Self-Imposed Carbon Taxes*

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Abstract

Why have firms chosen to self-impose a carbon tax where governments have failed to act? We provide an answer to this question by highlighting a novel mechanism in which a firm can use a self-imposed carbon tax to relax the intensity of price competition with its rivals, making it a profitable strategy. The mechanism we highlight does not depend on the self-imposed carbon tax shifting demand or yielding marketing benefits (e.g., making the firm's products more attractive to consumers because they are considered "green"). We discuss implications for market efficiency and the interaction of this mechanism with opportunities to invest in emission abatement technology.

Keywords: carbon tax, imperfect competition, oligopoly, strategic delegation
JEL codes: L13, L22, Q52, Q54

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1 Introduction

Carbon pricing can be an effective tool to combat climate change, forcing economic agents to internalize the environmental damage of their actions (Andersson, 2019). As a result, economists have called on countries and their governments to implement market-based policies such as a carbon tax (Arrow et al., 1997). Some companies, however, have chosen to self-impose a carbon tax where governments have not done so. Examples include Disney, Microsoft, and Shell.[1] Why would a firm self-impose a carbon tax?

Self-imposing a carbon tax is, in principle, costly because the firm is choosing to constrain itself (e.g., forcing itself to abate emissions when it would not otherwise abate them). In this paper, we show that a self-imposed carbon tax can be a tool for relaxing price competition with rival firms, potentially making it a profitable strategy. A self-imposed carbon tax increases equilibrium prices, and it can increase efficiency (by forcing the firm to at least partially internalize the environmental damage caused by production) despite a loss in consumer surplus. The mechanism we highlight does not depend on the self-imposed carbon tax shifting demand or yielding marketing benefits (e.g., making the firm's products more attractive to consumers because of being considered "green").

In line with the examples cited above, we propose a model that considers a decentralized firm consisting of the firm's headquarters and a downstream division, with the latter producing and selling a good to consumers. The downstream division chooses the price for its good to maximize its own profit (hence, the decentralized firm), and it faces competition from a rival firm selling a differentiated product. The firm's headquarters may impose a carbon tax on the downstream division (either per unit of the good sold or per unit of emissions). If a self-imposed carbon tax is in place, the downstream division pays the internal carbon taxes to the firm's headquarters. Because the internal carbon tax money is paid to the firm's headquarters, the money stays within the organization. This makes a self-imposed carbon tax distinct from participation in a voluntary carbon market, where a firm buys offsets from other organizations, with money leaving the firm to pay for these offsets.

What are the impacts of the self-imposed carbon tax? For the downstream division, this carbon tax is equivalent to an increase in its marginal cost of production. Consequently, the firm's equilibrium price increases with the carbon tax, which results in a loss of market share to the rival firm. From the perspective of the firm as a whole (headquarters plus the downstream division), the carbon tax results in a higher equilibrium price without a change in the marginal cost of production, since the carbon tax paid by the downstream division is

[1] See, for example, "Disney, Microsoft and Shell opt for self-imposed carbon emissions taxes", *The Guardian*, March 26, 2013 (`https://amp.theguardian.com/sustainable-business/carbon-emissions-tax-microsoft-disney-shell`).

collected by the firm's headquarters, dropping out of the consolidated profit function.[2] Thus, the carbon tax increases the firm's price-cost margin. This relaxing of the intensity of price competition comes at the cost of a lower market share, creating a tradeoff. We show that the benefits of relaxing the intensity of price competition can outweigh the costs, making a self-imposed carbon tax a profitable strategy. This result extends to when the government sets a carbon tax, too—in this case, we show that the firm sets an internal carbon tax that is generally greater than the government carbon tax.

When the downstream division of the firm has the possibility of investing in an emission abatement technology, a tension arises between the firm's headquarters' desire to relax the intensity of product market competition, via an internal carbon tax, and the impact of this internal carbon tax on the downstream division's investment decision. At its core, this tension relates to what is known as Arrow's replacement effect (Arrow, 1962). On the one hand, the internal carbon tax increases the firm's consolidated profit, lessening the net gains of the investment for the firm's headquarters; on the other hand, the internal carbon tax shifts profit away from the downstream division by increasing its cost of polluting, magnifying its incentives to invest.[3] The tension induces the firm's headquarters to lower its internal carbon tax, but the internal carbon tax remains weakly greater than the government carbon tax, reflecting that the benefits of relaxing product market competition induce an internal carbon tax that exceeds the government carbon tax even in the presence of investment opportunities.

We also ask whether a self-imposed carbon tax enhances market efficiency. Specifically, we compare social welfare under three cases: social planner solution, decentralized firm setting an internal carbon price greater than the government carbon tax, and a centralized firm facing a government carbon tax. We show that when the environmental damage of one unit of emissions is sufficiently large, the market equilibrium with a decentralized firm setting an internal carbon tax is second best. Why? Under imperfect competition, a centralized or decentralized firm imperfectly passes through the government carbon tax in the form of a higher price, making the market equilibrium socially inefficient. The self-imposed carbon tax helps decrease the efficiency gap relative to the planner's solution via a self-imposed carbon tax that exceeds the government carbon tax, thereby making the price difference between firms more closely match the social marginal cost difference (i.e., the sum of marginal cost

[2]For the purpose of the discussion in this paragraph, we assume that the marginal cost of production of the downstream division (excluding the carbon tax) is constant. As well, we assume the carbon intensity of the good is fixed and exogenous.

[3]Parra and Marshall (2024) consider the design of a vertical contract by a firm that lays out incentives for a supplier who provides an input but also develops an innovation (i.e., a next-generation input). In designing the contract, the firm needs to balance innovation incentives and its short-run profits to maximize discounted profits.

of production and marginal environmental damage). In this way, a self-imposed carbon tax complements a government carbon tax in promoting market efficiency.

This paper contributes to several strands of the literature. First, it contributes to our understanding of the equilibrium effects of carbon taxes in markets with imperfect competition (Fowlie, 2009, 2010; Fowlie et al., 2016).[4] In particular, we contribute to this strand by answering the question of whether a self-imposed carbon tax is a complement or substitute to a government carbon tax in promoting efficiency in oligopoly markets where firms imperfectly pass through government carbon taxes to consumers.

Second, the mechanism highlighted here relates to the literature on strategic delegation (see, e.g., Spencer and Brander, 1983; Vickers, 1985; Fershtman and Judd, 1987; Sklivas, 1987), where the firm may choose to delegate its decision making to secure a strategic advantage. The result that a self-imposed carbon tax is profitable relies on the assumption of a decentralized firm, where pricing is determined by a separate division from the one that chooses the carbon tax. Third, within decentralized organizations, the finding that a self-imposed carbon tax may be profitable relates to some results in strategic transfer pricing. Transfer prices are used to distribute resources within an organization, and the literature has shown that these can be used to achieve profits that are only attainable under collusion (Alles and Datar, 1998; Göx, 2000).[5]

Lastly, a small set of papers has identified conditions under which corporate social responsibility may be profitable for a firm, given its impact on the intensity of product market competition (e.g., Lee and Park, 2019; Xing and Lee, 2024). As mentioned above, we contribute to this strand by examining whether a self-imposed carbon tax serves as a complement or substitute to a government carbon tax in promoting efficiency. As well, we analyze the interaction between a self-imposed carbon tax and opportunities to invest in emission abatement technology and assess the impact of a self-imposed carbon tax on investment incentives.

The rest of the paper is organized as follows. Section 2 presents the model and key results, which demonstrate that a self-imposed carbon tax can be profitable. Section 3 discusses the impact of a self-imposed carbon tax on efficiency. Section 4 presents the analysis when the firm faces the opportunity to invest in an emission abatement technology. Section 5 presents extensions to our baseline model, and Section 6 concludes.

[4]See Timilsina (2022) for a survey of the literature on carbon taxes

[5]A similar result obtains in the context of a government setting an export subsidy or tax to promote domestic welfare in an imperfectly competitive international market (Brander and Spencer, 1984).

2 A Model of Self-Imposed Carbon Taxes

Consider a decentralized firm consisting of the headquarters of the firm and a downstream division that produces and sells a good to consumers. The downstream division is a profit center, seeking to maximize its own profit. In the model, this firm will be referred to as "firm 1." Firm 1 competes with firm 2 in the downstream product market, selling differentiated products to final consumers. Specifically, we model this product market game using a variant of Hotelling (1929). Throughout the model, we will assume that firm 1 emits carbon when producing, while firm 2 does not.

2.1 Demand

A unit mass of consumers is uniformly distributed along the unit interval $[0, 1]$, where each consumer is indexed by their location $x \in [0, 1]$. As mentioned, there are two firms. Firm 1 is located at $x = 0$ and firm 2 is located at $x = 1$. Each firm produces a single horizontally differentiated good.

Each consumer has a common intrinsic valuation v for consuming one unit of the good, irrespective of which firm supplies it. Consumers incur a transportation cost that increases linearly in the distance traveled. Specifically, if a consumer located at x purchases from firm $i \in \{1, 2\}$ located at $x_i \in \{0, 1\}$, the transport cost is given by $D(x, x_i) = \sigma^{-1}|x - x_i|$, where $\sigma > 0$ is the substitution parameter. Consumers purchase at most one unit of the good.

Unless otherwise noted, we focus on the case where all consumers are served in equilibrium. In this case, the consumer who is indifferent between firms 1 and 2 solves $v - p_1 - \sigma^{-1}x = v - p_2 - \sigma^{-1}(1 - x)$, where p_i is the price set by firm i. This equation yields

$$x^* (p_1, p_2) = \frac{1}{2} (1 + \sigma (p_2 - p_1)) .$$

Consumers to the left of x^* purchase from firm 1, while those to the right purchase from firm 2. Demand functions are therefore given by

$$q_1(p_1, p_2) = x^* (p_1, p_2) , \qquad q_2(p_1, p_2) = 1 - x^* (p_1, p_2) .$$

2.2 Downstream Pricing

Since firm 1 is decentralized, its pricing and production decisions are delegated within the organization to the downstream division.

Assume that the pricing decision maker in firm j faces a constant marginal cost of production, given by c_j. We allow costs to be asymmetric. In the case of firm 1, c_1 may combine the actual marginal cost of production and a carbon tax that the headquarters charges the downstream division for every unit of the good sold.

The timing of the product market game is as follows. Firms simultaneously choose prices (p_1, p_2). Consumers then decide from which firm to purchase (or not to purchase). Finally, profits are realized. Firm i's product market profit is given by

$$\pi_i(p_i, p_j) = (p_i - c_i) \cdot q_i(p_i, p_j),$$

where q_i denotes the demand served by firm i under prices (p_1, p_2). We focus on Nash equilibria in pricing strategies.

Solving the system of first-order conditions, we obtain the equilibrium prices,

$$p_1^* = \frac{1}{3}\left(\frac{3}{\sigma} + 2c_1 + c_2\right), \qquad p_2^* = \frac{1}{3}\left(\frac{3}{\sigma} + c_1 + 2c_2\right) \tag{1}$$

and quantity,

$$x^*(c_1, c_2) = \frac{1}{2} + \frac{\sigma}{6}\left(c_2 - c_1\right). \tag{2}$$

As well, the equilibrium product-market profit of firm i is given by

$$\pi_i = \frac{2}{\sigma}\left(\frac{1}{2} + \frac{\sigma}{6}\left(c_j - c_i\right)\right)^2. \tag{3}$$

In the case of firm 1, π_1 corresponds to the profit of the downstream division.

The equilibrium is interior provided that $x^* \in (0, 1)$, which requires $|c_2 - c_1| < 3/\sigma$. Full market coverage additionally requires that the indirect utility of the consumer located at x^* is non-negative, which is true when

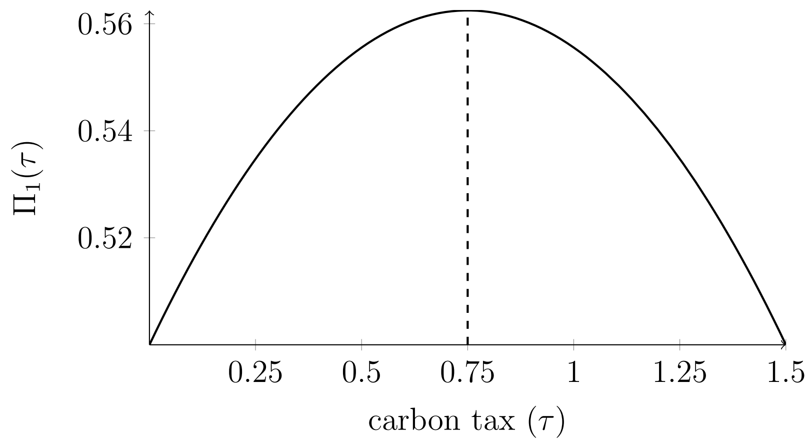
$$v \;\geq\; \frac{3 + \sigma\left(c_1 + c_2\right)}{2\sigma}.$$

2.3 Self-Imposed Carbon Tax

Let us now consider the equilibrium impact of a self-imposed carbon tax. We will start considering the case where there is no government carbon tax.

Assume $c_1 = c + (1 - \alpha)\tau$, where c is a constant marginal cost of production, τ is a carbon tax that headquarters imposes on its own downstream division per unit of emission (e.g., a ton of CO2), and $1 - \alpha$ is the carbon intensity of the good (i.e., tons of CO2 per unit produced). We will start assuming that α is exogenous, but we will later consider the case where the firm may choose to reduce its carbon intensity by investing in an emission

Figure 1: Optimal self-imposed carbon tax (when $\sigma = 1$ and $\alpha = 0$)



abatement project. Assume also that $c_2 = c$. For simplicity, we will set $c = 0$.

Since the carbon tax is self-imposed, the profit of firm 1, combining the profits of the downstream division and headquarters, is given by

$$\begin{aligned}\Pi_1(\tau) = \pi_1 + \tau(1-\alpha)q_1 &= (p_1 - \tau(1-\alpha) + \tau(1-\alpha))q_1 \\ &= \left(\frac{1}{\sigma} + \frac{2}{3}(1-\alpha)\tau\right)\left(\frac{1}{2} - \frac{\sigma(1-\alpha)\tau}{6}\right), \end{aligned} \tag{4}$$

where $(1-\alpha)\tau q_1$ is the carbon tax revenue collected from the downstream division by headquarters (i.e., headquarters' profit). Note that the carbon tax impacts equilibrium prices and quantities, but it otherwise drops out of the profit function since the carbon tax money paid by the downstream division stays within the organization (headquarters collects it).

What is the optimal self-imposed carbon tax? We optimize $\Pi_1(\tau)$ with respect to τ. The first-order necessary condition is given by

$$\frac{d\Pi_1}{d\tau} = \frac{1}{6} - \frac{2\sigma(1-\alpha)\tau}{9} = 0,$$

which holds when $\tau^* = \frac{3}{4(1-\alpha)\sigma}$. Since the profit function is concave in τ, this value is the optimal carbon tax. As an illustration, Figure 1 plots the profit function Π_1 as a function of τ and the optimal tax when $\sigma = 1$ and $\alpha = 0$.

What are the economics of this result? From the perspective of firm 1's downstream division, the carbon tax is equivalent to an increase in its marginal cost of production. From a strategic point of view, equilibrium prices are increasing in marginal costs, implying that the carbon tax causes a decrease in firm 1's market share. This distortion causes the profits of firm 1's downstream division to decrease.

When considering the perspective of firm 1 as a whole (combining the profits of the headquarters and the downstream division), the carbon tax creates a tradeoff. On the one hand, the carbon tax relaxes the intensity of price competition as equilibrium prices increase. This causes an increase in the price-cost margin of firm 1 as a whole, since $p_1 - (1-\alpha)\tau + (1-\alpha)\tau$ is increasing in τ (via the impact of τ on p_1). On the other hand, the greater equilibrium price caused by the carbon tax decreases firm 1's market share. The analysis above shows that for small enough values of the carbon tax, the increase in the price-cost margin more than compensates for the decrease in market share, making a self-imposed carbon tax optimal.

What is crucial here is that the carbon tax revenue stays inside the organization, implying that the carbon tax increases the organization's price-cost margin. Thus, the carbon tax drops out of the profit function except for its impacts on endogenous objects (price and quantity). In contrast, the price-cost margin of firm 1's downstream division, $p_1 - (1-\alpha)\tau$, decreases in τ because the carbon taxes exit the downstream division when paid to headquarters. This makes a carbon tax unambiguously costly for the downstream division of firm 1, as it decreases its price-cost margin and market share.

In summary, a self-imposed carbon tax can be profitable for the firm as a whole because it reduces the intensity of price competition.

2.4 Interaction with a Government Carbon Tax

Consider next that firm 1 faces a carbon tax t set by the government per unit of emissions. Firm 2 does not face this carbon tax, as we have assumed it produces without emitting carbon. Firm 1 must pay $t \cdot (1-\alpha) \cdot q_1$ to the government for its carbon emissions, but, as before, firm 1's headquarters may choose to set an internal carbon price τ that differs from t.

The behavior of the price decision-makers is as described above. Hence, the problem of firm 1's headquarters is to optimize the profit function

$$\begin{aligned} \Pi_1 &= \pi_1 + (\tau - t)(1-\alpha)q_1 = (p_1 - t(1-\alpha))q_1 \\ &= \left(\frac{1}{\sigma} + \frac{2}{3}(1-\alpha)\tau - (1-\alpha)t\right)\left(\frac{1}{2} - \frac{\sigma(1-\alpha)\tau}{6}\right) \end{aligned} \tag{5}$$

with respect to τ, where $t \cdot (1-\alpha) \cdot q_1$ are firm 1's carbon tax liabilities to be remitted to the government, and $\tau \cdot (1-\alpha) \cdot q_1$ is the tax revenue firm 1's headquarters collects from its downstream division. The first-order condition is given by

$$\frac{d\Pi_1}{d\tau} = \frac{\sigma}{18}\left(1-\alpha\right)\left(3\left(1-\alpha\right)t + \frac{3}{\sigma} - 4\left(1-\alpha\right)\tau\right) = 0$$

and the solution by

$$\tau^* = \frac{3}{4\left(1-\alpha\right)\sigma} + \frac{3}{4}t, \tag{6}$$

at which point the second-order condition holds. At τ^*, firm 1 produces

$$x^D = \frac{3}{8} - \frac{\sigma}{8}(1-\alpha)t, \tag{7}$$

where the supra-index stands for "decentralized firm". The quantity x^D is positive if and only if

$$t < \bar{t} \equiv \frac{3}{(1-\alpha)\sigma},$$

where $\bar{t}$ represents the largest tax leading firm 1 to produce a positive quantity.

Two observations are immediate from the solution τ^* in Equation 6. First, and as discussed above, $\tau^* > 0$ even when the government carbon tax equals zero, $t = 0$. This reflects the benefits of relaxing the intensity of price competition through a positive internal carbon tax, as discussed above. Second, τ^* is increasing in t (the government carbon tax), with a government carbon tax pass-through rate of 3/4. As well, $\tau^* > t$ for all $t < \bar{t}$ (the range of government carbon taxes for which firm 1 produces a positive quantity).

That the internal self-imposed carbon tax is always greater than the government carbon tax, and the internal pass-through rate of t on τ is less than one, suggests the firm's practice of using a self-imposed carbon tax impacts the government's ability to achieve an efficient market outcome via a carbon tax. Does a self-imposed carbon tax stand in the way of efficiency, or does it help promote efficiency? We turn to this question next.

3 Welfare Under Various Carbon Tax Regimes

We next examine the interaction between a self-imposed carbon tax and a government carbon tax in promoting market efficiency. We assume that a unit of emissions causes environmental damage, quantified at c_s. We conduct our analysis assuming that a government carbon tax of $t \leq c_s$ is in place.

3.1 Benchmarks

To answer the question of whether a self-imposed carbon tax hinders efficiency, we consider two benchmarks. The first one is a social planner's solution, and the second is when firm 1 is centralized (i.e., headquarters and the downstream division are a single unit).

3.1.1 Planner's Solution

The planner optimizes a social welfare function, choosing the quantity produced by each firm. The social welfare function is given by

$$W(x) = v - (1-\alpha)\, c_s x - \frac{x^2}{2\sigma} - \frac{(1-x)^2}{2\sigma}, \tag{8}$$

where $c_s > 0$ is the environmental damage of a unit of emissions, $(1-\alpha)x$ are the total emissions by firm 1, and $(x^2 + (1-x)^2)/\sigma$ are the aggregate transportation costs paid by all customers when the marginal customer is located at x.[6] In solving its problem, the planner trades off the cost of emissions against transportation costs—e.g., the allocation that minimizes emission costs ($x = 0$), maximizes aggregate transportation costs. Recall we have assumed that firm 2 produces without emitting carbon.

The first-order condition of the planner's problem is given by $W'(x) = 0$ and the planner's solution is

$$x^P = \frac{1}{2} - \frac{\sigma}{2}(1-\alpha)\, c_s, \tag{9}$$

where the supra-index stands for the "planner's solution". In the planner's solution, firm 1 produces a positive quantity whenever the environmental damage of a unit of emissions is small enough: $c_s < 1/((1-\alpha)\sigma)$.

Recall that the consumer who is indifferent between firm 1 and firm 2 is located at $x^*(p_1, p_2) = \frac{1}{2}(1 + \sigma(p_2 - p_1))$. For the planner's solution to be implemented in a market equilibrium (i.e., $x^*(p_1, p_2) = x^P$), the price difference between firms must equal $p_1 - p_2 = (1-\alpha)c_s$. That is, the price difference must reflect the difference in the social marginal cost of the two products, where the social marginal cost equals the sum of the marginal cost of production (zero in this case) and the marginal environmental damage ($(1-\alpha)c_s$ in the case of firm 1).

[6]Formally, aggregate transportation costs are given by $(\int_0^x z dz + \int_x^1 (1-z) dz)/\sigma$.

3.1.2 Centralized Firm

We also consider the case when firm 1 is a centralized firm. That is, the firm's headquarters and its downstream division are a single unit. The equilibrium prices and quantities equal those in Equation 1 and Equation 2 when $c_1 = (1-\alpha)t$ and $c_2 = 0$. The equilibrium quantity in this case equals

$$x^C = \frac{1}{2} - \frac{\sigma}{6}(1-\alpha)\,t, \tag{10}$$

where the supra-index stands for "centralized firm". As in the decentralized scenario, firm 1 produces a positive quantity as long as $t < \bar{t}$. As well, $\tau = t$, as there is no internal carbon price decision. In addition, the centralized equilibrium price gap between firms is $p_1^C - p_2^C = (1-\alpha)t/3$, which leads to an efficient allocation unless the tax triples the social cost of carbon ($t = 3c_s$), an unfeasible outcome in our setup.

3.2 Comparing Equilibrium Quantities

Comparing the equilibrium quantities when firm 1 is decentralized (i.e., the firm uses a self-imposed carbon tax), firm 1 is centralized, and the market allocation chosen by the planner is a first step towards understanding the welfare implications of a self-imposed carbon tax.

We establish three results, which we summarize in the following lemma.

Lemma 1 *Consider the case when centralized and decentralized production is positive under a carbon tax ($t < \bar{t}$). Equilibrium quantities are ordered as follows:*

1. $x^D < x^C$.
2. $x^P < x^C$.
3. *Assume further that* $t = c_s$. $x^D < x^P \iff c_s < 1/(3\sigma(1-\alpha))$.

The first is that $x^D < x^C$ for all $t < \bar{t}$. That is, a decentralized firm 1 (using a self-imposed carbon tax) always produces less than a centralized firm 1, provided they produce a positive quantity. Using the values in Equation 7 and Equation 10, it is immediate to note that

$$x^D < x^C \iff \frac{3}{8} - \frac{\sigma}{8}(1-\alpha)t < \frac{1}{2} - \frac{\sigma}{6}(1-\alpha)\,t \iff t < \frac{3}{(1-\alpha)\sigma} = \bar{t},$$

where $t < \bar{t}$ is the condition for $x^C > 0$ and $x^D > 0$. That is, the self-imposed carbon tax, by magnifying the carbon tax burden faced by firm 1's price decision-maker (i.e., $\tau^* > t$), decreases firm 1's quantity relative to when the firm is centralized (and $\tau = t$).

The second result is that $x^P < x^C$ for all $t < \bar{t}$. That is, a centralized firm will always produce more than what the planner would choose for firm 1 to produce. To see this result, note that

$$x^P < x^C \iff \frac{1}{2} - \frac{\sigma}{2}(1-\alpha)c_s < \frac{1}{2} - \frac{\sigma}{6}(1-\alpha)\,t \iff t < 3c_s,$$

which always holds as $t \le c_s$ by assumption.[7] This result stems from the fact that firm 1 passes on less than $(1-\alpha)t$ to consumers in the form of a higher price. A price difference of $p_1 - p_2 = (1-\alpha)t = (1-\alpha)c_2$ is required for the market equilibrium to match the planner's solution, but this is never the case, as firm 1's cost pass-through is imperfect: $\partial p_1/\partial c_1 = 2/3$ (see Equation 1).

Lastly, we note that the ordering between x^D and x^P depends on the value of the environmental cost of a unit of emissions, c_s. Consider the case when $t = c_s$ and $x^D, x^P > 0$ (that is, $t = c_s < 1/((1-\alpha)\sigma)$. We then have that

$$x^D < x^P \iff \frac{3}{8} - \frac{\sigma}{8}(1-\alpha)\,c_s < \frac{1}{2} - \frac{\sigma}{2}(1-\alpha)\,c_s \iff c_s < \frac{1}{3\sigma\,(1-\alpha)}.$$

That is, when the environmental damage caused by a unit of emissions is sufficiently low, a decentralized firm 1 produces too little relative to the social planner's solution. The self-imposed carbon tax relaxes the intensity of price competition, thereby magnifying market power. While this leads to a decreased environmental cost, the firm does not internalize the transportation costs of consumers when raising its price, creating a tension between environmental and transportation costs from the perspective of social welfare. When the value of c_s is small enough, the transportation costs effect of a price increase dominates, leading firm 1 to produce too little.

On the other hand, whenever the environmental damage is sufficiently large, $\bar{t} = 3/(\sigma(1-\alpha)) > c_s > 1/(3\sigma\,(1-\alpha))$, then a decentralized firm 1 produces too much relative to the planner's market allocation: $x^C > x^P$.[8]

3.3 Comparing Welfare when $t = c_s$

Given that the welfare function is non-monotonic in x (the quantity produced by firm 1) due to the tradeoff between transportation costs and environmental damage (see Equation 8), the results in Lemma 1 regarding the ordering of quantities are not sufficient to order the social welfare obtained under the various solutions we consider (i.e., centralized firm 1,

[7]Note that $x^P = 0$ when $c_s > 1/((1-\alpha)\sigma)$. The result holds true in this case too, as $x^C > 0$ when $t < 3/((1-\alpha)\sigma)$.

[8]Recall that $3/(\sigma(1-\alpha)) > t$ is a requirement for $x^D > 0$ and $x^P = 0$ when $c_s > 1/(\sigma\,(1-\alpha))$

decentralized firm 1, planner's solution), but they do help establish some results regarding the welfare impacts of a self-imposed carbon tax.

In particular, when the environmental damage of a unit of emissions is sufficiently large, $c_s > 1/(3\sigma(1-\alpha))$, Lemma 1 establishes that $x^P < x^D < x^C$ (provided $x^C, x^D > 0$, i.e., $t = c_s < 3/((1-\alpha)\sigma)$). In this case, $W(x^P) > W(x^D) > W(x^C)$ (see Equation 8), that is, social welfare under a decentralized firm 1 exceeds social welfare under a centralized firm 1. Why? As mentioned, a centralized firm 1 cost pass-through rate is less than one (see Equation 1)—by passing on to consumers less than $(1-\alpha)t$, the market equilibrium fails to reach the planner's allocation. On the other hand, a decentralized firm 1 sets an internal carbon tax of $\tau^* > t$, which decreases quantity beyond x^C despite an imperfect tax pass-through. That is, the self-imposed carbon tax complements a government carbon tax when the environmental damage of a unit of emissions is sufficiently large. A market equilibrium with a decentralized firm 1 is thus the second-best solution in this range of parameters.

The condition in the previous paragraph—i.e., $W(x^P) > W(x^D) > W(x^C)$ when $c_s > 1/(3\sigma(1-\alpha))$—is a sufficient rather than a necessary condition for ordering welfare. Evaluating the welfare function at x^D and x^C (see Equation 7 and Equation 10, respectively) gives rise to

$$W\left(x^D\right) - W\left(x^C\right) = \frac{(17\sigma(1-\alpha)c_s - 3)(3 - \sigma(1-\alpha)c_s)}{576\sigma}.$$

The comparison only depends on the sign of the first parentheses, as the second parenthesis is non-negative for all the relevant $c_s \leq \frac{3}{(1-\alpha)\sigma}$. The first parenthesis is positive for

$$c_s > \frac{3}{17(1-\alpha)\sigma}.$$

We can thus establish the following result.

Proposition 1 *Assume $t = c_s$, and that centralized and decentralized production is positive under the carbon tax ($c_s < \bar{t}$). The market equilibrium under a decentralized firm 1 (i.e., when a self-imposed carbon tax is optimal) is second-best (i.e., $W(x^D) > W(x^C)$) when $c_s > 3/(17(1-\alpha)\sigma)$.*

That the market equilibrium under a decentralized firm 1 does not always dominate stems from the fact that prices are greater under a decentralized firm 1. The greater prices push x^D closer to zero relative to x^C (recall $x^D < x^C$), increasing aggregate transportation costs, but reducing environmental damages. When the environmental damage of a unit of emissions is sufficiently low, the greater prices under a decentralized firm 1 create more bad (i.e., greater transportation costs) than good (i.e., less environmental damage).

3.4 Comparing Welfare when $t < c_s$

For completeness, we also consider the case where the government carbon tax is less than $t < c_s$. In this case, evaluating the welfare function at x^D and x^C (see Equation 7 and Equation 10, respectively) gives rise to a social welfare difference between the decentralized firm 1 and centralized firm 1 cases of

$$W\left(x^D\right) - W\left(x^C\right) = \frac{\left(\left(24c_s - 7t\right)\left(1-\alpha\right)\sigma - 3\right)\left(3 - \left(1-\alpha\right)t\sigma\right)}{576\sigma}.$$

This welfare difference is positive (i.e., $W\left(x^D\right) - W\left(x^C\right) > 0$) when

$$\frac{3}{7}\left(8c_s - \frac{1}{\left(1-\alpha\right)\sigma}\right) > t$$

which is never true if c_s is too low (i.e., $c_s < 1/\left(8\left(1-\alpha\right)\sigma\right)$). Also, when $t = c_s$, the condition collapses to that in Proposition 1. As above, provided that the environmental damage of a unit of emissions is sufficiently high, a self-imposed carbon tax complements a government carbon tax in promoting efficiency.

Proposition 2 *Assume $t \leq c_s$, and that centralized and decentralized production is positive under a carbon tax ($t < \bar{t}$). The market equilibrium under a decentralized firm 1 (i.e., when a self-imposed carbon tax is optimal) is second-best (i.e., $W(x^D) > W(x^C)$) when*

$$\frac{3}{7}\left(8c_s - \frac{1}{\left(1-\alpha\right)\sigma}\right) > t.$$

4 Endogenous Emission Abatement Technology

We next consider the case in which firm 1 is able to invest in an emission abatement project. We assume that firm 1's baseline carbon intensity is $1-\alpha$, but the firm can decrease its carbon intensity to 0 upon investing K in an abatement technology (i.e., the investment increases α to 1). How does firm 1's internal carbon pricing interact with the possibility of investing in the abatement project?

We compare equilibrium outcomes in two cases: i) firm 1 is a decentralized firm; and ii) firm 1 is a centralized firm. Throughout our analysis, we assume the existence of a government carbon tax equal to $t = c_s$.

4.1 Centralized Firm

Consider the problem of the centralized firm. Using Equation 3 when $c_1 = (1 - \alpha)c_s$ and $c_2 = 0$—recall the firm faces a government carbon tax equal to $t = c_s$—we know that firm 1's profit in this case equals

$$\pi_1^C(\alpha) = \frac{1}{18\sigma}\left(3 - \sigma(1-\alpha)c_s\right)^2.$$

and the firm invests in the abatement technology when

$$\pi_1^C(1) - \pi_1^C(\alpha) > K.$$

The term $\pi_1^C(1) - \pi_1^C(\alpha)$ represents the incremental rent of adopting the abatement technology. As usual, the firm invests in the technology when the incremental rent from adopting is larger than its cost. Note that when the baseline technology is cleaner (higher α), the gains of adopting the technology are less. That is, the firm's baseline technology determines the "replacement effect"—i.e., when a firm's current profit is greater, the incentive to invest in a new technology is less, all else equal (Arrow, 1962).

4.2 Decentralized Firm

We assume the decentralized firm 1 delegates both pricing and the abatement technology investment to its downstream division.[9] As before, firm 1's headquarters sets an internal carbon price of τ.

The Problem of the Downstream Division Let $\pi_1^D(\tau;\alpha)$ be the downstream division's profit when it owns technology α and faces an internal carbon tax τ. Using Equation 3 when $c_1 = (1-\alpha)\tau$, we know that the downstream division's profit equals

$$\pi_1^D(\tau;\alpha) = \frac{1}{18\sigma}\left(3 - \sigma(1-\alpha)\tau\right)^2$$

which is increasing in the abatement α and decreasing in the self-imposed tax τ.

Firm 1's downstream division invests in the abatement technology when

$$\pi_1^D(\cdot, 1) - \pi_1^D(\tau;\alpha) > K,$$

where we have dropped dependence on τ when $\alpha = 1$, as the firm no longer pollutes in that

[9] We will discuss the scenario in which the parent decides on the abatement technology in footnote 12.

case. As in the case of the centralized firm, the baseline technology α affects the downstream division's incremental rent of investing in the new abatement technology.

Before we turn to the problem of the firm's headquarters, a few observations are in order. First, observe $\pi_1^D(\cdot, 1) = \pi_1^C(1)$ since, when $\alpha = 1$, the firm no longer pollutes, and the internal carbon prices drop out of the profit function entirely. Second, when $\tau > c_s$, it follows that $\pi_1^C(\alpha) > \pi_1^D(\tau; \alpha)$; whereas when $\tau = c_s$, $\pi_1^C(\alpha) = \pi_1^D(c_s; \alpha)$. This implies that the downstream division of a decentralized firm 1 will have greater incentives to invest in the abatement technology than the centralized firm when $\tau > c_s$, as their incremental rent of adoption satisfies:

$$\pi_1^D(\cdot, 1) - \pi_1^D(\tau; \alpha) > \pi_1^D(\cdot, 1) - \pi_1^C(\alpha) = \pi_1^C(1) - \pi_1^C(\alpha),$$

and identical incentives to invest when $\tau = c_s$.

The Problem of the Firm's Headquarters Although the downstream division makes the investment decision in abatement technology, the firm's headquarters has preferences regarding whether the technology should be acquired. Let the firm's consolidated profit when it has abatement technology α and it imposes a tax τ to its downstream division be given by $\Pi_1(\tau; \alpha)$—i.e., Equation 5 when the government imposes a carbon tax $t = c_s$.

The firm's headquarters wants the investment to take place when

$$\Pi_1(\cdot, 1) - \Pi_1(\tau; \alpha) > K.$$

The incremental rent of the parent company may differ from that of the downstream division, resulting in a misalignment of preferences over investment between the downstream division and the firm's headquarters. For example, the downstream division may find it profitable to invest when the firm's headquarters wants to avoid the investment. When designing the optimal self-imposed carbon tax, the firm's headquarters will then need to maximize profit, subject to aligning preferences over the investment.

To better understand this misalignment in investment incentives, note from Equation 5 that $\Pi_1(\tau; \alpha) > \pi_1^D(\tau; \alpha)$ whenever $\tau > c_s$, and that these profit values are equal when $\tau = c_s$. Also, $\Pi_1(\cdot, 1) = \pi_1^D(\cdot, 1)$ when $\alpha = 1$, as the firm no longer pollutes in this case. These facts combined imply that whenever the decentralized firm sets a self-imposed tax $\tau > c_s$, the firm's headquarters has *less* incentives to invest in the abatement technology than its downstream division,

$$\Pi_1(\cdot, 1) - \pi_1^D(\tau; \alpha) = \pi_1^D(\cdot; 1) - \pi_1^D(\tau; \alpha) > \Pi_1(\cdot, 1) - \Pi_1(\tau; \alpha)$$

creating a tension at the moment of choosing the optimal self-imposed tax.

At its core, this tension relates to Arrow's replacement effect (Arrow, 1962). On the one hand, the internal carbon tax increases the firm's consolidated profit, thereby lessening the net gains of the investment for the firm's headquarters. On the other hand, the internal carbon tax shifts profit away from the downstream division by increasing its cost of pollution, thereby magnifying the downstream division's incentives to invest. The optimal internal carbon tax must then balance the profit gains from relaxing product market competition while ensuring that the internal carbon tax does not induce an unwanted investment by the downstream division.

Let us consider the headquarter's problem when the optimal, unconstrained, self-imposed tax τ^* (see Equation 6) leads to a miss alignment between the firm's headquarters and the downstream division. In this case, the firm's headquarters wants to implement the technology when

$$\Pi_1(\cdot, 1) - \Pi_1(\tau^*_{\text{constr}}, \alpha) > K$$

where τ^*_{constr} maximizes the headquarter's profit $\Pi_1(\tau, \alpha)$ with respect to τ subject to the downstream division not adopting the abatement technology, or $\pi_1^D(\tau, \alpha) \geq \pi_1^D(\cdot, 1) - K$. To solve this problem, it is useful to divide the situation into two sub-cases depending on whether the centralized firm wants to invest.

The first sub-case is when the centralized firm does not want to invest, that is,

$$\Pi_1(\tau^*, \alpha) > \pi_1^C(\alpha) > \Pi_1(\cdot, 1) - K > \pi_1^D(\tau^*, \alpha),$$

and also, the decentralized firm's headquarters wants to avoid the investment at the unconstrained, optimal τ^* (i.e., $\Pi_1(\tau^*, \alpha) > \Pi_1(\cdot, 1) - K$), but at the unconstrained optimal τ^*, it has created sufficient incentives for its downstream division to find it profitable to invest (i.e., $\Pi_1(\cdot, 1) - K > \pi_1^D(\tau^*, \alpha)$, where $\Pi_1(\cdot, 1) = \pi_1^D(\cdot, 1)$).

As noted, $\pi_1^D(\tau, \alpha)$ is decreasing in τ and the consolidated profit $\Pi_1(\tau, \alpha)$ is increasing in τ in the range $\tau \in [c_s, \tau^*]$.[10] The decentralized firm 1 trades off the benefits of a higher τ against incentivizing an investment it wants to avoid and sets τ^*_{constr} such that

$$\pi_1^D(\cdot, 1) - K = \pi_1^D(\tau^*_{\text{constr}}; \alpha),$$

which implies $c_s < \tau^*_{\text{constr}} < \tau^*$.[11] That is, the possibility of the investment attenuates the

[10]The profit function is continuous, the first-order condition holds at τ^* only, and the second-order condition holds at that point too.

[11]Recall that we are analyzing the case where $\Pi_1(\cdot, 1) - K < \pi_1^D(c_s, \alpha) = \pi^C(\alpha)$ when when $\tau = c_s$, and also $\Pi_1(\cdot, 1) - K > \pi_1^D(\tau^*, \alpha)$ when $\tau = \tau^*$. The result then follows from the intermediate value theorem.

internal carbon tax, and the investment decisions of the centralized and decentralized firms are aligned: no investment takes place.

The second sub-case occurs when the centralized firm does want to invest, that is,

$$\Pi_1(\tau^*, \alpha) > \Pi_1(\cdot, 1) - K > \pi_1^C(\alpha) > \pi_1^D(\tau^*, \alpha)$$

and also, the decentralized firm 1 wants to avoid the investment at the unconstrained optimal τ^* (i.e., $\Pi_1(\tau^*, \alpha) > \Pi_1(\cdot, 1) - K$), but at the unconstrained optimal τ^*, it has created sufficient incentives for firm 1's downstream division to find it profitable to invest (i.e., $\Pi_1(\cdot, 1) - K > \pi_1^D(\tau^*, \alpha)$, where $\Pi_1(\cdot, 1) = \pi_1^D(\cdot, 1)$).

A similar analysis follows. The constrained problem of the firm forces it to decrease τ such that $\Pi_1(\cdot, 1) - K = \pi_1^D(\tau^*_{\text{constr}}, \alpha)$ to avoid the investment. Note, however, that when $t = c_s$, it is still the case that $\Pi_1(\cdot, 1) - K > \pi_1^D(c_s, \alpha) = \pi_1^C(\alpha)$ (by assumption). And when $\tau = c_s$, $\pi_1^C(\alpha) = \pi_1^D(c_s, \alpha) = \Pi_1(c_s, \alpha)$, as firm 1's headquarters earns no internal carbon pricing revenue when $\tau = c_s$. Since we are in the case where $\pi_1^C(\alpha) > \Pi_1(\cdot, 1) - K$, deterring the investment forces firm 1 to lower τ beyond the point where the firm's headquarters starts to find it profitable to adopt the abatement technology. That is, the firm can do no better than earning a constrained profit equal to $\Pi_1(\cdot, 1) - K$, which can be achieved by setting any $\tau^*_{\text{constr}} \in [c_s, \tau^*]$. The investment decisions of centralized and decentralized firms, therefore, remain aligned, and both types of firms invest.[12]

Lastly, there are two other trivial scenarios in which the firm's headquarters and the downstream division investment decisions are aligned: when both want to avoid the investment (so, the optimal self-imposed tax remains at its unconstrained, optimal level, τ^*) and when both want to invest. We ignore these cases for expositional brevity.

We summarize these results in the following proposition. Except when the investment is unavoidable or never profitable, the possibility of an investment that is not profitable from firm 1's headquarters perspective introduces a constraint that limits the firm's ability to relax the intensity of product market competition via an internal carbon price, as the internal carbon price may induce an unwanted investment.

Proposition 3 (Equilibrium Investments and Self-Imposed Carbon Taxes)

1. *When $\pi_1^D(\tau^*, \alpha) > \Pi_1(\cdot, 1) - K$ and $\pi_1^C(\alpha) > \Pi_1(\cdot, 1) - K$, no investment takes place. The decentralized firm sets its optimal, unconstrained, self-imposed tax $\tau = \tau^*$.*

[12] When the adoption decision lies with the headquarters, it chooses an optimal self-imposed carbon tax without constraints. The headquarters adopts whenever $\Pi_1(\cdot, 1) - K > \Pi_1(\tau^*, \alpha)$ and sets $\tau = \tau^*$ otherwise. The investment decisions of the centralized and decentralized firms are no longer aligned in this case.

2. When $\Pi_1^D(\tau^*, \alpha) > \pi_1^C(\alpha) > \Pi_1(\cdot, 1) - K > \pi_1^D(\tau^*, \alpha)$, no investment takes place. The decentralized firm sets a constrained self-imposed tax $\tau = \tau^*_{constr} \in (c_s, \tau^*)$.

3. When $\Pi_1(\tau^*, \alpha) < \Pi_1(\cdot, 1) - K$ and $\pi_1^C(\alpha) < \Pi_1(\cdot, 1) - K$, the investment takes place for the centralized and decentralized firm. The decentralized firm's internal carbon price loses strategic value, as the investment is unavoidable.

4. When $\Pi_1(\tau^*, \alpha) > \Pi_1(\cdot, 1) - K > \pi_1^C(\alpha) > \pi_1^D(\tau^*, \alpha)$, the investment takes place for the centralized and decentralized firm. The decentralized firm's internal carbon price loses strategic value, as the benefit of manipulating τ to deter the investment exceeds the cost.

4.3 Welfare

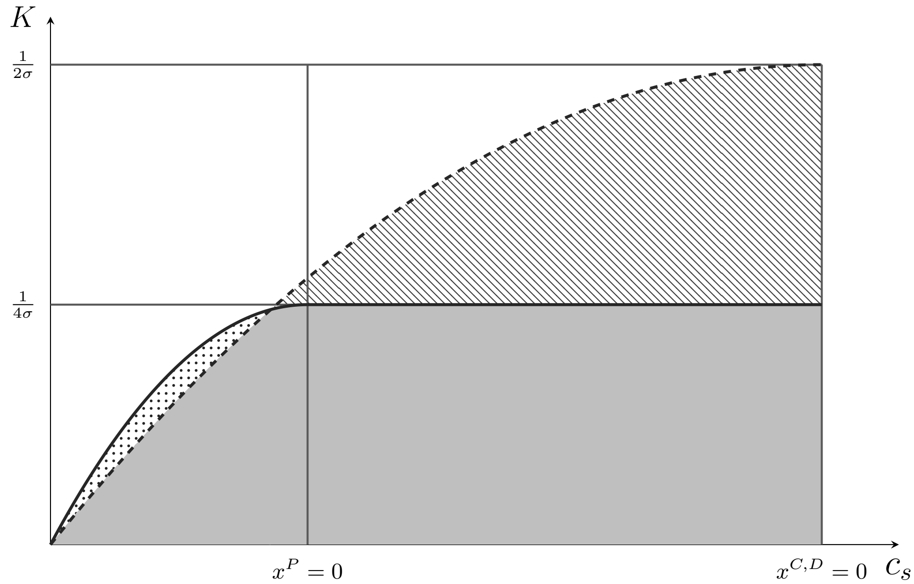
What do these results imply for the welfare comparison among the different carbon tax regimes? The welfare comparison between the cases of a centralized and a decentralized firm depends on two variables: the adoption of the abatement technology and total production. As shown above, a centralized firm makes the same investment decision as a decentralized firm. Therefore, we must consider two cases.

When both the centralized and decentralized firms invest, firm 1 plays a symmetric product market game with firm 2 (without pollution), and the equilibrium quantity matches the planner's solution, $x^* = 1/2$, regardless of whether the firm is centralized or decentralized. That is, conditional on investing, every market equilibrium achieves the first-best solution. In turn, when the centralized and decentralized firms do not invest, the welfare comparison under the centralized and decentralized cases amounts to the results in Proposition 1, where we establish sufficient conditions—mainly, the cost of carbon c_s not being too low—that make the market equilibrium under a decentralized firm 1 second best.[13] That is, the existence of an investment opportunity does not affect the result that a self-imposed carbon tax complements a government tax in promoting efficiency.

As discussed above, a centralized and decentralized firm invests under the same circumstances, but are these investments efficient? Compared to the social planner, the firm can either under- or overinvest in the adoption of the abatement technology. These results are illustrated in Figure 2. The dashed line represents the combination of investment cost, K, and the environmental damage of a unit of emissions, c_s that makes market firms indifferent between investing in the abatement technology or not. The solid line represents the same curve for the planner. For a given investment cost K, an environmental damage value c_s

[13]When the decentralized firm is constrained, we obtain the same qualitative results as in Proposition 1, with analogous arguments.

Figure 2: Planner vs. firm – investment regions ($\sigma = 1$ and $\alpha = 1/2$ depicted).



to the left of the dashed lines (solid line for the planner) results in no investment. That is, the environmental damage value is too low to incentivize adoption. Similarly, the c_s to the right of the dashed line are environmental damage values sufficiently high (relative to the investment cost) that induce adoption of the abatement technology.

The vertical lines in Figure 2 represent the maximum c_s, for given values of σ and α, for which the planner is willing to produce ($c_s < 1/((1-\alpha)\sigma)$) and the maximal c_s for which the firm is willing to produce $c_s < \bar{t} = 3/((1-\alpha)\sigma)$. Since the planner always has the option to shut down firm 1 and fully allocate the market to firm 2, the firm produces for a larger set of parameters, as this leads to a positive profit, albeit at a social cost. Similarly, the horizontal lines in Figure 2 represent the maximal investment cost K under which the planner is willing to invest, $\frac{1}{4\sigma}$, and the (de)centralized firm is willing to invest, $\frac{1}{2\sigma}$. Because the planner always has the option of closing firm 1 and obtaining a social benefit of $\frac{1}{4\sigma}$, the planner is willing to invest in a lower range of investment costs, K, than the firm.

The shaded area in Figure 2 represents parameter combinations in which both the planner and firm adopt the technology and, therefore, any market equilibrium achieves the first-best outcome. This occurs when the environmental damage value c_s is high enough to induce investment, but low enough for the planner to invest in the technology. The white area represents parameter combinations in which neither the planner nor the firm adopts the technology. For this region, efficiency is characterized, in qualitative terms (due to the constrained self-imposed tax), by Proposition 1, as discussed above. The dotted area represents underinvestment in the abatement technology stemming from the firm not fully internalizing the social cost of pollution. In this scenario, since $x^D \leq x^C$, the self-imposed carbon tax remains the second-best solution under the qualifications of Proposition 1. Finally, the stripped area represents the regions of over-investment—in this area the planner shuts down firm 1, but the firm still produces and invests for those parameters in a market equilibrium. Any market equilibrium is a second-best solution in this region.

In summary, when the firm has the opportunity to invest in an abatement technology, a market equilibrium featuring a decentralized firm setting a self-imposed carbon tax is the second-best outcome, provided the environmental damage associated with a unit of emissions is not too low. This result is in line with those in Proposition 1 and Proposition 2.

5 Extensions

We consider two extensions to our baseline analysis with exogenous abatement technology. We first allow for the firm to have 'corporate social responsability' (Lee and Park, 2019; Xing and Lee, 2024). This translates to a situation where the firm's headquarters voluntarily commits to paying a higher price per unit of emissions than the government carbon tax (e.g., by contributing to a carbon offset program). We then consider the case where the equilibrium of the product market game features consumers who are not served (i.e., the market is partially covered).

5.1 Corporate Social Responsibility

Consider the scenario where the government carbon tax is less than the environmental damage of a unit of emissions $t < c_s$. Assume firm 1 voluntarily chooses to offset carbon emissions by paying beyond the government carbon tax for each unit of emissions. That is, the firm pays t and $(c_r - t)$ per unit of emissions to the government and a carbon offset program, respectively, where $t < c_r \leq c_s$. We refer to this behavior as 'corporate social responsibility,' and we do not formally model why the firm chooses to engage in this practice. We also assume throughout that $t < \bar{t} = 3/((1-\alpha)\sigma)$.

The problem of firm 1's headquarters is to optimize the profit function

$$\begin{aligned}\Pi_1 &= \pi_1^D + (\tau - c_r)(1-\alpha)q_1 = (p_1 - c_r(1-\alpha))q_1 \\ &= \left(\frac{1}{\sigma} + \frac{2}{3}(1-\alpha)\tau - (1-\alpha)c_r\right)\left(\frac{1}{2} - \frac{\sigma(1-\alpha)\tau}{6}\right)\end{aligned}$$

with respect to τ, where $t \cdot (1-\alpha) \cdot q_1$ are firm 1's carbon tax liabilities to be remitted to the government, $(c_r - t) \cdot (1-\alpha) \cdot q_1$ are voluntary payments the firm makes to offset emissions, and $\tau \cdot (1-\alpha) \cdot q_1$ is the tax revenue firm 1's headquarters collects from its downstream division. In this case, the optimal self-imposed carbon tax τ^* is the same as in Equation 6, but replacing t with c_r.

As in Section 3, we find that the market equilibrium under a decentralized firm 1 (i.e., when a self-imposed carbon tax is optimal) is second-best (i.e., $W(x^D) > W(x^C)$) when

$$t < t^{SR}(c_s, c_r) = \frac{3}{4}\left(8c_s - c_r - \frac{1}{(1-\alpha)\sigma}\right).$$

This condition is the same as the one in Proposition 2 when $t = c_r$, but becomes weaker when $c_r > t$, suggesting that corporate social responsibility increases the range of parameter values for which a market structure with a decentralized firm 1 is second-best. That is, a self-imposed carbon tax, corporate social responsibility, and a government carbon tax complement each other in promoting efficiency.

5.2 Partial Market Coverage

If the condition for full market coverage fails to hold, that is, if

$$v < \frac{3 + \sigma(c_1 + c_2)}{2\sigma},$$

each firm operates as a local monopoly. In this scenario, the marginal consumer served by firm 1 solves $v - p_1 - \sigma^{-1}x = 0$, which implies a demand function for firm 1's product given by

$$q_1(p_1) \equiv x^*(p_1) = \sigma(v - p_1).$$

The profit of firm 1's downstream division is thus given by

$$\pi_1(p_1) = \sigma(p_1 - c_1)(v - p_1).$$

Taking the first-order condition with respect to price and solving for p_1^* and x^* yields

$$p_1^* = \frac{1}{2}(v + c_1) \quad \text{and} \quad x^*(p_1) = \frac{\sigma}{2}(v - c_1).$$

As above, assume $c_1 = (1-\alpha)\tau$, and for simplicity assume no government carbon tax. The profit of firm 1, combining the profits of the downstream division and headquarters, is then given by

$$\begin{aligned}\Pi_1(\tau) = \pi_1 + \tau(1-\alpha)q_1 &= (p_1 - \tau(1-\alpha) + \tau(1-\alpha))q_1 \\ &= \frac{\sigma}{4}\left(v^2 - \tau^2(1-\alpha)^2\right).\end{aligned}$$

From the profit function above, it is clear that it is optimal for firm 1 to set $\tau^* = 0$. That is, in the absence of direct competition between firms, a positive self-imposed carbon tax is no longer optimal. Why? Recall that the benefit of a self-imposed carbon tax is to relax the intensity of product market competition between firms. A self-imposed carbon tax leads to a greater equilibrium price-cost margin due to the softening of competition, but comes at the cost of a lower market share. When firms no longer compete directly, the benefit of a self-imposed carbon tax vanishes.

6 Concluding Remarks

Some companies have chosen to impose a carbon tax on themselves, where governments have failed to act. This paper provides an explanation for this phenomenon, showing that this strategy can be profitable because of its impact on the intensity of price competition. Importantly, the result does not rely on the firm using the carbon tax to signal to consumers that the firm is "green" or to achieve any marketing benefit that may shift demand. Despite a loss in consumer surplus due to higher equilibrium prices, the self-imposed carbon tax may enhance market efficiency.

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