$ and can be lower than the organizational carbon footprint Φ^w that results from socially optimal marketing activities. Under a green product strategy, stronger climate concerns may increase the organizational carbon footprint Φ^* even if it is optimal to lower the carbon footprint κ^*.*

Proposition 4 shows how marketing activities drive the organizational carbon footprint. An interesting insight is that profit-maximizing decisions about the carbon footprint and price may lead to a smaller organizational carbon footprint than socially optimal decisions because the exploitation of the pricing power reduces demand and thereby the climate externality. The result also shows that offering a greener product in response to stronger consumers' climate concerns does not necessarily reduce a firm's overall level of carbon emissions. This occurs because the demand effect of lowering the carbon footprint may translate into higher sales and thus a greater organizational footprint—a situation where a firm that offers a green product can become a victim of its own success. For marketers, this implies that improving the climate performance of the product in response to consumer pressure does not necessarily improve brand attitude (Olsen, Slotegraaf and Chandukula 2014), defined as the overall evaluation of the brand (Keller 2003).

Proposition 4 is also important for marketers because carbon regulation often restricts the organizational carbon footprint. Designing greener products can therefore be in conflict with the objective of meeting climate targets mandated by law. This points to a potential tension between the objectives of marketers and managers who are in charge of the organization's carbon management.

5 Carbon Regulation

Regulators are increasingly putting a price on carbon to make firms pay for their climate externalities—costs that are otherwise borne by society. This section first explores how a binding cap on the organizational carbon footprint affects marketing activities. We next investigate how a cap-and-trade system that is implemented with a given probability affects expected firm profitability.[6] Finally, we show how a carbon tax affects marketing activities and the organizational carbon footprint, and quantify the expected cost of the tax to the firm.

[6]The advantage of the cap-and-trade system over binding carbon caps is that a firm with low compliance cost can sell the allowances in the emissions market. For example, *Tesla* generates significant revenues by selling zero emission vehicle credits in the US.

5.1 Binding Carbon Caps

Regulators often attempt to limit a firm's organizational carbon footprint by imposing a binding carbon cap $R \geq 0$. In such a business environment, the firm solves

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

where $\Phi(\kappa,p;\lambda)$ is the organizational carbon footprint. We denote the unique constrained profit-maximizing marketing activities by (κ^r, p^r). The next result summarizes the impact of a binding carbon cap.

Proposition 5 (Carbon Caps). *A binding carbon cap reduces the firm's organizational carbon footprint and profit, but has an ambiguous effect on the profit-maximizing carbon footprint and price. A binding carbon cap may induce the firm to increase the carbon footprint κ^r to reduce sales and thereby comply with the regulation.*

A binding carbon cap has the obvious effect of reducing the firm's overall carbon emissions 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 of lowering κ: If $\Phi_\kappa(\kappa,p;\lambda) < 0$, then lowering the carbon footprint leads to higher overall emissions 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 $\Phi_\kappa(\kappa,p) > 0$, lowering κ relaxes the carbon constraint, which provides an incentive for the firm to reduce the carbon footprint. The impact on price is ambiguous because of the simultaneous demand and cost effect of a change in κ.

5.2 Profit Impact of Cap-and-Trade Systems

Introducing and tightening carbon regulation lead to regulatory uncertainty for the firm. To capture this uncertainty, suppose that a regulator is expected to introduce 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 their marketing activities to meet the regulatory constraint at the organizational level, or stick to their current decisions about the carbon footprint and price and purchase carbon allowances at a market price ω in an emissions market. Suppressing the arguments of the functions to simplify exposition, the respective profits are denoted by π^r and $\pi^* - \omega(\Phi^* - R)$, where $\omega(\Phi^* - R)$ is the cost to the firm of purchasing carbon allowances if it decides to not meet the carbon cap. The following result summarizes the expected cost of regulation (CR).

Proposition 6 (Profit Impact). *The expected cost of a carbon cap to the firm is given by* $CR = \rho \min\{\pi^* - \pi^r, \omega(\Phi^* - R)\}$*, where* $\rho(\pi^* - \pi^r)$ *is the expected reduction in profit when the firm complies with the carbon cap and* $\rho\omega(\Phi^* - R)$ *is the expected reduction in profit when 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* ω *is higher.*

Proposition 6 confirms the intuition that cap-and-trade regulation with a binding carbon cap reduces the expected profit of the firm. Further the cost of regulation is increasing in the probability of regulation and the market price for emissions. This is important because firms should anticipate changes in the regulatory environment and thus want to invest in the adoption of a greener technology to comply with expected regulation.

5.3 Profit Impact of Carbon Taxes

Environmental regulation may impose a carbon tax (rather than carbon caps) to limit the climate impact of the firm. The key difference between these regulatory instruments is that, while a carbon cap limits the organizational footprint, a carbon tax imposes a price on the organizational footprint. To reflect this, assume that $t \geq 0$ is the tax rate on carbon emissions. Under this proportional carbon tax, the firm solves

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

Note that a proportional carbon tax raises the unit cost of production to $c(\kappa)+t\kappa$. We denote the optimized profit under a carbon tax by $\pi^*(t)$. The next result summarizes the impact on the marketing activities and firm profit

Proposition 7 (Carbon Taxation). *A proportional carbon tax $t > 0$ reduces the optimal carbon footprint if $\pi_{\kappa t} > (\pi_{\kappa p}\pi_{pt})/\pi_{pp}$ and has an ambiguous effect on the organizational carbon footprint $\Phi^*(t)$. The cost of the regulation is given by $CR = \rho\{\pi^*(0) - \pi^*(t)\} > 0$, which increases in the implementation probability ρ and the tax rate t.*

Proposition 7 shows that a carbon tax induces the firm to offer a greener product if the marginal profit of increasing κ is sufficiently responsive to an increase in the tax rate. The impact of the tax on the organizational footprint $\Phi^*(t)$ is ambiguous because the product's lower carbon footprint may increase sales and therefore the overall emissions. Proposition 7 also shows that the uncertain introduction of a carbon tax reduces expected profit for the firm: 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; Ailawadi and Harlam 2009; Gómez, Rao and McLaughlin 2007; Kumar, Rajiv and Jeuland 2001; Moorthy 2005; Tyagi 1999). The profit effect is stronger the more likely it is that the regulator introduces a carbon tax.

The results show that carbon regulation in the form of either carbon caps or carbon taxes reduces expected firm profitability. This leads to the natural question which form of regulatory intervention is more costly to the firm. Recall that under a carbon cap, the firm has two options: adjust the product design to meet the carbon cap or purchase carbon allowances to offset the excess emissions. However, the firm only has one option under a carbon tax: adjust the product design to the new cost structure. In the case of compliance, the cost to the firm depends on the relative magnitude of π^r and $\pi^*(t)$, whereas it depends on the relative magnitude of the offset cost $\omega(\Phi^* - R)$ and the cost of the tax $\pi^* - \pi^*(t)$ in the case of non-compliance. In the case of noncompliance, one can expect carbon caps will be less costly for the firm if the gap between the organizational carbon footprint and the carbon cap R is not too large because the carbon price ω only applies to excess emissions whereas the carbon tax applies to the organizational footprint.

6 Investing in Green Technology

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 regulation, the following result holds.

Proposition 8 (Regulatory Pressure). *A firm facing the risk of regulation adopts the green technology if* $\pi_1^* - F \geq \pi_0^* - (CR_0^* - CR_1^*)$.

Proposition 8 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 organizational carbon footprint. Regulatory pressure can thus provide incentives for marketing managers and firms to do good for the climate by offering greener products, the standard link from to regulation to promoting innovation (Porter and can der Linde 1995).

7 Conclusion

This paper has explored the impact of climate concerns on marketing activities and the resulting organizational carbon footprint. Our analysis showed that reducing the carbon footprint of a product is always optimal if it increases efficiency by eliminating waste. Under cost-increasing sustainability, 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. Furthermore, we showed that greener product design may actually increase the organizational carbon footprint, an instance where a firm that offers a green product becomes a victim of its own success due to higher sales. Finally, we showed how marketing activities, firm profitability, and green technology adoption are affected by carbon regulation in the form of cap-and-trade systems and carbon taxes.

The results confirm the intuition that climate concerns of consumers and regulators tend to reduce the carbon footprint of products and organizations. However, in many plausible cases, overall carbon emissions can increase due to the increase in demand for products with a lower carbon footprint. Importantly, the logic here applies beyond carbon emissions, e.g. to other pollutants and water or plastic footprints, and ecological footprints more broadly, which all play a key role in managing corporate social responsibility (CSR).

The analysis provides new insights into how marketers should respond to climate concerns by adjusting product design and pricing. 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 and pricing. In contrast, climate concerns of the government that lead to carbon regulation force the firm to adjust its marketing activities to account for the price on the climate externality. These insights inform marketers under what conditions their activities contribute to a better world by reducing the carbon impact of the organization. Designing greener products is not sufficient to reduce the organizational carbon footprint—the climate externality. More broadly, our results can also be used to understand how firms can contribute to reduce 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 and pricing. However, climate concerns may provide an opportunity to invest in green technologies, which allow the firm to reduce the cost of compliance with regulation. Interestingly, climate regulation can motivate marketers to push for a greener technology that reduces the carbon footprint of the product. Hence, taking a proactive approach to deal with climate concerns rather than resisting change can mitigate the impact of more stringent regulation on firm profitability.

Our analysis also helps marketers to deal with an internal carbon price—a shadow price used within an organization to reflect the external cost of carbon emissions. An internal carbon price impacts the marketing activities and the overall carbon footprint in the same way as a carbon tax set by a regulator. The *United Nations Global Compact* calls companies to set an internal price at a minimum of $100 per metric ton by 2020 to put climate at the heart of strategy and decision-making.[7] *Microsoft* took leadership and introduced 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 overall carbon footprint of the organization. This points to a possible tension between internal stakeholders, such as marketers and managers who are responsible for carbon management at the organizational level, which shapes brand image. Resolving the tension between "green products" and "green organizations" is important to position products and brands.

Of course, this paper has some limitations. First, future research could examine how climate concerns are being shaped. One approach could be to assume that climate concerns are influenced by the firm's climate impact. This is the same as assuming that the firm's brand image drives product perception. Another approach could be to assume that the firm can influence the climate concerns via persuasive advertising. However, because climate concerns reduce demand, the incentives to engage in advertising must come from a simultaneous impact from a greener brand image that has the opposite effect on demand.

Another extension of the model is to consider not only production emissions, but also emissions that occur in the consumption stage. This would allow marketers to understand what drives the life-cycle carbon footprint of a product (cradle-to-grave approach). The

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

interesting aspect of such an extension is that the emissions in the consumption are driven by consumer behavior that cannot be influence by the firm.

Third, one could study the role of competition. The behavior of current competitors can affect both demand and the likelihood and severity of governmental regulations. In addition, new competitors may enter the market including some with innovative ways to reduce carbon emissions. Technological breakthroughs that improve the ability to produce products 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 total industry pollution/carbon emissions and total country level emissions.

Another limitation is that we do not have data on what managers would (as opposed to should) do. Empirical analysis of actual behavior would definitely be helpful in this regard. Alternatively, survey data on how managers would respond (or have responded) to increased climate concerns could provide important insights. Given the importance of the topic, further empirical, analytical, and simulation work (e.g. agent based) is definitely called for.

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Appendix

Proof of Proposition 1. The profit-maximizing product 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):

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

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

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

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 $\mu_1 = 0$. 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 optimal 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. Under a green product strategy, $\kappa^* \in (0, \overline{\kappa})$ and the first-order conditions (A.1) and (A.2) hold with equality. Applying Cramer's rule yields

$$\frac{d\kappa^*(\lambda)}{d\lambda} = -\frac{\pi_{pp}\pi_{\kappa\lambda} - \pi_{\kappa p}\pi_{p\lambda}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}} \tag{A.3}$$

and

$$\frac{dp^*(\lambda)}{d\lambda} = -\frac{\pi_{\kappa\kappa}\pi_{p\lambda} - \pi_{p\kappa}\pi_{\kappa\lambda}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}}. \tag{A.4}$$

The expression in the denominators of (A.3) and (A.4) 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 optimal 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. Following convention, the consumer surplus is defined as $S(\kappa, p; \lambda) = \int_p^\infty D(\kappa, y; \lambda)dy$ and welfare is defined as the total surplus, that is, $W(\kappa, p; \lambda) = S(\kappa, p; \lambda) + \pi(\kappa, p; \lambda)$, where $\pi(\kappa, p; \lambda)$ is given in (3). 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

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

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.

Next, we establish that the gap between the profit-maximizing carbon footprint and the socially optimal carbon footprint vanishes for linear demand. Suppose that the valuations for the intrinsic product features v are uniformly distributed over the interval $[0,d]$, where $d > 0$. In this case, demand in (2) boils down to

$$D(\kappa, p) = 1 - \frac{p + v(\kappa)}{d}.$$

The profit is therefore given by

$$\pi(\kappa, p) = (p - c(\kappa)) \left(1 - \frac{p + v(\kappa)}{d}\right).$$

Solving the first-order condition yields

$$p^*(\kappa) = \frac{c(\kappa) + d - v(\kappa)}{2}.$$

By substitution, it follows that

$$\overline{\pi}(\kappa) = \frac{(c(\kappa) - d + v(\kappa))^2}{4d}.$$

The consumer surplus can be derived as

$$S(\kappa, p) = \int_p^{d - v(\kappa)} \left(1 - \frac{y + v(\kappa)}{d}\right) dy = \frac{(d - p - v(\kappa))^2}{2d},$$

where the choke-off point $d - v(\kappa)$ is the price that results in zero sales. Maximizing welfare yields the familiar result that $p^s(\kappa) = c(\kappa)$. Substituting the optimal price back into the welfare function yields

$$\overline{W}(\kappa) = \frac{(c(\kappa) - d + v(\kappa))^2}{2d}.$$

The ratio of maximized profit to maximized welfare can be calculated as $\beta(\kappa) = \frac{1}{2}$. Consequently, $\beta'(\kappa) = 0$ and the privately optimal carbon footprint coincides with the socially optimal carbon footprint. □

Proof of Proposition 4. The organizational carbon footprint is obtained by multiplying the carbon footprint per unit of product by the corresponding demand:

$$\Phi^*(\lambda) = \kappa^*(\lambda) D(\kappa^*(\lambda), p^*(\lambda); \lambda). \tag{A.5}$$

To show that the organizational carbon footprint for privately optimal decisions (κ^*, p^*) can exceed the corresponding level for socially optimal decisions (κ^w, p^w), recall from Proposition 3 that $\kappa^* = \kappa^w$ when demand is linear in price. Since the firm distorts price upward, the firm sells too little from a social point of view, which implies that $\kappa^* D(\kappa^*, p^*; \lambda) < \overline{\kappa} D(\overline{\kappa}, \overline{p}; \lambda)$.

Differentiating (A.5) with respect to λ yields

$$\frac{d\Phi^*(\lambda)}{d\lambda} = \frac{d\kappa^*(\lambda)}{d\lambda} D + \kappa^*(\lambda)\left(D_\kappa \frac{d\kappa^*(\lambda)}{d\lambda} + D_p \frac{dp^*(\lambda)}{d\lambda} + D_\lambda\right), \qquad \text{(A.6)}$$

where the arguments of the demand function are suppressed for convenience. Proposition 1 implies that the terms on the right-hand side cannot be signed unambiguously. Therefore, under some conditions, stronger climate concerns may increase the organizational footprint even if it is optimal for the firm to offer a greener product. □

Proof of Proposition 5. 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):

$$D(\kappa^r, p^r) + (p^r - c(\kappa^r)) D_p(\kappa^r, p^r) - \mu_3 \Phi_p(\kappa^r, p^r) = 0 \quad \text{(A.7)}$$

$$-c'(\kappa^r) D(\kappa^r, p^r) + (p^r - c(\kappa^r)) D_\kappa(\kappa^r, p^r) + \mu_1 - \mu_2 + \mu_3 \Phi_\kappa(\kappa^r, p^r) = 0 \quad \text{(A.8)}$$

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

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 regulation. □

Proof of Proposition 6. If the firm meets the carbon cap, the cost of regulation (CR) is given by the difference between the actual profit and the expected profit under the carbon regulation:

$$\Delta\pi^R \equiv \pi^* - [\rho \pi^r + (1 - \rho)\pi^*] = \rho(\pi^* - \pi^r).$$

Instead, if the firm purchases carbon allowances, the CR is given by the difference between the actual profit and the expected profit net of the cost to offset the emissions:

$$\Delta\pi^k \equiv \pi^* - [\rho(\pi^* - \omega(\Phi(p^*, \kappa^*) - R)) + (1-\rho)\pi^*] = \rho\omega(\Phi(p^*, \kappa^*) - R).$$

The firm chooses the option that yields the higher expected profit. Thus, the expected profit impact of regulation is given by $\rho \min\{\pi^* - \pi^r, \omega(\Phi(p^*, \kappa^*) - R)\}$. □

Proof of Proposition 7. To understand the impact of a carbon tax, consider an interior solution and suppose that $\pi_{\kappa t} > \min\left\{\frac{\pi_{\kappa p}\pi_{pt}}{\pi_{pp}}, \frac{\pi_{\kappa\kappa}\pi_{pt}}{\pi_{p\kappa}}\right\}$. Totally differentiating the (necessary and sufficient) first-order conditions and applying Cramer's rule yields

$$\frac{d\kappa^*(t)}{dt} = -\frac{\pi_{pp}\pi_{\kappa t} - \pi_{\kappa p}\pi_{pt}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}} \tag{A.9}$$

and

$$\frac{dp^*(t)}{dt} = -\frac{\pi_{\kappa\kappa}\pi_{pt} - \pi_{p\kappa}\pi_{\kappa t}}{\pi_{pp}\pi_{\kappa\kappa} - \pi_{\kappa p}\pi_{p\kappa}}. \tag{A.10}$$

The expression in the denominators of (A.9) and (A.10) 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.

The organizational carbon footprint can be derived as

$$\Phi^*(t) \equiv \kappa^*(t)D(p^*(t), \kappa^*(t), t). \tag{A.11}$$

Differentiating (A.11) with respect to the tax rate t yields

$$\frac{d\Phi^*(t)}{dt} = \frac{d\kappa^*(t)}{dt}D + \kappa^*(t)\left(D_p\frac{dp^*(t)}{dt} + D_\kappa\frac{d\kappa^*(t)}{dt}\right), \tag{A.12}$$

where the arguments of the demand function are suppressed for convenience. Since $\frac{d\kappa^*(t)}{dt} < 0$, the first term on the right-hand side of (A.12) 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 organizational carbon footprint is ambiguous.

Let $\pi^*(t)$ denote the optimized profit given the tax rate t. The cost of regulation is defined as the difference between the actual profit and the expected profit under the carbon tax:

$$\Delta\pi \equiv \pi^*(0) - [\rho\pi^*(t) + (1-\rho)\pi^*(0)] = \rho\{\pi^*(0) - \pi^*(t)\},$$

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 organizational carbon footprint. □

Proof of Proposition 8. If the firm adopts the green technology, the actual profit is given by $\pi_1^* - F$. Using the CR defined in Proposition 6, 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. □