

The NGO's Dilemma: How to Influence Firms to Replace a Potentially Hazardous Substance

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We study an NGO's decisions when it attempts to remove a potentially hazardous substance from commercial use in a market with competing firms. Specifically, we determine under what market and regulatory conditions an NGO should target the industry versus the regulatory body in order to influence firms to replace the substance. We examine how the NGO's strategy changes as the NGO's pragmatism (i.e., the extent to which the NGO incorporates firms' profits into its decision making) increases. Our results demonstrate that when the NGO is less pragmatic, it should examine the existing market structure to determine whether to target the industry or the regulatory body. However, as the pragmatism of the NGO increases, the NGO should increasingly leverage the competition between firms to ensure that a replacement is available to consumers. We examine multiple extensions including varying the competition dynamics, the NGO targeting both the industry *and* the regulatory body, the time discounting of replacement costs, and a firm potentially lobbying to counteract an NGO's activism. We show that the ability of a firm to lobby can benefit consumers by motivating the NGO to exert more effort and increase the market sensitivity to a substance, thereby forcing the firm to replace.

Key words: Non-governmental organizations, environmental regulations, hazardous substance uncertainty, public politics, private politics, game theory

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1. Introduction

Recently, the uncertain environmental and health impacts of consumer products and the chemicals they contain have been a popular topic in the news. Articles and studies have been released on a wide range of substances and products such as bisphenol-A (BPA) in food containers (Freinkel 2012), triclosan in soaps and toothpastes (Layton 2010), and phthalates in fashion goods (Pous 2012). Although all of these substances are of high concern for consumers, governments, corporations, and non-governmental organizations (NGOs), none have been definitively proven as harmful. When an unregulated substance or chemical is identified as *potentially* hazardous, it invokes consumer fears, scientific debate, and as a result, difficult decisions for both firms and NGOs. Firms must choose whether to replace the substance in light of rising consumer concerns, high replacement costs, and uncertain regulatory and substance risks. At the same time, an NGO interested in compelling firms to remove the substance from commercial use must decide where to direct its resources. Should it directly target the industry to increase the market sensitivity to the substance, or should it petition governmental organizations

to increase the likelihood of regulation? In this paper, we investigate who an NGO should target, *the industry* or *the regulatory body*, in order to influence firms to replace a potentially hazardous substance.

An NGO's strategy for removing a potentially hazardous substance from commercial use is complicated by the level of consumer sensitivity to the substance and uncertainty regarding the substance risk and regulation. Consequently, how an NGO should direct its effort can vary depending on the scenario. Consider the following strategies. To increase the likelihood of either regulation banning the substance or firms replacing the substance in anticipation of regulation, an NGO can *target the regulatory body*. For example, since its formation in 2007, the European Union's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) directive for monitoring and detecting potentially harmful chemicals has been criticized for not being aggressive enough in identifying substances of very high concern (SVHC). As a result, an NGO called ChemSec established The SIN (Substitute It Now!) List to "[accelerate] the REACH legislative process" and to identify additional SVHC (The SIN List 2012). Alternatively, by acting on consumer fears and firms' concerns over corporate image and market share, an NGO can *directly target an industry* to force firms to replace a substance. As Paul Gilding, former head of Greenpeace, noted, "smart activists are now saying, 'O.K., you want to play markets – let's play'" (Friedman 2001). For example, in the spring of 2010, Greenpeace held protests at the corporate headquarters of Samsung for what Greenpeace felt were "broken promises" by the company to remove potentially hazardous substances from its product lines (Williams 2010).

In this setting, NGOs are not the only decision makers. When a substance within a firm's products is identified as potentially hazardous, a firm must make difficult decisions while managing both costs and risks. A firm's cost to remove a substance from its products can be substantial. For example, the Consumer Electronics Association estimates that the initial compliance requirements for the EU's Restriction of Hazardous Substances (RoHS) directive, which restricts the use of only six substances, cost the global electronics industry \$32 billion (Carbone 2008). New directives such as REACH and accompanying NGO initiatives such as The SIN List, guarantee there will be many more substances of concern for firms to manage in the future. However, regulation and costs are not the only threats firms face. Consumers today are more sensitive to the potential dangers, whether real or perceived, of the products they buy and use. As a result, a potentially hazardous substance can represent both an opportunity and a risk for a firm. For example, in the plastic baby bottle market, when BPA first became a substance of concern for consumers, many larger firms did not have a BPA-free alternative. As the sales of BPA-free baby bottles increased five-fold at some retailers, a niche market opportunity emerged for smaller firms with a BPA-free product (IEHN 2008, Kuchment 2008). Finally, a firm may not believe that a substance is harmful. As a result, a firm may choose to lobby either the regulatory body or consumers to counteract negative sentiment towards a substance. For example, the leading producers of brominated flame retardants (BFRs) in the U.S. mounted both consumer campaigns and political lobbying in an attempt to highlight the safety benefits of BFRs (Callahan and Roe 2012).

In this paper, we consider a competition-based model, in which two firms sell a product containing a potentially hazardous substance. Although the substance is not regulated, an NGO exists that would like to influence the firms to replace the substance. How much an NGO should consider firms' well-being when devising its strategy is a current debate within the environmental movement (The Economist 2010). To capture this aspect, we define an NGO's pragmatism as the extent to which it incorporates firms' profits into its decision making; we examine how the NGO's strategy changes as its pragmatism increases. Our goal is to determine when an NGO should target the industry versus the regulatory body, based on market structure, potential environmental benefit, and NGO pragmatism. This research is directed towards NGOs active in the chemicals space (e.g., ChemSec, Environmental Defense Fund, and Greenpeace) and companies interested in learning more about an NGO's perspective. In today's technology-driven world, given the scale and speed with which activists can launch campaigns (Soule 2009), understanding secondary stakeholders' motivations and strategies is critical for a firm.

To the best of our knowledge, we are the first to analytically study an activist's strategic choice of where to allocate its resources under different market and regulatory conditions. Our results show that there is an important interplay between the NGO's pragmatism and the NGO's optimal strategic choice. For example, if the NGO does not significantly consider firms' well-being in its decision making, then the NGO's goal is solely to maximize the number of consumers receiving a replacement. Thus, the NGO's strategy should be to induce all firms or at least a dominant firm to replace by any means necessary. Whether or not the NGO should target the industry or the regulatory body to do so is driven by the market structure. In contrast, unless the market consists of similar-sized firms and the benefit from replacement is very high or very low, a more pragmatic NGO should target the industry and leverage the competition between firms to ensure that a replacement is available to consumers. We also examine how varying the competition dynamics, the option to target both the industry and the regulatory body, the time discounting of replacement costs, and the ability of a firm to lobby to offset the NGO's activism impact the NGO's optimal strategy. For example, we show that a firm's ability to lobby can benefit consumers because the NGO may respond by increasing its effort, thereby increasing the market sensitivity to the substance and forcing the firm to replace.

The remainder of the paper is organized as follows. In §2 we review the relevant literature and in §3 we introduce the base model formulation. We present our findings regarding the NGO's optimal strategy in §4 and discuss extensions to our base model in §5. In §6 we analyze how the potential for a firm to lobby can impact the NGO's strategy. In §7 we highlight our insights and conclude the paper.

2. Literature Review

Next, we discuss the literature relevant to the NGO's decisions. Note that our work also relates to the emerging literature on analytical modeling of firms' environmental investment decisions (e.g., Cortazar et al. 1998, Fisher 2000, Kraft et al. 2012), environmental regulation and operations management (e.g.,

Atasu et al. 2009, Chen 2001, Plambeck and Wang 2009), and nonprofit operations management (e.g., DeVericourt and Lobo 2009, Privett and Erhun 2011).

Public versus Private Politics: Within the political economy literature, how activists influence corporations can be classified into two broad categories: public politics and private politics. Public politics studies how activists can advance their agendas through petitioning government and regulatory bodies. While it is frequently used, influencing firms through public politics can be time-consuming and costly for activists (see Lyon and Maxwell (2004) for an overview of the traditional public policy life cycle). As such, there is a growing interest in private politics among activists and academics. Private politics examines how activists can directly target firms, bypassing the need for regulation or government interaction. Within the literature, Baron (2001, 2003) introduced the concept of private politics by studying how activists can compel firms to act and what are firms' optimal strategic responses to activists' campaigns. Our interests are at the intersection of public and private politics, as there is a lack of research that considers both strategy types (Baron 2011, Soule 2009). Although Calveras et al. (2007) and Reid and Toffel (2009) study both private and public politics, neither work examines the strategic choice of one method over the other. We add to the literature by analyzing when an NGO should target the industry (private politics) versus the regulatory body (public politics).

NGO Pragmatism: Within the environmental literature, there is a growing opinion that a division is forming among activists (Dowie 1996, Schwartz and Paul 1992, Speth 2008). Conner and Epstein (2007) divide their study of NGOs into two broad categories: purists, who typically seek change through confrontation, and pragmatists, who instead prefer to work with firms to solve environmental problems. Hoffman (2009) disagrees with this classification, stating that although most scholars classify environmental NGOs into two camps, "dark greens" and "bright greens," there is actually a wide variety of environmental NGOs and thus, "shades of green." Studying whether an NGO should collaborate or confront firms is beyond the scope of our analysis as it requires a deeper understanding of an NGO's philosophy and donor base. However, based on our discussions with academic and NGO leaders, we recognize the importance of capturing the differences that can exist between NGOs' philosophies. Hence, we define the pragmatism of the NGO as the extent to which the NGO incorporates firms' profits into its objective function, with the NGO's pragmatism taking a continuum of potential values.

Modeling an NGO's Objective Function: Defining a nonprofit's objective can be difficult because a nonprofit may have multiple or conflicting goals (Steinberg 1986, Weisbrod 1998). Within the nonprofit literature, the nonprofit's objective function is often modeled as a linear combination of different objectives (Harrison and Lybecker 2005, Liu and Weinberg 2004, Steinberg 1986). For example, Harrison and Lybecker (2005) model a nonprofit hospital's objective function as a linear combination of the hospital's profit and motive (e.g., quality of care) minus the hospital's cost. Conversely, within the political economy and strategy literature, activists' objective functions are often modeled around a single goal (Baron 2001, Baron and Diermeier 2007, Lenox and Eesley 2009). For

example, Baron (2001) examines how an activist can use boycotts to influence a firm to reduce its pollution levels. The activist's objective is to minimize the expected level of pollution and its cost of effort to boycott. We combine these approaches, defining the NGO's objective as a linear combination of environmental benefit and firms' profits, minus the NGO's cost of effort to target either the industry or the regulatory body. Note that we do not directly model the revenue the NGO earns from donations. Instead, we assume that our modeling of environmental benefit implicitly reflects donor satisfaction with the NGO. We discuss this assumption in more detail in §7.

3. The Model

We analyze a setting in which two firms, with market share percentages θ_1 and θ_2 , sell a product containing a potentially hazardous substance. Hereafter, references to firm size (i.e., large or small) are with respect to market share. The two firms represent the entire market (i.e., $\theta_1 + \theta_2 = 1$ with $\theta_1 \geq \theta_2$), and M represents the total market size in terms of revenue; Table 1 summarizes our notation. There exists an NGO that would like to remove the substance from the market. Although the substance is not regulated, there is a belief among the firms and the NGO that regulation may occur. The sequence of events is as follows: (i) The NGO determines who to target, the industry or the regulatory body, and the level of effort ϵ to exert. (ii) The two firms decide simultaneously whether to immediately replace the substance at cost $K(\theta_i)$ or to defer replacement. (iii) Regulation occurs with probability $r(\epsilon)$; if regulation occurs and a firm has not replaced the substance, then the firm is forced to replace. The firms must decide whether to proactively replace or to defer replacement and wait to see if regulation happens. Note that deferring replacement is a viable option since not all potentially hazardous substances are proven to be harmful (e.g., aspartame in diet soft drinks; see Brody 1983, Halliday 2008).

By compelling firms to replace the substance, either by targeting the industry or the regulatory body, the NGO reduces the number of consumers exposed to the substance. Depending on the NGO's strategy, the effort level ϵ the NGO exerts affects either the proportion of the market sensitive to the substance and preferring a product with a replacement substance, $\xi(\epsilon)$, or the likelihood of regulation, $r(\epsilon)$. The notation $x(\epsilon)$ denotes the impact of the NGO's effort on $\xi(\epsilon)$ and $r(\epsilon)$. In our base model, we consider a linear impact (i.e., $x(\epsilon) = \epsilon$); in §5 we relax this assumption.

Once the NGO determines whom to target and the corresponding effort level, the two firms then compete in a static game of complete information; i.e., they make their own replacement decisions simultaneously without observing the other's action. Firm i 's strategy s_i is either to replace the substance at cost $K(\theta_i)$ or to defer replacement (D) and wait to see if regulation occurs. The first row in each cell of Table 2 shows the payoff for the large firm and the second row shows the payoff for the small firm given the strategy profile. We assume that the replacement cost $K(\theta_i)$ is concave and increasing in θ_i . Hence, a large-market-share firm incurs a higher total replacement cost than a small-market-share firm, but the average cost (i.e., $K(\theta_i)/\theta_i$) is lower for the large firm due to economies

Table 1 Notation

<i>NGO Parameters</i>	
b	Marginal environmental benefit to consumers if the substance is replaced; $b > 0$
γ	The level of NGO pragmatism with a larger value implying the NGO is more pragmatic and thus, more concerned with firms' profits; $\gamma \in [0, 1]$
c	Cost factor associated with the NGO's effort level; $c > 0$
ϵ	Effort level exerted by the NGO; $\epsilon \in [0, 1]$
ϵ_S^N	Optimal effort level exerted by the NGO under NGO strategy N (targeting the industry or the regulatory body) to induce firm replacement equilibrium S ; $\epsilon_S^N \in [0, 1]$
π_S^N	NGO's payoff given effort level ϵ_S^N under NGO strategy N and firm replacement equilibrium S
<i>Firm Parameters</i>	
θ_i	Market share percentage of firm $i \in \{1, 2\}$; $\theta_1 + \theta_2 = 1$ with $\theta_1 \geq \theta_2$, $-i$ denotes firm i 's competitor
$K(\theta_i)$	Firm i 's cost to immediately replace the substance; $K(\theta_i)$ is concave and increasing in θ_i
s_i	Firm i 's strategy; $s_i \in \{K(\theta_i)$ (replace), D (defer replacement)}; $s_i^*(\epsilon)$ is firm i 's equilibrium strategy given ϵ
<i>Market and Regulation Parameters</i>	
M	Total market size in terms of revenue
$x(\epsilon)$	Impact of the NGO's effort level on either the final percentage of the market sensitive to the substance or the final probability of regulation
q	Existing percentage of the market sensitive to the substance before the NGO exerts any effort; $q \in [0, 1]$
$\xi(\epsilon)$	Final percentage of the market sensitive to the substance; if the NGO targets the industry, then $\xi(\epsilon) = q + (1 - q)x(\epsilon)$, otherwise $\xi(\epsilon) = q$
p	Existing probability of regulation before the NGO exerts any effort; $p \in [0, 1]$
$r(\epsilon)$	Final probability of regulation; if the NGO targets the regulatory body, then $r(\epsilon) = p + (1 - p)x(\epsilon)$, otherwise $r(\epsilon) = p$
α	Regulation penalty; $\alpha \geq 1$

of scale. We also assume that a firm's replacement cost is based on its initial market share. Although the cost to develop a replacement substance may be independent of firm size, the cost to implement a replacement is typically increasing in firm size due to large firms' high existing inventory costs and complex supply chains. For example, the average cost of compliance for RoHS was \$6.5 million for companies with sales greater than \$1 billion, and \$2.9 million for companies with sales between \$100 million and \$1 billion, with a large portion of the firms' replacement costs due to modifying current operations and writing off existing inventory (Carbone 2008).

Table 2 Two-Firm Competition

		Firm 2 (s_2)	
		$K(\theta_2)$	D
Firm 1 (s_1)	$K(\theta_1)$	$M\theta_1 - K(\theta_1)$ $M\theta_2 - K(\theta_2)$	$M\theta_1 + M\theta_2\xi(\epsilon) - K(\theta_1)$ $M\theta_2 - M\theta_2\xi(\epsilon) - r(\epsilon)\alpha K(\theta_2)$
	D	$M\theta_1 - M\theta_1\xi(\epsilon) - r(\epsilon)\alpha K(\theta_1)$ $M\theta_2 + M\theta_1\xi(\epsilon) - K(\theta_2)$	$M\theta_1 - M\theta_1\xi(\epsilon) - r(\epsilon)\alpha K(\theta_1)$ $M\theta_2 - M\theta_2\xi(\epsilon) - r(\epsilon)\alpha K(\theta_2)$

Note: If the NGO targets the industry, then $\xi(\epsilon) = q + (1 - q)x(\epsilon)$ and $r(\epsilon) = p$. If the NGO targets the regulatory body, then $r(\epsilon) = p + (1 - p)x(\epsilon)$ and $\xi(\epsilon) = q$.

If the NGO targets the industry, then the NGO's effort impacts the percentage of the market sensitive to the substance and thus preferring to switch to a product with a replacement substance. We model the resulting market sensitivity as $\xi(\epsilon) = q + (1 - q)x(\epsilon)$, where q is the existing percentage of the market sensitive to the substance and $(1 - q)x(\epsilon)$ is the increase in the market sensitivity caused by

the NGO's effort. If instead, the NGO targets the regulatory body, then the NGO's effort no longer affects the market sensitivity to the substance and $\xi(\epsilon) = q$. The portion of firm i 's market share that is sensitive to the substance is then given by $M\theta_i\xi(\epsilon)$. If firm i replaces the substance but firm $-i$ does not, instead choosing to wait to see if regulation occurs, then firm i incurs market share gain $M\theta_{-i}\xi(\epsilon)$ for being the first to replace and firm $-i$ incurs market share loss $M\theta_{-i}\xi(\epsilon)$. When both firms replace, there is no shift in market share between the firms. When both firms defer replacement, then both firms lose market share as sensitive consumers leave the market.

After the firms make their decisions, regulation of the substance is announced with probability $r(\epsilon)$. If the NGO targets the regulatory body, then the final probability of regulation takes the form $r(\epsilon) = p + (1 - p)x(\epsilon)$. Here p is the existing probability of regulation before the NGO exerts any effort and $(1 - p)x(\epsilon)$ is the increase in the probability of regulation caused by the NGO's effort. If instead, the NGO targets the industry, then the final probability of regulation is no longer affected by the NGO's effort and $r(\epsilon) = p$. If regulation occurs and firm i has not yet replaced the substance, then it is forced to replace at cost $\alpha K(\theta_i)$ with $\alpha \geq 1$. This cost represents the penalty a firm incurs for not having devoted enough time towards developing and implementing a replacement throughout its product lines. As Mark Newton, Dell's senior manager for environmental sustainability, noted, "Being ahead of the curve on regulation indicates overall good management. Late adaptation has cost implications, for example the cost of making major changes in a very limited time frame" (ChemSec 2009).

The NGO's objective is to maximize the net benefit of influencing firms to replace the substance. In particular, the NGO's decisions are driven by the environmental benefit gained from replacement, potentially the firms' profits (depending on the NGO's pragmatism), and the cost to campaign against the industry or the regulatory body. We broadly define environmental benefit to mean the environment or health benefit consumers receive from a replacement substance. We measure environmental benefit as $bg(\theta_1, \theta_2, \epsilon)$, where b is the marginal environmental benefit to consumers if a substance is replaced and $g(\theta_1, \theta_2, \epsilon)$ is the expected percentage of the market that receives a replacement substance:

$$g(\theta_1, \theta_2, \epsilon) = \begin{cases} \theta_1 + \theta_2 = 1 & \text{if } s_1 = K(\theta_1) \text{ and } s_2 = K(\theta_2), \\ (1 - r(\epsilon))(\theta_i + \theta_{-i}\xi(\epsilon)) + r(\epsilon) & \text{if } s_i = K(\theta_i) \text{ and } s_{-i} = D, \\ r(\epsilon)(1 - \xi(\epsilon))(\theta_1 + \theta_2) = r(\epsilon)(1 - \xi(\epsilon)) & \text{if } s_1 = D \text{ and } s_2 = D. \end{cases} \quad (1)$$

As discussed earlier, the values of $\xi(\epsilon)$ and $r(\epsilon)$ depend on the NGO's strategy. We assume that consumers make their product choice before the regulation outcome is realized. Thus, if both firms defer, then sensitive consumers leave the market and do not return, even if regulation eventually occurs.

We are interested in how an NGO's philosophy towards firms can alter its strategy for influencing firms' replacement decisions. We define $\gamma \in [0, 1]$ as a measure of the NGO's pragmatism. If $\gamma = 0$, then the NGO is only concerned with the environmental benefit. As γ increases, the NGO becomes more

pragmatic and includes the firms' profits into its objective function. We denote the extent to which the NGO considers the firms' profits as $\gamma h(\theta_1, \theta_2, \epsilon)$, where $h(\theta_1, \theta_2, \epsilon)$ is the total profit of both firms:

$$h(\theta_1, \theta_2, \epsilon) = \begin{cases} M - K(\theta_1) - K(\theta_2) & \text{if } s_1 = K(\theta_1) \text{ and } s_2 = K(\theta_2), \\ M - K(\theta_i) - r(\epsilon)\alpha K(\theta_{-i}) & \text{if } s_i = K(\theta_i) \text{ and } s_{-i} = D, \\ M - r(\epsilon)\alpha K(\theta_1) - r(\epsilon)\alpha K(\theta_2) & \text{if } s_1 = D \text{ and } s_2 = D. \end{cases} \quad (2)$$

Similar to Equation (1), the value of $r(\epsilon)$ depends on the NGO's strategy.

The NGO's payoff function is then given by

$$\pi_{NGO}(\epsilon) = bg(\theta_1, \theta_2, \epsilon) + \gamma h(\theta_1, \theta_2, \epsilon) - c\epsilon^2, \quad (3)$$

where $c\epsilon^2$ is the NGO's cost as a function of the exerted effort level and c is the NGO's cost factor.

Next, we examine the NGO's optimal strategy for influencing firms to replace a potentially hazardous substance. To analyze our setting, we theoretically characterize the subgame perfect Nash equilibrium, solving for the NGO's optimal effort and the firms' equilibrium replacement strategies; the detailed analysis is deferred to Appendix A. All proofs are available from the authors upon request. We also conduct an extensive numerical analysis with the following parameter set: $M = 500$, $K(\theta_i) = k\sqrt{\theta_i}$ with $k \in \{225, 300, 375, 450\}$, $\theta_1 \in [0.55, 0.95]$ with an increment of 0.01, $b \in [1, 700]$ with an increment of 7, $c = 100$, $\gamma \in [0, 1]$ with an increment of 0.25, $p \in [0.025, 0.525]$ with an increment of 0.025, $q \in [0.025, 0.525]$ with an increment of 0.025, and $\alpha \in [0.50, 3.00]$ with an increment of 0.25. We discuss the details of all numerical results in Appendix C. Results found in the appendix and the online appendix are referenced as A.x and O.x here. To simplify notation, hereafter we use K_i to denote $K(\theta_i)$.

4. Should the NGO Target the Industry or the Regulatory Body?

In this section, we answer our primary research question: Under what conditions should the NGO target the industry versus the regulatory body? Observe that due to the existing regulatory environment and market sensitivity, NGO activism may not always be necessary to induce firms to replace a potentially hazardous substance. Given the concavity of the firms' replacement costs with respect to market share, the average replacement cost per dollar of revenue is higher for the small firm (i.e., $K_2/\theta_2 > K_1/\theta_1$). This implies that the small firm has less incentive to proactively replace. Hence, if the existing regulatory and market conditions are such that the small firm proactively replaces (i.e., $K_2 \leq \alpha p K_2 + M\theta_2 q$), then both firms will replace even if the NGO exerts no effort (Lemma A.4).

Our analysis will focus on scenarios in which $K_2 > \alpha p K_2 + M\theta_2 q$; that is, neither the existing regulatory threat nor the existing market sensitivity to the substance is large enough to induce both firms to proactively replace. Hence, the NGO must take action to induce firms to proactively replace. Figure 1, which is referenced throughout §4, illustrates the NGO's optimal strategy (target the Industry or the Regulatory body) and the resulting firm replacement equilibrium when $\gamma > 0$ and $\gamma = 0$. We characterize the equilibria with respect to two values: the ratio of the marginal environmental benefit to the NGO's cost factor (b/c) and the market share of the large firm (θ_1). This allows us to compare

high versus low benefit-to-cost scenarios, with either a homogeneous (θ_1 close to 0.5) or a dominant-firm (θ_1 close to 1) market structure. We present two figures, $\gamma > 0$ and $\gamma = 0$, to highlight the impact of the NGO's pragmatism on its optimal strategy. We define π_S^N as the NGO's payoff given the optimal effort level ϵ_S^N under NGO strategy N , when firm replacement equilibrium S is induced. Table A.3 (Appendix C.1) provides a numerical summary of the equilibrium regions by firm and NGO strategies.

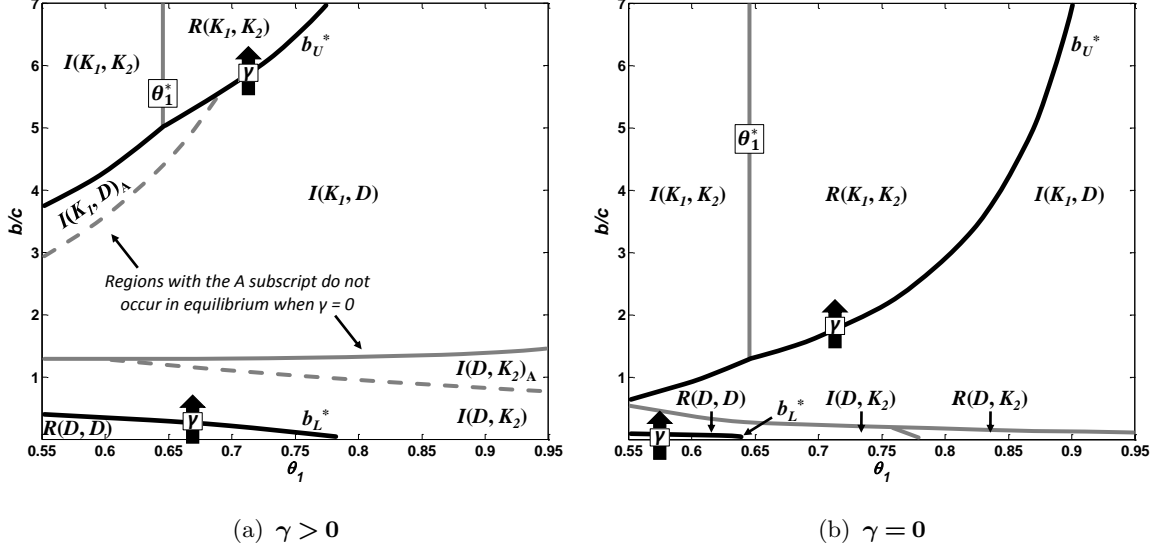


Figure 1 Equilibria Under the NGO's Optimal Strategy - Target Industry or Regulation

Note: We define $b_U^* = \{b_U^*(\theta_1) : \forall \theta_1 \in (0.50, 1.00)\}$ and $b_L^* = \{b_L^*(\theta_1) : \forall \theta_1 \in (0.50, 1.00)\}$. The wide black arrows indicate the direction in which the boundary shifts when γ increases. The direction was shown analytically for b_U^* and numerically for b_L^* . The following values were used to generate Figure 1: $b \in [1, 700]$ with an increment of 0.25, $c = 100$, $\gamma \in \{0.0, 0.5\}$, $\alpha = 1.25$, $p = 0.125$, $q = 0.175$, $M = 500$, $K(\theta_i) = 225\sqrt{\theta_i}$, $\theta_1 \in [0.55, 0.95]$ with an increment of 0.003125.

First, we demonstrate how the different equilibrium regions are positioned with respect to the benefit-to-cost ratio b/c . Specifically, there exist an upper threshold $b_U^*(\theta_1)$ and a lower threshold $b_L^*(\theta_1)$ that partition the parameter region into three distinct firm replacement equilibrium segments.

PROPOSITION 1. *There exist thresholds $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ such that*

$$(s_1^*(\epsilon), s_2^*(\epsilon)) = \begin{cases} (D, D) & \text{if } b < b_L^*(\theta_1), \\ (K_1, D)/(D, K_2) & \text{if } b \in [b_L^*(\theta_1), b_U^*(\theta_1)], \\ (K_1, K_2) & \text{if } b \geq b_U^*(\theta_1). \end{cases}$$

A similar result holds with respect to the NGO's cost factor c , with the firm replacement equilibrium changing from (K_1, K_2) to $(K_1, D)/(D, K_2)$ to (D, D) as c increases.

By Proposition 1, as the benefit-to-cost ratio b/c increases, the resulting firm replacement equilibrium under the NGO's optimal strategy changes from both firms deferring (D, D) when the ratio is low, to either the large firm (K_1, D) or the small firm (D, K_2) replacing, to finally both firms replacing (K_1, K_2) when the ratio is high. Within the $(K_1, D)/(D, K_2)$ region, when b/c is high, the NGO is incentivized to compel the large firm to replace to ensure a larger portion of consumers receive a replacement. As a result, under either NGO strategy (i.e., I or R), the firm equilibrium changes from (D, K_2) to (K_1, D) as the benefit-to-cost ratio b/c increases (Proposition A.1).

With respect to market structure, we observe that $b_U^*(\theta_1)$ is increasing and $b_L^*(\theta_1)$ is decreasing as the market structure shifts from a homogeneous to a dominant-firm market (Table A.4, Appendix C.1). When the marginal environmental benefit b is high, the NGO exerts high effort to induce the large firm to replace. However, as θ_1 increases, inducing the small firm to also replace is harder due to the small firm's increasing average cost of replacing; i.e., K_2/θ_2 increases as θ_2 decreases. Thus, the NGO prefers to induce (K_1, D) versus (K_1, K_2) . Conversely, when b is low, it is too costly for the NGO to induce the large firm to replace. As θ_1 increases, the small firm is motivated to proactively replace and gain market share from the dominant firm. Thus, the NGO prefers to induce (D, K_2) versus (D, D) .

We next discuss each equilibrium region in more detail and how the pragmatism of the NGO (γ) impacts these regions.

4.1. Both Firms Defer Replacement of the Substance: (D, D)

When the firms are homogeneous in size and the benefit-to-cost ratio is very low, the NGO induces the (D, D) equilibrium (see Figure 1). Proposition 2 demonstrates that when the induced replacement equilibrium is (D, D) , the NGO always prefers to target the regulatory body instead of the industry.

PROPOSITION 2. *Within the parameter region such that the firms' replacement equilibrium is (D, D) , $\pi_{D,D}^R \geq \pi_{D,D}^I$ always holds.*

Although neither firm proactively replaces in this region, it is beneficial for the NGO to apply some pressure to the regulatory body and thereby increase the likelihood that the firms are eventually forced to replace. Note that within the $R(D, D)$ region, due to the low environmental benefit from firms replacing the substance, the NGO exerts either a low effort level or no effort. In addition, the size of the $R(D, D)$ region is increasing in γ if the small firm's cost to proactively replace the substance (K_2) is high, as a pragmatic NGO does not want to create a significant cost burden for the small firm (Proposition A.2). In our extensive numerical analysis, we observe that the size of the $R(D, D)$ region is almost always increasing in γ (Table A.5, Appendix C.1).

4.2. One Firm Replaces the Substance: $(K_1, D)/(D, K_2)$

Between thresholds $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$, either only the large firm or only the small firm replaces the substance. Within this region, for a wide range of parameter values, the NGO's preferred strategy is to target the industry and increase the market sensitivity to the substance (Lemma A.3, Proposition A.3, and Table A.3, Appendix C.1). By increasing the market sensitivity, the NGO can leverage the competition between firms to induce either the large firm to replace to avoid a significant loss in market share (when b/c is high) or the small firm to replace to gain market share (when b/c is low). Numerically, we find that targeting the regulatory body is the NGO's preferred strategy only when the NGO does not include the firms' profits in its decisions (γ is low) and the existing market sensitivity (q) is high and thus, targeting the industry is less effective (Table A.7, Appendix C.1).

Within the $(K_1, D)/(D, K_2)$ region, we observe how incorporating the firms' profits into its decision making can complicate the NGO's strategy. As shown in Figure 1(a), when the NGO considers the firms' profits (i.e., $\gamma > 0$), equilibrium regions $I(K_1, D)_A$ and $I(D, K_2)_A$ can occur. Within these regions, the NGO exerts enough effort such that it could maximize the environmental benefit. However, it chooses to instead maximize its payoff by limiting total firm replacement costs at the expense of inducing a lower environmental benefit. For example, within the $I(K_1, D)_A$ region the NGO's payoff-maximizing strategy is to compel only the large firm to replace even though the NGO's exerted effort is sufficient to induce both firms to replace (K_1, K_2) . Inducing $I(K_1, D)_A$ enables the NGO to reduce the total firm replacement costs, but at the same time ensures that sensitive consumers can obtain a replacement from the large firm. Similar results hold for the $I(D, K_2)_A$ region, except that in this region the tradeoff the NGO faces is between targeting the small firm (D, K_2) or the large firm (K_1, D) to replace. The $I(D, K_2)_A$ region is more likely to occur when there exists a dominant firm in the market (Proposition A.4). Conversely, the $I(K_1, D)_A$ region occurs when the benefit-to-cost ratio is higher and the firms are more homogenous in size (Proposition A.5), since inducing the small firm to also replace (i.e., achieving (K_1, K_2)) incurs a high cost for the small firm when θ_2 is large. When the NGO does not incorporate the firms' profits into its decisions (i.e., $\gamma = 0$), $I(K_1, D)_A$ and $I(D, K_2)_A$ do not occur in equilibrium (Lemma A.2). This is because the NGO's cost to induce $I(K_1, D)_A$ or $I(D, K_2)_A$ is the same as that of inducing $I(K_1, K_2)$ or $I(K_1, D)$, respectively; however, the latter equilibria generate a strictly higher environmental benefit.

The $I(K_1, D)_A$ and $I(D, K_2)_A$ regions, which we refer to as *regions of potential contention*, highlight a fundamental issue an NGO must address – whether or not to incorporate the firms' well-being in its decision making. A pragmatic NGO may be criticized for choosing not to maximize the environmental benefit. By not aggressively pursuing the full or an extensive removal of the substance from commercial use, the NGO may risk the safety of consumers and possibly damage its credibility. This finding is consistent with Conner and Epstein's argument that “pragmatism isn't cheap” (2007, p. 62).

4.3. Both Firms Replace the Substance: (K_1, K_2)

Within the (K_1, K_2) region, the NGO's optimal strategy can be to target either the industry or the regulatory body. By Proposition 3, the choice of strategy is independent of the benefit-to-cost ratio (b/c) and how much the NGO incorporates the firms' profits into its decisions (γ). Instead, the NGO's optimal choice only depends on the market structure (θ_1).

PROPOSITION 3. *When both firms replace in equilibrium, there exists a threshold θ_1^* such that $\pi_{K_1, K_2}^I > \pi_{K_1, K_2}^R$ for $\theta_1 < \theta_1^*$, and $\pi_{K_1, K_2}^I \leq \pi_{K_1, K_2}^R$ for $\theta_1 \geq \theta_1^*$. Also, θ_1^* is independent of b , c , and γ .*

In the (K_1, K_2) region, both firms replace regardless of the NGO's strategy. Thus, the environmental benefit is the same, the firms earn the same profits, and the NGO's choice of strategy is only determined by which strategy requires a lower effort to induce both firms to replace. As previously discussed, due to

the concavity of the replacement cost, the NGO's effort level to induce (K_1, K_2) is driven by the small firm's replacement cost and market share. When the market structure is homogeneous (i.e., $\theta_1 \approx \theta_2$), the small firm can potentially lose significant market share if the large firm proactively replaces. Hence, the NGO should target the industry to pressure the small firm to replace. However, as θ_1 increases, the small firm's market share shrinks and using competition to induce both firms to replace becomes less effective. Therefore, as the large firm becomes more dominant, the NGO's optimal strategy shifts from targeting the industry to targeting the regulatory body (see Figure 1).

Threshold $b_U^*(\theta_1)$ is increasing in γ and thus, the size of the (K_1, K_2) region is decreasing in γ (Proposition A.6). As the NGO becomes more pragmatic, it is more concerned with the firms' profits. Thus, it is more inclined to only ensure that a replacement is *available* to consumers by inducing (K_1, D) or (D, K_2) instead of (K_1, K_2) . Conversely, if the NGO is less concerned with the firms' profits (i.e., γ is close to 0), then the NGO prefers to target both firms to replace, (K_1, K_2) , if there is not a dominant firm in the market; i.e., θ_1 is not too high. If there is a dominant firm, then the less pragmatic NGO prefers to target the industry and induce (K_1, D) instead of (K_1, K_2) (see Figure 1(b)).

4.4. The Impact of Regulation and Market Sensitivity on the NGO's Strategy

Finally, we examine how the NGO's strategy changes with respect to the existing regulatory threat (α and p) and the existing market sensitivity (q). First, when the regulatory threat increases, the effort level the NGO must exert to induce firms to replace decreases. Thus, replacement equilibrium (K_1, K_2) occurs for lower benefit-to-cost ratios, and equilibrium region (D, D) decreases in size; i.e., $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ are decreasing in α and p (Proposition A.6 and Table A.5, Appendix C.1). In addition, only within the (K_1, K_2) region does the NGO's strategy choice highly depend on the regulatory threat. Specifically, if the increase in threat is due to additional costs (i.e., α increases), then for a wider range of high θ_1 values, the NGO should target the regulatory body and leverage the threat of additional costs due to regulation to induce both firms to replace; i.e., θ_1^* decreases in α (Corollary A.2). This is particularly true if the firms' costs to replace are high (Table A.3, Appendix C.1). If instead, the increase in regulatory threat is due to an increase in the existing probability of regulation (p), then for a wider range of low θ_1 values, the NGO should target the industry; i.e., θ_1^* increases in p (Corollary A.2). This is because the NGO's potential to further increase the likelihood of regulation is limited; i.e., the portion that the NGO can influence, $1 - p$, is small.

As the existing market sensitivity to the substance (q) increases, it becomes easier for the NGO to induce firms to replace and hence, the (D, D) region decreases in size; i.e., $b_L^*(\theta_1)$ decreases in q (Table A.5, Appendix C.1). However, whether the NGO should target a single firm or both firms to replace (i.e., whether $b_U^*(\theta_1)$ is increasing or decreasing in q) depends on the pragmatism of the NGO γ and the size of the regulation penalty α (Table A.6, Appendix C.1). If γ is low, then the size of the (K_1, K_2) region is increasing in q ; i.e., $b_U^*(\theta_1)$ decreases in q . Conversely, if the NGO is more pragmatic, then a high existing market sensitivity implies that the resulting environmental benefit will be high as long

as one firm proactively replaces and gains market share from its competitor. Hence, if the regulation penalty α is high, and thus, it is easier to induce one of the firms to replace, then the pragmatic NGO is less likely to induce (K_1, K_2) and $b_U^*(\theta_1)$ is increasing in q . Finally, we find that in the (K_1, K_2) region, the range of θ_1 values in which the NGO targets the industry shrinks as q increases (i.e., θ_1^* decreases in q), since the value of targeting the industry decreases as q increases; i.e., the portion that the NGO can influence, $1 - q$, is small (Corollary A.2).

5. Extensions to the Base Model

Next, we analyze multiple extensions to our base model by altering our assumptions regarding competition dynamics, the effectiveness of the NGO's effort, and the firms' replacement costs. Our results demonstrate the impact of varying these factors on the NGO's optimal strategy. They also show that the insights discussed in §4 are robust and valid for a number of different scenarios.

We first examine how altering the **competition dynamic** can affect an NGO's strategy when it *targets the industry*. When promoting their agenda, activists often target large, visible firms within an industry (Lenox and Eesley 2009). To capture this effect, we study a scenario where the NGO targets only the large firm and thus, the large firm has to make its replacement decision before the small firm. In this setting, the small firm's potential loss in market share can vary depending on whether there is a spillover effect from the NGO's activism towards the large firm. We model the extent to which the small firm incurs a potential market share loss with the parameter $\delta \in [0, 1]$: $\delta = 0$ indicates that the small firm does not incur any market loss even if it defers and the large firm replaces, whereas $\delta = 1$ indicates that the small firm remains subject to the same potential market loss as in the base model; i.e., it is expected to lose all of its sensitive consumers if it defers replacement.

We model the firm competition as a Stackelberg game (Appendix O.1). Lemma O.1 shows that if the small firm is subject to the same level of market share loss as the large firm when it defers replacement (i.e., $\delta = 1$), then the only difference in the equilibria is that the NGO can induce (K_1, D) with a lower level of effort in the Stackelberg setting than in the base model. Conversely, when the small firm is not subject to market share loss (i.e., $\delta = 0$), targeting the industry is a less effective strategy for the NGO. In particular, (K_1, K_2) does not occur in equilibrium and the NGO needs to exert a higher level of effort than in the base model to induce (D, K_2) or (K_1, D) . These findings suggest that if the NGO's effort towards the large firm also puts the small firm at risk of losing its sensitive consumers, then consumers are better off in the Stackelberg setting as compared to the base model. However, if there is no market risk for the small firm, then consumers are actually worse off as the asymmetric competition between the firms makes it more difficult for the NGO to induce firms to proactively replace.

We next study how allowing the NGO to divide its effort to **target both the industry and the regulatory body** impacts the NGO's strategy. Under this scenario, the NGO's effort affects the market sensitivity *and* the probability of regulation, although the total effort cannot exceed 100% (i.e., $\epsilon_S^I + \epsilon_S^R \leq 1$). We first observe that for the majority of the parameter space, the firm replacement

equilibria that the NGO induces remain unchanged from the base model. Nevertheless, the most significant strategy changes occur when the NGO is less pragmatic and it requires an additional source of pressure to increase the environmental benefit; i.e., when γ and the regulation penalty α are low (Table A.8, Appendix C.2). The less pragmatic NGO is less concerned with the firms' profits and thus, prefers to induce the firms to replace the substance by any means necessary. The changes in strategy occur when the NGO attempts to induce a firm equilibrium that generates a higher percentage of the market receiving a replacement substance. That is, the major equilibrium shifts are from (D, K_2) to (K_1, D) and from (K_1, D) to (K_1, K_2) . Thus, compared to the base model, the thresholds between equilibrium regions (e.g., the boundary between (K_1, D) and (D, K_2) , and $b_U^*(\theta_1)$) shift downward when the NGO can target both the industry and the regulatory body.

Third, we examine the sensitivity of the NGO's optimal strategy with respect to **the effectiveness of its effort** for three aspects. First, the NGO's cost factor c for targeting either party may vary. We observe that when a strategy becomes more costly, the NGO prefers the alternative strategy for a larger parameter region (Table A.9, Appendix C.2). However, our insights in §4 are robust to possible errors in estimating the NGO's cost factor. This is shown by the fact that for 90.7% of the 131 million samples tested, the equilibria do not change, even if the NGO's cost factor for one strategy is double that of the other strategy. Second, the impact of the NGO's effort on the market sensitivity or the probability of regulation may not be 100% effective. We model this by replacing $x(\epsilon)$ with $x_S(\epsilon) = w_S\epsilon$, where $w_S \in (0, 1]$ and $S \in \{I, R\}$. We again find that when a strategy becomes less effective, the NGO prefers the alternative strategy for a larger parameter region (Table A.10, Appendix C.2).

The third aspect regards the varying difficulty of influencing the market sensitivity or the probability of regulation for different substances. For substances where a small amount of effort can have a significant effect, we model the impact of the NGO's effort $x(\epsilon)$ as concave in ϵ . Conversely, for substances that require a large amount of effort to influence consumers or the regulatory body, we model $x(\epsilon)$ as convex in ϵ . We highlight three observations (Tables A.11 and A.12, Appendix C.2). First, when the NGO's effort has a significant impact, the region in which both firms defer (D, D) decreases in size as it becomes easier for the NGO to induce firms to replace. Surprisingly, the region where both firms replace (K_1, K_2) can shrink in size when the NGO is pragmatic. This is because the pragmatic NGO only needs to exert a low effort to significantly increase the market sensitivity, and thus, the environmental benefit when one firm proactively replaces and gains market share from its competitor. Second, the $I(D, K_2)_A$ and $I(K_1, D)_A$ regions also increase in size when the NGO's impact increases. Thus, the easier it is for the NGO to influence consumers or regulation, the more of a concern the regions of potential contention become for the NGO. Finally, when the benefit-to-cost ratio (b/c) is low, the existing market sensitivity (q) is high, and the impact of the NGO's effort is low, targeting the regulatory body is used more often within the $(K_1, D)/(D, K_2)$ region. Since in this case

the NGO's effort has less of an impact on the probability of regulation and thus, the firms' expected costs, a pragmatic NGO is more willing to target the regulatory body to ensure that a firm replaces.

Our next extension examines how **time discounting** can alter the NGO's choice to target the regulatory body. A firm can often realize significant savings by deferring expensive replacement costs. For example, to control costs and to implement on their own timetables, many consumer electronics firms set future target dates by which the implementation of replacements for potentially hazardous substances such as phthalates and BFRs will be complete (Dell Inc. 2012, Samsung Electronics 2012). We model this scenario by setting $\alpha < 1$; i.e., the firms incur a lower replacement cost (in terms of net present value) by deferring than by proactively replacing. We observe that targeting the regulatory body is less effective when $\alpha < 1$ as the NGO can no longer leverage the threat of regulation costs to induce firms to replace (Table A.13, Appendix C.2). Targeting the regulatory body remains effective only when the benefit-to-cost ratio is very low and the NGO expects neither firm to replace in equilibrium; i.e., $R(D, D)$. Our findings suggest that given the sometimes lengthy process to regulate a substance in the U.S., NGOs such as Greenpeace are correct in directly targeting the industry to influence firms such as Samsung to proactively replace a substance (Williams 2010).

Finally, due to resource constraints, there may be cases where **the firms' replacement costs are decreasing in market share**; i.e., the small firm incurs a higher total replacement cost than the large firm. To examine this setting, we model $K(\theta)$ as decreasing in θ (Appendix O.2). We highlight three observations. First, due to its higher replacement cost, the small firm has even less incentive to proactively replace and thus, equilibria $I(D, K_2)$ and $R(D, K_2)$ no longer occur. Instead, the potential firm equilibria are for both firms to replace, only the large firm to replace, or both firms to defer. The placement and structure of these equilibrium regions (with respect to θ_1 and b/c), however, remains consistent with that in the base model (Table O.1, Appendix O.2.1). Second, due to the small firm's high cost to replace, we observe that the (D, K_2) equilibrium region in our base model is primarily replaced by (K_1, D) when the replacement costs are decreasing in market share (Table O.2, Appendix O.2.1). Third, a change in the NGO's optimal strategy occurs between the $R(K_1, K_2)$ and $I(K_1, D)$ regions. In particular, when there exists a dominant firm in the market, since inducing the small firm to proactively replace is too costly, the NGO prefers to induce $I(K_1, D)$ as opposed to $R(K_1, K_2)$ for a larger parameter space than in the base model. Conversely, when the firms are homogeneous in size, the replacement cost for the small firm is much lower, and hence the NGO prefers to induce $R(K_1, K_2)$ rather than $I(K_1, D)$ for a larger parameter space than in the base model. When the small firm faces higher replacement costs than the large firm, the NGO should focus more on ensuring that either the large firm proactively replaces, or if the firms are similar in size, both firms proactively replace.

6. A Firm can Lobby to Counteract an NGO's Activism

A firm may believe that a substance is not harmful and hence, it may direct resources to either fighting potential regulation or campaigning to educate consumers about the substance. For example, when a

nonprofit called The Campaign for Safe Cosmetics lobbied the Colorado state legislator to prohibit the sale of cosmetics containing potentially hazardous substances, industry leaders such as Johnson & Johnson helped defeat the bill by counter-lobbying (Reisch 2010). Similarly, when the safety of BPA was questioned, a group of consumer product companies, including Coca-Cola and Del Monte, devised strategies to change consumer sentiment towards BPA (Kissinger and Rust 2009, Layton 2009). In this section, we analyze the NGO's optimal strategy when the *large firm* can lobby either consumers or the regulatory body to counteract the NGO's activism. We model only the large firm having the option to lobby because often in practice only a large firm or a group of large firms have sufficient resources to alter consumer perception or government regulation (Callahan and Roe 2012). The analysis of this setting is detailed in Appendix O.3, with all numerical results presented in Appendix O.3.2.

To model our lobbying scenario, we update the sequence of events in §3 as follows. After the NGO determines its strategy and effort level, the large firm then decides whether or not to lobby to offset the NGO's activism. If the large firm chooses to lobby, then it must determine its lobbying effort $l \in [0, 1]$, with l only impacting the party that the NGO targets; i.e., consumers or the regulatory body. We assume that its lobbying effort has a linear impact on either the market sensitivity $\xi(\epsilon, l)$ or the probability of regulation $r(\epsilon, l)$. If the NGO targets the industry and the large firm chooses to lobby consumers, then $\xi(\epsilon, l) = q + (1 - q)x(\epsilon)(1 - l)$ and $r(\epsilon, l) = p$. If instead, the NGO targets the regulatory body and the large firm lobbies against regulation, then $r(\epsilon, l) = p + (1 - p)x(\epsilon)(1 - l)$ and $\xi(\epsilon, l) = q$. The large firm incurs lobbying cost $c_L l^2$, where c_L is its lobbying cost factor. After the large firm makes its lobbying choice, the two firms then decide simultaneously whether to immediately replace the substance or to defer replacement. Finally, with probability $r(\epsilon, l)$ regulation occurs.

Our first result shows that the large firm lobbies only when it expects to defer replacement.

PROPOSITION 4. *The large firm's optimal strategy for when to lobby is as follows. In the equilibrium:*

- (a) *Where both firms replace or only the large firm replaces, the large firm does not lobby.*
- (b) *Where only the small firm replaces, the large firm always lobbies.*
- (c) *Where neither firm replaces and the NGO exerts positive effort, the large firm always lobbies.*

In addition, we observe that the regions of potential contention become less of an issue for the NGO when the large firm can lobby. In particular, $I(D, K_2)_A$ disappears (Corollary O.1) and $I(K_1, D)_A$ decreases in size (Appendix O.3.2). Within the latter region, the possibility for the large firm to lobby causes the NGO to reduce its effort just enough such that the large firm does not lobby. Thus, the large firm never lobbies if it expects to replace. Conversely, it always lobbies when the NGO exerts positive effort and it expects to defer replacement; i.e., in regions (D, K_2) and (D, D) .

In general, the ability of the large firm to lobby does not significantly change the NGO's strategy or the resulting firm replacement equilibria (Table O.5, Appendix O.3.2). For example, if the equilibrium in our base model is for the NGO to induce both firms to replace (i.e., (K_1, K_2)), then it remains

the equilibrium in our lobbying scenario. This is because the potential environmental benefit and the market structure needed to compel both firms to replace already exist. Thus, the additional threat of the large firm lobbying does not alter the NGO's strategy and the corresponding effort level (Corollary O.2). In addition, for the majority of the region where the equilibrium in the base model is for only the large firm to replace (i.e., (K_1, D)), the NGO exerts either equal or lower effort in the lobbying scenario to induce the same equilibrium (Proposition O.1).

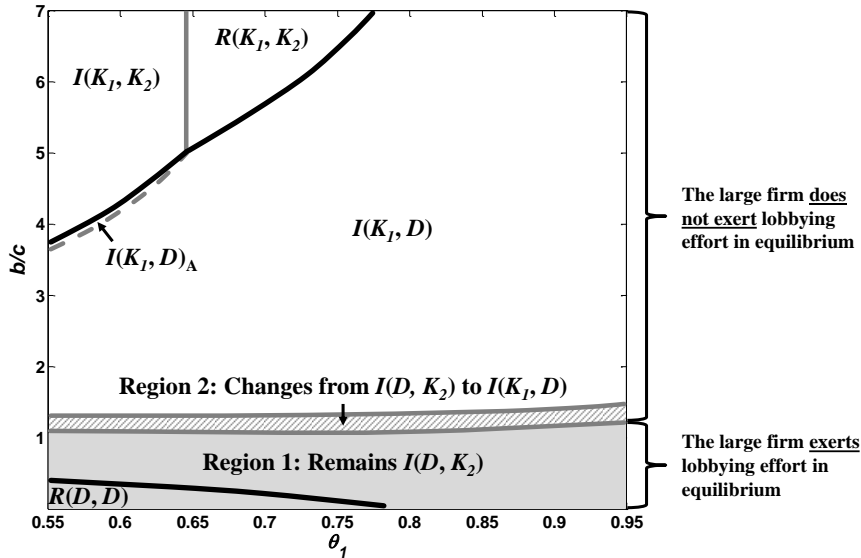


Figure 2 How the Large Firm's Ability to Lobby Impacts the Equilibria Under the NGO's Optimal Strategy

Figure 2 demonstrates how the firms' equilibrium strategies change compared to Figure 1(a) when the large firm can lobby. Comparison to Figure 1(b) is similar and thus omitted. The lobbying cost factor $c_L = 25$; all other parameters are identical to those in Figure 1(a).

Figure 2 shows how the firm replacement equilibria under the NGO's optimal strategy in the lobbying scenario compare to those in the base model. We observe that lobbying has the most impact on the firms' and the NGO's strategies *within the parameter region where the replacement equilibrium is $I(D, K_2)$ in our base model*. In this region, the environmental benefit can actually *increase* since the firm replacement equilibrium can shift from (D, K_2) in our base model to (K_1, D) in our lobbying scenario. First, consider the $I(D, K_2)$ region in our base model when the benefit-to-cost ratio is low (Region 1 in Figure 2). Within this parameter region, if the large firm can lobby, then it exerts a significant amount of effort to influence consumers and to prove the substance is not harmful. Given that the benefit-to-cost ratio is low, the NGO cannot easily increase the market sensitivity to the substance and thus, it decreases its effort level. The resulting replacement equilibrium in the lobbying scenario remains for the small firm to proactively replace the substance; i.e., $I(D, K_2)$. If instead, the benefit-to-cost ratio is higher (Region 2), then the NGO incrementally increases its effort (compared to our base model) in response to the possibility that the large firm lobbies. This increase in effort increases the market sensitivity and thus, the need for the large firm to address the market risks associated with the substance. Instead of lobbying, the large firm directs its resources to proactively replace the substance to avoid a significant potential loss in market share; i.e., the equilibrium shifts

from $I(D, K_2)$ to $I(K_1, D)$. Thus, by having the ability to lobby, the large firm inadvertently increases the NGO's activism, which in turn forces the large firm to proactively replace the substance.

The large firm exerts lobbying effort only when the marginal environmental benefit from having a replacement is low and thus, the large firm expects to defer replacement in equilibrium. For this case, the large firm lobbies and successfully reduces the NGO's effort. In contrast, when the marginal environmental benefit from replacement is high, the ability to lobby can adversely impact the large firm as the NGO maintains and may even increase its effort to force the large firm to replace. Although a firm lobbying consumers or the regulatory body can be costly for the NGO, it does not necessarily reduce the environmental benefit. When the benefit-to-cost ratio is high, the NGO can still induce either both firms or at least the large firm to proactively replace the substance.

7. Managerial Insights and Conclusion

Potentially hazardous substances are a major concern for both consumers and corporations. Today, we are still unsure of the health and environmental impacts for an alarming number of chemicals and substances in commercial use. The EU recognizes this problem and has taken measures with the advent of regulation such as REACH. In the U.S., even as public awareness of and sensitivity to environmental hazards increase, proper regulations for monitoring and controlling potentially hazardous substances are still not in place. As Dr. Richard Denison, Senior Scientist at the Environmental Defense Fund noted, "by failing to identify, let alone control, the long and growing list of chemicals in everyday products that we now know can harm people and the environment, [the U.S. Toxic Substances and Control Act] has forced states, businesses, workers and consumers to try to act on their own to address what should be a national priority" (Safer Chemicals Healthy Families 2010). Due to this lack of regulatory guidance, an opportunity exists for NGOs to play an influential role in setting regulatory standards and changing firms' substance management policies. In this paper, we study how an NGO can influence firms to replace a potentially hazardous substance from their products. Our analysis yields valuable insights that can guide NGOs as they make their strategic decisions.

First, we find that **an NGO's optimal strategy to compel firms to replace a potentially hazardous substance depends heavily on the pragmatism of the NGO**. If the NGO does not significantly include firms' profits in its decision making, then the NGO's goal is solely to maximize the number of consumers receiving a replacement. Hence, the NGO's optimal strategy is often to exert enough effort such that all firms or at least a dominant firm proactively replaces the substance (see Figure 1(b)). Whether it should target the industry or the regulatory body is driven by the market structure. When the market is either very homogeneous or dominated by a large firm, the NGO should target the industry and increase the market sensitivity to the substance. By targeting the industry, the NGO can either leverage the competition between similar-sized firms to induce all firms to replace, or leverage the risk of a significant market share loss to compel a dominant firm to replace. Conversely, when firms are heterogeneous in size but there is not a dominant firm in the market, the NGO should

utilize the threat of regulation and additional replacement costs to induce all firms to replace. If targeting a single party is not sufficient and the NGO needs additional force to achieve its desired environmental benefit, then a less pragmatic NGO may benefit from dividing its effort to target both the industry and the regulatory body.

As the NGO becomes more pragmatic, it increasingly incorporates the firms' well-being into its decision making. Thus, a pragmatic NGO's optimal strategy is not always to maximize the number of consumers receiving a replacement. Instead, for a wide range of benefit-to-cost ratios and market structures, the NGO should target the industry to induce only large firms or only small firms to replace (see Figure 1(a)). This is particularly true for substances in which a small amount of effort by the NGO can significantly increase the market sensitivity or the probability of regulation. Only if the firms are homogeneous in size and the environmental benefit from replacing a substance is very low or very high should the NGO consider targeting the regulatory body. By not forcing the entire industry to replace, a pragmatic NGO manages to limit total firm replacement costs while ensuring that a replacement is available to sensitive consumers.

However, **a pragmatic NGO must carefully weigh the tradeoff between limiting total firm replacement costs and maximizing the environmental benefit.** In attempting to appease both consumers and firms, an NGO can create precarious decisions for itself. This is especially true when either (i) the environmental benefit from replacement is high and the market is homogeneous, or (ii) the environmental benefit is lower and the market consists of a dominant firm. We define these parameter regions as regions of potential contention. Here, the pragmatic NGO faces a difficult tradeoff of whether to increase the environmental benefit or to mitigate the firms' costs. The critical question the NGO must address is, to what extent it should ensure that a replacement is available to sensitive consumers. For example, if the environmental benefit from replacement is high and the market is homogeneous in size, then the NGO's optimal strategy in the region of potential contention is to target large firms to proactively replace. This strategy increases the environmental benefit while lowering small firms' costs. However, *for the same amount of effort*, the NGO could influence all firms to replace and increase the number of consumers receiving a replacement. By not pushing for the full replacement of a substance in the market, the NGO risks the safety of consumers and thus may damage its credibility.

Finally, we show that although a large firm's ability to lobby either consumers or the regulatory body often impedes an NGO's effort, it does not necessarily reduce the expected environmental benefit. Instead, **consumers can benefit from the lobbying competition between an NGO and a large firm.** When the environmental benefit from replacement is high, the NGO does not alter its optimal strategy and the firm does not lobby. Only when the environmental benefit from replacement is lower can lobbying by a firm influence an NGO's strategy. In this scenario, a large firm's threat to lobby can entice the NGO to increase the market sensitivity to the substance and thus, benefit consumers by forcing the firm to replace (see Figure 2). For example, the Environmental Working Group (EWG)

became incensed when it learned that Coca-Cola and Del Monte developed a public relations campaign to promote the safety of BPA. In response, EWG increased its effort to raise consumer awareness and force the firms to remove BPA from their products (Environmental Working Group 2009).

In this paper, we develop a stylized model which can be extended to study a broad range of scenarios. A few key assumptions deserve more discussion. First, to capture the competition between firms without over-complicating our model, we study a two-firm market. Our findings, however, can be interpreted in the context of multiple firms. For example, the dominant-firm market structure can represent either a multi-firm market setting with a single dominant firm or one in which a group of large firms take collective actions. Second, we implicitly capture donor influence in the environmental benefit component of the NGO's objective function. This component should be positively correlated with the amount of donations that the NGO may receive. We prefer to keep a parsimonious model regarding donor influence due to our focus on the interaction between the NGO and the firms. However, we acknowledge that environmental benefit and donor satisfaction may have different weights in affecting an NGO's action and that studying how donations impact an NGO's decisions is an important problem that is gaining attention in both the strategy and operations management literature. Finally, we assume that firms do not exit the market. While replacing a substance can be costly, firms do not exit a market if the product containing the substance is important.

There are a few aspects of our model which would benefit from further analysis. First, many industries are working together to reduce and eliminate the risk of potentially hazardous substances. As Nardono Nimpuno, Senior Policy Advisor at ChemSec, noted, "collaboration is increasing between downstream users as well as across the tiers of the supply chain" (Nimpuno 2011). Analyzing a scenario in which firms can take collective actions would generate valuable insights for integrated industries. Second, the quality of a replacement substance may vary and it may impact consumer demand. Analyzing the firms' quality decisions in conjunction with their replacement strategies could provide further insights into how competition affects the NGO's decisions. Finally, there are two potential forms of asymmetric information in our setting. First, due to the complex process required to replace a substance, an NGO may not know the firms' true replacement costs. Second, within the chemicals industry, upstream chemical manufacturers may be more familiar with the regulatory outlook for a substance than either NGOs or downstream manufacturers. Modeling either scenario would be beneficial.

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Appendix A: Equilibria

In this section, we discuss the detailed analysis regarding the NGO's optimal effort level and the firms' equilibrium replacement strategies under our base model for two scenarios: (I) the NGO targets only the industry, and (II) the NGO targets only the regulatory body. In each scenario, we solve for the subgame perfect Nash equilibrium $(\epsilon^*, s_1^*(\epsilon), s_2^*(\epsilon))$ defined as follows.

DEFINITION 1. *The strategy profile $(\epsilon^*, s_1^*(\epsilon), s_2^*(\epsilon))$ constitutes a subgame perfect Nash equilibrium (SPNE) if it satisfies: (a) For all $i \in \{1, 2\}$, $\epsilon \in [0, 1]$, and given firm $-i$'s strategy $s_{-i}^*(\epsilon)$, $s_i^*(\epsilon) \in \arg \max_{s_i \in \{K(\theta_i), D\}} \Pi_i(s_i, s_{-i}^*(\epsilon))$, where $\Pi_i(\cdot, \cdot)$ is firm i 's payoff function given the two firms' replacement strategies; and (b) $\epsilon^* \in \arg \max_{\epsilon \in [0, 1]} \pi_{NGO}(\epsilon, s_1^*(\epsilon), s_2^*(\epsilon))$, where $\pi_{NGO}(\cdot, \cdot, \cdot)$ is the NGO's payoff function given its effort level and the resulting replacement strategies by the two firms.*

Next, we analyze the SPNE in Scenarios (I) and (II). In each scenario, we first derive the firms' equilibrium replacement strategies and then determine the NGO's optimal effort level. We assume that the NGO's effort has a linear impact on $\xi(\epsilon)$ and $r(\epsilon)$; i.e., $x(\epsilon) = \epsilon$.

A.1. Scenario (I): The NGO Targets Only the Industry

For this scenario, we define $\xi(\epsilon) = q + (1 - q)\epsilon$ and $r(\epsilon) = p$ in Table 2. We first analyze firm 1's best response given firm 2's strategy. Note that we break the indifference point in favor of K_1 . We follow the same convention for firm 2. Given that $s_2 = K_2$, firm 1's best response is $s_1 = K_1$ if $\epsilon \geq (K_1(1 - \alpha p) - M\theta_1 q)/(M\theta_1(1 - q))$, and $s_1 = D$ otherwise. Given that $s_2 = D$, firm 1's best response is $s_1 = K_1$ if $\epsilon \geq (K_1(1 - \alpha p) - Mq)/(M(1 - q))$, and $s_1 = D$ otherwise. Similarly, given that $s_1 = K_1$, firm 2's best response is $s_2 = K_2$ if $\epsilon \geq (K_2(1 - \alpha p) - M\theta_2 q)/(M\theta_2(1 - q))$, and $s_2 = D$ otherwise. Given that $s_1 = D$, firm 2's best response is $s_2 = K_2$ if $\epsilon \geq (K_2(1 - \alpha p) - Mq)/(M(1 - q))$, and $s_2 = D$ otherwise. Since $\theta_1 \in [1/2, 1]$, $\theta_1 \geq \theta_2$, and $K(\theta)$ is concave and increasing in θ , we know that $K_2/\theta_2 \geq K_1/\theta_1 \geq K_1 \geq K_2$. Thus, the firms' equilibrium replacement strategies given NGO effort level ϵ are

$$(s_1^*(\epsilon), s_2^*(\epsilon)) = \begin{cases} (D, D) & \text{if } \epsilon \in \left[0, \frac{K_2(1-\alpha p) - Mq}{M(1-q)}\right), \\ (D, K_2) & \text{if } \epsilon \in \left[\frac{K_2(1-\alpha p) - Mq}{M(1-q)}, \frac{K_1(1-\alpha p) - M\theta_1 q}{M\theta_1(1-q)}\right), \\ (K_1, D) & \text{if } \epsilon \in \left[\frac{K_1(1-\alpha p) - Mq}{M(1-q)}, \frac{K_2(1-\alpha p) - M\theta_2 q}{M\theta_2(1-q)}\right), \\ (K_1, K_2) & \text{if } \epsilon \in \left[\frac{K_2(1-\alpha p) - M\theta_2 q}{M\theta_2(1-q)}, 1\right]. \end{cases} \quad (4)$$

Note that for all four firm equilibria to possibly arise, we need $(K_2(1 - \alpha p) - Mq)/(M(1 - q)) > 0$ and $(K_2(1 - \alpha p) - M\theta_2 q)/(M\theta_2(1 - q)) < 1$. These conditions are equivalent to $Mq < K_2(1 - \alpha p) < M\theta_2$. To focus on the most interesting scenario where all four cases can occur in equilibrium, we will assume in the subsequent analysis that this condition holds.

We also note from Equation (4) that, when $\epsilon \in [(K_1(1 - \alpha p) - Mq)/(M(1 - q)), (K_1(1 - \alpha p) - M\theta_1 q)/(M\theta_1(1 - q))]$, both (D, K_2) and (K_1, D) can arise as the firms' equilibrium replacement strategies. To resolve the issue of multiple equilibria, we follow the refinement concept of risk dominance developed by Harsanyi and Selten (see, e.g., Harsanyi and Selten 1988, Harsanyi 1995) to find the condition under which one of the two equilibria is selected. For (K_1, D) to risk dominate (D, K_2) , the collective loss of deviating from (K_1, D) must be higher than the collective loss of deviating from (D, K_2) . Mathematically, this is given by $(\Pi_1(K_1, D) - \Pi_1(D, D))(\Pi_2(K_1, D) - \Pi_2(K_1, K_2)) \geq (\Pi_1(D, K_2) - \Pi_1(K_1, K_2))(\Pi_2(D, K_2) - \Pi_2(D, D))$. Simplifying this inequality, we have (K_1, D) risk dominates (D, K_2) if $\epsilon \geq [(K_1\theta_1 - K_2\theta_2)(1 - \alpha p) - M(\theta_1 - \theta_2)q]/[M(\theta_1 - \theta_2)(1 - q)]$. We next show that $K_1 < (K_1\theta_1 - K_2\theta_2)/(\theta_1 - \theta_2) < K_1/\theta_1$ if $K(\theta)$ is concave and increasing in θ . When $\theta_1 > \theta_2$, the inequality holds because $K_1 > K_2$ and $K_2/\theta_2 > K_1/\theta_1$. When $\theta_1 = \theta_2 = 1/2$, we have $\lim_{\theta \rightarrow 1/2} [K(\theta)\theta - K(1 - \theta)(1 - \theta)]/[\theta - (1 - \theta)] = K(1/2) + K'(1/2)/2$ by L'Hôpital's rule. Since $K(\theta)$ is increasing, $K(1/2) + K'(1/2)/2 > K(1/2)$. Since $K(\theta)$ is concave, $K(0) < K(1/2) + K'(1/2)(0 - 1/2)$, i.e., $K'(1/2)/2 < K(1/2)$ with $K(0) = 0$. Thus, $K(1/2) + K'(1/2)/2 < 2K(1/2)$ and the strict inequality remains.

Thus, the firms' equilibrium replacement strategies under the refinement of risk dominance are

$$(s_1^*(\epsilon), s_2^*(\epsilon)) = \begin{cases} (D, D) & \text{if } \epsilon \in \left[0, \frac{K_2(1-\alpha p) - Mq}{M(1-q)}\right), \\ (D, K_2) & \text{if } \epsilon \in \left[\frac{K_2(1-\alpha p) - Mq}{M(1-q)}, \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1-q)}\right), \\ (K_1, D) & \text{if } \epsilon \in \left[\frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1-q)}, \frac{K_2(1-\alpha p) - M\theta_2 q}{M\theta_2(1-q)}\right), \\ (K_1, K_2) & \text{if } \epsilon \in \left[\frac{K_2(1-\alpha p) - M\theta_2 q}{M\theta_2(1-q)}, 1\right]. \end{cases} \quad (5)$$

To derive the NGO's optimal effort level which maximizes its payoff, we consider four cases in Equation (5). In Case (D, D) , the NGO's payoff function is given by $\pi_{NGO}(\epsilon) = bp(1 - q)(1 - \epsilon) + \gamma[M(1 - q)(1 - \epsilon) - \alpha p(K_1 + K_2)] - c\epsilon^2$. Therefore, the NGO's optimal effort level in Case (D, D) is $\epsilon_{D,D}^I = 0$, where the superscript denotes the case of the NGO targeting the Industry, and the subscript denotes the corresponding firm replacement equilibrium. Now consider Case (D, K_2) . The NGO's payoff function is given by $\pi_{NGO}(\epsilon) = b[(1 - p)((q + (1 - q)\epsilon)\theta_1 + \theta_2) + p] + \gamma[M - \alpha pK_1 - K_2] - c\epsilon^2$. Note that $d\pi_{NGO}(\epsilon)/d\epsilon = b(1 - p)(1 - q)\theta_1 - 2c\epsilon$ and $d^2\pi_{NGO}(\epsilon)/d\epsilon^2 = -2c < 0$. Hence, $\pi_{NGO}(\epsilon)$ is strictly concave in ϵ in Case (D, K_2) , and the optimal effort level ϵ_{D,K_2}^I is achieved at either the solution to the first-order condition or the boundaries:

$$\epsilon_{D,K_2}^I = \begin{cases} \frac{K_2(1-\alpha p) - Mq}{M(1-q)} & \text{if } \frac{b(1-p)(1-q)\theta_1}{2c} < \frac{K_2(1-\alpha p) - Mq}{M(1-q)}, \\ \frac{b(1-p)(1-q)\theta_1}{2c} & \text{if } \frac{K_2(1-\alpha p) - Mq}{M(1-q)} \leq \frac{b(1-p)(1-q)\theta_1}{2c} < \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1-q)}, \\ \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1-q)} & \text{if } \frac{b(1-p)(1-q)\theta_1}{2c} \geq \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1-q)}. \end{cases} \quad (6)$$

Hereafter, we denote the lower-boundary solution as $\epsilon_{D,K_2}^{I_B}$ and the upper-boundary solution as $\epsilon_{D,K_2}^{I_A}$. In addition, we slightly abuse the notation by using ϵ_{D,K_2}^I to denote only the interior solution.

Formally speaking, $\epsilon_{D,K_2}^{I_A}$ should be equal to $[(K_1\theta_1 - K_2\theta_2)(1 - \alpha p) - M(\theta_1 - \theta_2)q] / [M(\theta_1 - \theta_2)(1 - q)]$ minus an infinitesimal number since the value of ϵ falls in an interval that is open on the right (see the second line of Equation (5)). We report it as the boundary value to avoid unnecessary complexity in our notation. We use $I(D, K_2)_A$ to denote the $I(D, K_2)$ equilibrium achieved at the upper-boundary solution. This equilibrium is based on the ε -equilibrium concept, which is a slight relaxation of Nash equilibrium. One can verify that an SPNE exists if we adopt mixed strategies at the boundary between $I(D, K_2)$ and $I(K_1, D)$ rather than breaking the tie in favor of $I(K_1, D)$. However, we prefer to use ε -equilibria to focus on pure strategies because mixed strategies are often difficult to interpret. The use of ε -equilibria is common in the literature; see, e.g., Mailath et al. (2005) and Radner (1980).

Next consider Case (K_1, D) . The NGO's payoff function is given by $\pi_{NGO}(\epsilon) = b[(1 - p)(\theta_1 + (q + (1 - q)\epsilon)\theta_2) + p] + \gamma[M - K_1 - \alpha p K_2] - c\epsilon^2$. Note that $d\pi_{NGO}(\epsilon)/d\epsilon = b(1 - p)(1 - q)\theta_2 - 2c\epsilon$ and $d^2\pi_{NGO}(\epsilon)/d\epsilon^2 = -2c < 0$. Hence, $\pi_{NGO}(\epsilon)$ is strictly concave in ϵ in Case (K_1, D) , and the optimal effort level $\epsilon_{K_1,D}^I$ is achieved at either the solution to the first-order condition or the boundaries:

$$\epsilon_{K_1,D}^I = \begin{cases} \frac{(K_1\theta_1 - K_2\theta_2)(1 - \alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1 - q)} & \text{if } \frac{b(1-p)(1-q)\theta_2}{2c} < \frac{(K_1\theta_1 - K_2\theta_2)(1 - \alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1 - q)}, \\ \frac{b(1-p)(1-q)\theta_2}{2c} & \text{if } \frac{(K_1\theta_1 - K_2\theta_2)(1 - \alpha p) - M(\theta_1 - \theta_2)q}{M(\theta_1 - \theta_2)(1 - q)} \leq \frac{b(1-p)(1-q)\theta_2}{2c} < \frac{K_2(1 - \alpha p) - M\theta_2 q}{M\theta_2(1 - q)}, \\ \frac{K_2(1 - \alpha p) - M\theta_2 q}{M\theta_2(1 - q)} & \text{if } \frac{b(1-p)(1-q)\theta_2}{2c} \geq \frac{K_2(1 - \alpha p) - M\theta_2 q}{M\theta_2(1 - q)}. \end{cases} \quad (7)$$

Hereafter, we denote the lower-boundary solution as $\epsilon_{K_1,D}^{I_B}$ and the upper-boundary solution as $\epsilon_{K_1,D}^{I_A}$. In addition, we slightly abuse the notation by using $\epsilon_{K_1,D}^I$ to denote only the interior solution. Similarly, the $I(K_1, D)_A$ equilibrium follows the ε -equilibrium concept. We highlight $I(K_1, D)_A$ and $I(D, K_2)_A$ in Figure 1(a) as they represent the regions of potential contention for the NGO.

Finally, consider Case (K_1, K_2) . The NGO's payoff function is given by $\pi_{NGO}(\epsilon) = b + \gamma(M - K_1 - K_2) - c\epsilon^2$. Hence, the NGO's optimal effort level in Case (K_1, K_2) is $\epsilon_{K_1,K_2}^I = (K_2(1 - \alpha p) - M\theta_2 q) / (M\theta_2(1 - q))$. To eventually derive the SPNE for this scenario, we shall compare the NGO's payoff under its optimal effort level in the above four cases and analyze the conditions under which each case arises in equilibrium. We omit the detailed algebra and conditions here. Instead, we summarize the following lemmas regarding conditions that exclude certain cases in the comparison.

LEMMA A.1. *If the firm equilibrium $I(K_1, D)$ is achieved at either the interior or the upper-boundary solution, then $I(D, K_2)$ must be achieved at the upper-boundary solution.*

LEMMA A.2. *If $\gamma = 0$, then (a) $I(D, K_2)_A$ is dominated by $I(K_1, D)_B$, and (b) $I(K_1, D)_A$ is dominated by $I(K_1, K_2)$.*

A.2. Scenario (II): The NGO Targets Only the Regulatory Body

For this scenario, we define $r(\epsilon) = p + (1 - p)\epsilon$ and $\xi(\epsilon) = q$ in Table 2. With a similar equilibrium analysis as in §A.1 and using the refinement concept of risk dominance, we can obtain that the firms' equilibrium replacement strategies given NGO effort level ϵ are

$$(s_1^*(\epsilon), s_2^*(\epsilon)) = \begin{cases} (D, D) & \text{if } \epsilon \in \left[0, \frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)}\right), \\ (D, K_2) & \text{if } \epsilon \in \left[\frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)}, \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(K_1\theta_1 - K_2\theta_2)(1-p)}\right), \\ (K_1, D) & \text{if } \epsilon \in \left[\frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(K_1\theta_1 - K_2\theta_2)(1-p)}, \frac{K_2(1-\alpha p) - M\theta_2 q}{\alpha K_2(1-p)}\right), \\ (K_1, K_2) & \text{if } \epsilon \in \left[\frac{K_2(1-\alpha p) - M\theta_2 q}{\alpha K_2(1-p)}, 1\right]. \end{cases} \quad (8)$$

Note that for all four firm equilibria to possibly arise, we need $(K_2(1 - \alpha p) - Mq)/(\alpha K_2(1 - p)) > 0$ and $(K_2(1 - \alpha p) - M\theta_2 q)/(\alpha K_2(1 - p)) < 1$. Given assumptions $Mq < K_2(1 - \alpha p) < M\theta_2$ in §A.1 and $\alpha \geq 1$, the two conditions hold. Thus, we again focus on the most interesting scenario where the above four cases can occur in equilibrium.

To derive the NGO's optimal effort level which maximizes its payoff, we consider four cases in Equation (8). Case (D, D) : The NGO's payoff function is given by $\pi_{NGO}(\epsilon) = b(p + (1 - p)\epsilon)(1 - q) + \gamma[M(1 - q) - \alpha(p + (1 - p)\epsilon)(K_1 + K_2)] - c\epsilon^2$. Note that $d\pi_{NGO}(\epsilon)/d\epsilon = b(1 - p)(1 - q) - \gamma\alpha(1 - p)(K_1 + K_2) - 2c\epsilon$ and $d^2\pi_{NGO}(\epsilon)/d\epsilon^2 = -2c < 0$. Hence, $\pi_{NGO}(\epsilon)$ is strictly concave in ϵ in Case (D, D) , and the optimal effort level $\epsilon_{D,D}^R$ is achieved at either the solution to the first-order condition or the boundaries (the superscript denotes the case of the NGO targeting the Regulation):

$$\epsilon_{D,D}^R = \begin{cases} \max\left\{0, \frac{b(1-p)(1-q) - \gamma\alpha(1-p)(K_1 + K_2)}{2c}\right\} & \text{if } \frac{b(1-p)(1-q) - \gamma\alpha(1-p)(K_1 + K_2)}{2c} < \frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)}, \\ \frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)} & \text{if } \frac{b(1-p)(1-q) - \gamma\alpha(1-p)(K_1 + K_2)}{2c} \geq \frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)}. \end{cases} \quad (9)$$

Hereafter, we use $\epsilon_{D,D}^{RA}$ to denote the upper-boundary solution.

Case (D, K_2) : The NGO's payoff function is given by $\pi_{NGO}(\epsilon) = b[p + (1 - p)\epsilon + (1 - p)(1 - \epsilon)(q\theta_1 + \theta_2)] + \gamma[M - \alpha(p + (1 - p)\epsilon)K_1 - K_2] - c\epsilon^2$. Note that $d\pi_{NGO}(\epsilon)/d\epsilon = b(1 - p)(1 - q)\theta_1 - \gamma\alpha(1 - p)K_1 - 2c\epsilon$ and $d^2\pi_{NGO}(\epsilon)/d\epsilon^2 = -2c < 0$. Thus, $\pi_{NGO}(\epsilon)$ is strictly concave in ϵ in Case (D, K_2) , and the optimal effort level ϵ_{D,K_2}^R is achieved at either the solution to the first-order condition or the boundaries:

$$\epsilon_{D,K_2}^R = \begin{cases} \frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)} & \text{if } \frac{b(1-p)(1-q)\theta_1 - \gamma\alpha(1-p)K_1}{2c} < \frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)}, \\ \frac{b(1-p)(1-q)\theta_1 - \gamma\alpha(1-p)K_1}{2c} & \text{if } \frac{K_2(1-\alpha p) - Mq}{\alpha K_2(1-p)} \leq \frac{b(1-p)(1-q)\theta_1 - \gamma\alpha(1-p)K_1}{2c} < \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(1-p)(K_1\theta_1 - K_2\theta_2)}, \\ \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(1-p)(K_1\theta_1 - K_2\theta_2)} & \text{if } \frac{b(1-p)(1-q)\theta_1 - \gamma\alpha(1-p)K_1}{2c} \geq \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(1-p)(K_1\theta_1 - K_2\theta_2)}. \end{cases} \quad (10)$$

Hereafter, we denote the lower-boundary solution as ϵ_{D,K_2}^{RB} and the upper-boundary solution as ϵ_{D,K_2}^{RA} .

In addition, we slightly abuse the notation by using ϵ_{D,K_2}^R to denote only the interior solution.

Case (K_1, D) : The NGO's payoff function is given by $\pi_{NGO}(\epsilon) = b[p + (1 - p)\epsilon + (1 - p)(1 - \epsilon)(\theta_1 + q\theta_2)] + \gamma[M - K_1 - \alpha(p + (1 - p)\epsilon)K_2] - c\epsilon^2$. Note that $d\pi_{NGO}(\epsilon)/d\epsilon = b(1 - p)(1 - q)\theta_2 - \gamma\alpha(1 - p)K_2 -$

$2c\epsilon$ and $d^2\pi_{NGO}(\epsilon)/d\epsilon^2 = -2c < 0$. Hence, $\pi_{NGO}(\epsilon)$ is strictly concave in ϵ in Case (K_1, D) , and the optimal effort level $\epsilon_{K_1, D}^R$ is achieved at either the solution to the first-order condition or the boundaries:

$$\epsilon_{K_1, D}^R = \begin{cases} \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(1-p)(K_1\theta_1 - K_2\theta_2)} & \text{if } \frac{b(1-p)(1-q)\theta_2 - \gamma\alpha(1-p)K_2}{2c} < \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(1-p)(K_1\theta_1 - K_2\theta_2)}, \\ \frac{b(1-p)(1-q)\theta_2 - \gamma\alpha(1-p)K_2}{2c} & \text{if } \frac{(K_1\theta_1 - K_2\theta_2)(1-\alpha p) - M(\theta_1 - \theta_2)q}{\alpha(1-p)(K_1\theta_1 - K_2\theta_2)} \leq \frac{b(1-p)(1-q)\theta_2 - \gamma\alpha(1-p)K_2}{2c} < \frac{K_2(1-\alpha p) - M\theta_2 q}{\alpha K_2(1-p)}, \\ \frac{K_2(1-\alpha p) - M\theta_2 q}{\alpha K_2(1-p)} & \text{if } \frac{b(1-p)(1-q)\theta_2 - \gamma\alpha(1-p)K_2}{2c} \geq \frac{K_2(1-\alpha p) - M\theta_2 q}{\alpha K_2(1-p)}. \end{cases} \quad (11)$$

Hereafter, we denote the lower-boundary solution as $\epsilon_{K_1, D}^{R_B}$ and the upper-boundary solution as $\epsilon_{K_1, D}^{R_A}$. In addition, we slightly abuse the notation by using $\epsilon_{K_1, D}^R$ to denote only the interior solution.

Case (K_1, K_2) : The NGO's payoff function is given by $\pi_{NGO}(\epsilon) = b + \gamma(M - K_1 - K_2) - c\epsilon^2$. Hence, the NGO's optimal effort level in Case (K_1, K_2) is $\epsilon_{K_1, K_2}^R = (K_2(1 - \alpha p) - M\theta_2 q) / (\alpha K_2(1 - p))$.

To derive the SPNE for this scenario, we shall compare the NGO's payoff under its optimal effort level in the above four cases and analyze the conditions under which each case arises in equilibrium. We omit the detailed algebra and conditions here. Instead, we summarize the following lemma regarding the exclusion of certain cases in the comparison.

- LEMMA A.3. (a) $R(D, D)_A$ is dominated by $R(D, K_2)_B$.
 (b) $R(D, K_2)_A$ is dominated by $R(K_1, D)_B$.
 (c) $R(K_1, D)_A$ is dominated by $R(K_1, K_2)$.
 (d) If $R(K_1, D)$ is achieved at the interior solution, then $R(D, K_2)$ is dominated.

Appendix B: Summary of Additional Theoretical Results

LEMMA A.4. If $\alpha p K_2 + M\theta_2 q \geq K_2$, then, regardless of whether the NGO targets the industry or the regulatory body, the NGO's optimal effort level is $\epsilon = 0$ and both firms replace in equilibrium.

PROPOSITION A.1. Given the NGO's targeting strategy N where $N \in \{I, R\}$, there exists a unique threshold $b_M^N(\theta_1)$ such that (K_1, D) is induced if $b \geq b_M^N(\theta_1)$ and (D, K_2) is induced if $b < b_M^N(\theta_1)$.

PROPOSITION A.2. $b_L^*(\theta_1)$ is increasing in γ if $\frac{K_2}{K_1 + K_2} \epsilon_{D, K_2}^{R_B} > \epsilon_{D, D}^R$, where $\epsilon_{D, K_2}^{R_B}$ is the NGO's optimal effort level when the $R(D, K_2)$ equilibrium is achieved at the lower-boundary solution.

PROPOSITION A.3. When $I(K_1, D)$ is achieved at the interior solution, it dominates $R(K_1, D)$ and $R(K_1, D)_B$, where the subscript B indicates the equilibrium is achieved at the lower-boundary solution. Similarly, when $I(D, K_2)$ is achieved at the interior solution, it dominates $R(D, K_2)$ and $R(D, K_2)_B$.

PROPOSITION A.4. When $K(\theta) = k\theta^a$ with $a \in (0, 1)$ or $K(\theta) = k - k \exp\{-\beta\theta\}$ with $\beta \in (0, 2]$, $I(D, K_2)_A$ occurs for large values of θ_1 .

PROPOSITION A.5. $I(K_1, D)_A$ occurs for small values of θ_1 . As b increases, the largest value of θ_1 at which $I(K_1, D)_A$ occurs is higher.

Within the $I(K_1, D)_A$ region, if the NGO's optimal strategy to induce (K_1, K_2) is to target regulation, then for a lower effort level the NGO could induce both firms to replace by targeting regulation.

COROLLARY A.1. If (K_1, K_2) is achieved by targeting the regulatory body, then $\epsilon_{K_1, K_2}^R < \epsilon_{K_1, K_2}^I$. Thus, for regions in which $\pi_{K_1, D}^I > \pi_{K_1, K_2}^R \geq \pi_{K_1, K_2}^I$, we have $\epsilon_{K_1, K_2}^R < \epsilon_{K_1, K_2}^I = \epsilon_{K_1, D}^I$.

PROPOSITION A.6. $b_U^*(\theta_1)$ is decreasing in α and increasing in γ .

COROLLARY A.2. θ_1^* is decreasing in α and q , and increasing in p .

Appendix C: Numerical Analysis

Next, we present the results of the numerical analysis for §4 and §5. We eliminate cases in which $K_2 \leq \alpha p K_2 + M \theta_2 q$ in our analysis.

C.1. Should the NGO Target the Industry or the Regulatory Body?

Summary of the NGO's Strategy: As shown in the last row of Table A.3, the NGO targets the industry in 64.0% of all cases tested and the regulatory body in the remaining 36.0%. The NGO's choice of which party to target is mostly influenced by the firms' replacement costs and the regulation penalty. This is especially true within the (K_1, K_2) region. For example, when the firms' replacement costs and the regulation penalty are high (see row $\alpha \geq 2$ in the middle panel of Table A.3), within the (K_1, K_2) region the NGO's preferred strategy is to target the regulatory body and leverage the threat of additional costs to induce $R(K_1, K_2)$. We observe that in this case, $R(K_1, K_2)$ occurs in 45.9% of all cases tested whereas $I(K_1, K_2)$ only occurs in 0.2% of all cases. Conversely, when the firms' replacement costs and the regulation penalty are low (see row $1 \leq \alpha < 2$ in the top panel of Table A.3), the NGO's preferred strategy is to target the industry and utilize the competition between firms to induce $I(K_1, K_2)$. We observe that, $R(K_1, K_2)$ only occurs in 9.9% of all cases tested whereas $I(K_1, K_2)$ occurs in 50.9% of all cases. The additional analysis with $k \in \{75, 150\}$ was performed to highlight the impacts of the replacement costs and the regulation penalty on the NGO's strategy.

Table A.3 NGO Strategy by Replacement Cost and Regulation Penalty

Low Replacement Cost: $k \in \{75, 150\}$										
α	$I(D, K_2)$	$I(K_1, D)$	$I(K_1, K_2)$	I Total	$R(D, D)$	$R(D, K_2)$	$R(K_1, D)$	$R(K_1, K_2)$	R Total	Total
$1 \leq \alpha < 2$	294,180 2.8%	3,612,756 34.0%	5,408,800 50.9%	9,315,736 87.6%	133,475 1.3%	2,033 0.0%	123,884 1.2%	1,056,906 9.9%	1,316,298 12.4%	10,632,034 100.0%
$\alpha \geq 2$	188,325 2.3%	1,863,871 23.4%	2,075,680 26.1%	4,122,876 51.7%	84,095 1.1%	1,236 0.0%	24,336 0.3%	3,735,470 46.9%	3,845,137 48.3%	7,968,013 100.0%
Total	477,505 2.6%	5,476,627 29.4%	7,484,480 40.2%	13,438,612 72.3%	217,570 1.2%	3,269 0.0%	148,220 0.8%	4,792,376 25.8%	5,161,435 27.7%	18,600,047 100.0%

High Replacement Cost: $k \in \{225, 300, 375, 450\}$										
α	$I(D, K_2)$	$I(K_1, D)$	$I(K_1, K_2)$	I Total	$R(D, D)$	$R(D, K_2)$	$R(K_1, D)$	$R(K_1, K_2)$	R Total	Total
$1 \leq \alpha < 2$	9,204,033 25.3%	15,180,940 41.7%	1,722,630 4.7%	26,107,603 71.7%	1,782,679 4.9%	76,880 0.2%	943,673 2.6%	7,509,630 20.6%	10,312,862 28.3%	36,420,465 100.0%
$\alpha \geq 2$	5,579,322 19.2%	8,692,780 29.9%	48,088 0.2%	14,320,190 49.2%	1,141,835 3.9%	22,954 0.1%	264,664 0.9%	13,359,400 45.9%	14,788,853 50.8%	29,109,043 100.0%
Total	14,783,355 22.6%	23,873,720 36.4%	1,770,718 2.7%	40,427,793 61.7%	2,924,514 4.5%	99,834 0.2%	1,208,337 1.8%	20,869,030 31.8%	25,101,715 38.3%	65,529,508 100.0%

Total	15,260,860 18.1%	29,350,347 34.9%	9,255,198 11.0%	53,866,405 64.0%	3,142,084 3.7%	103,103 0.1%	1,356,557 1.6%	25,661,406 30.5%	30,263,150 36.0%	84,129,555 100.0%
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Note: Parameter values shown are the number of occurrences for each equilibrium given the α and k value ranges.

How $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ Change With θ_1 : As shown in Table A.4, for almost all cases, $b_U^*(\theta_1)$ increases in θ_1 and $b_L^*(\theta_1)$ decreases in θ_1 . Thus, the size of the $(K_1, D)/(D, K_2)$ region is almost always

increasing in θ_1 . Note that the comparative static results for $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ with respect to θ_1 are found by comparing whether, for a given parameter set, the benefit-to-cost ratio (b/c) corresponding to the threshold increases or decreases when we increment θ_1 to the next value in the numerical sample. All future comparative static results are obtained in a similar manner.

Table A.4 Comparative Statics of Thresholds $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ with Respect to θ_1

Threshold	Inc/Dec	No. of Cases	θ_1	p	α	q	γ	b	k
$b_U^*(\theta_1)$	Increasing	385,385	0.74	0.24	1.92	0.24	0.32	285.7	323.1
$b_U^*(\theta_1)$	Decreasing	3,826	0.74	0.09	2.26	0.11	0.31	368.9	398.4
$b_L^*(\theta_1)$	Increasing	156	0.63	0.28	1.47	0.03	0.28	99.4	315.4
$b_L^*(\theta_1)$	Decreasing	330,403	0.73	0.20	1.47	0.13	0.53	84.22	359.3

Note: Parameter values shown are averages.

How $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ Change with p , α , q , and γ : As shown in Table A.5, for almost all cases, $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ decrease in p and α , and $b_L^*(\theta_1)$ decreases in q and increases in γ . As shown in Table A.6, how $b_U^*(\theta_1)$ changes with q depends on the regulation penalty (α), the pragmatism of the NGO (γ), the marginal environmental benefit (b), and replacement cost (k).

Table A.5 Comparative Statics of Thresholds $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ with Respect to Model Parameters

Threshold	Parameter	No. of Cases	Decreasing	Increasing
$b_U^*(\theta_1)$	p	355,300	96.4%	3.6%
$b_U^*(\theta_1)$	α	380,485	99.9%	0.1%
$b_L^*(\theta_1)$	p	320,772	94.0%	6.0%
$b_L^*(\theta_1)$	α	317,002	100.0%	0.0%
$b_L^*(\theta_1)$	q	333,558	100.0%	0.0%
$b_L^*(\theta_1)$	γ	280,081	0.1%	99.9%

Note: Tests for α and γ are included to complement the proofs of Proposition A.2 and A.6.

Table A.6 Comparative Statics of Threshold $b_U^*(\theta_1)$ with Respect to q

Threshold	Inc/Dec	No. of Cases	θ_1	p	α	γ	b	k
$b_U^*(\theta_1)$	Increasing	171,533	0.76	0.20	2.21	0.42	365.2	343.6
$b_U^*(\theta_1)$	Decreasing	177,045	0.70	0.28	1.64	0.21	225.4	305.6

Note: Parameter values shown are averages.

The NGO's Strategy Within the $(K_1, D)/(D, K_2)$ Region: As shown in Table A.7, the NGO targets the industry in 96.7% of all cases tested. Equilibria $R(K_1, D)$ and $R(D, K_2)$ occur when the NGO does not significantly incorporate firms' profits in its decision making (i.e., γ is close to 0) and the existing market sensitivity q is high (also see Figure 1(b)). Note, we assume the NGO prefers to target the regulatory body when the NGO is indifferent between the two strategies. For many of the $R(K_1, D)$ and $R(D, K_2)$ cases, we find that the NGO obtains the same payoff by targeting the industry.

Table A.7 NGO's Strategy Within the $(K_1, D)/(D, K_2)$ Region

Payoff Increase	No. of Cases	%	θ_1	b	p	α	q	γ	k
$I(K_1, D)$	23,873,600	59.7%	0.78	367.4	0.25	1.73	0.28	0.62	324.0
$I(D, K_2)$	14,783,480	37.0%	0.76	248.6	0.16	1.74	0.28	0.71	383.5
$R(K_1, D)$	1,210,580	3.0%	0.87	228.7	0.19	1.52	0.38	0.02	365.3
$R(D, K_2)$	99,834	0.3%	0.74	18.5	0.18	1.51	0.33	0.00	382.3

Note: Parameter values shown are averages.

C.2. Extensions to the Base Model

Due to computational constraints, for the extensions of the NGO targeting both parties (Table A.8) and the NGO's effort being less than 100% effective (Table A.10), we adjust our parameter set as follows: $\theta_1 \in [0.55, 0.95]$ with an increment of 0.0125, $b \in [1, 700]$ with an increment of 10, $c = 100$, $p \in [0.025, 0.525]$ and $q \in [0.025, 0.525]$ with an increment of 0.0625 for both, and $\alpha \in [0.50, 3.00]$ with an increment of 0.50. All other extensions are analyzed with the same parameter set as in §3.

The NGO Targets Both the Industry *and* the Regulatory Body: To test how the NGO's strategy changes if it can allocate its effort between parties, we compare our results in §4 with the case in which the NGO can target both the industry *and* the regulatory body. While in some cases, targeting one party may reduce the cost of targeting the second party, we test a worst-case scenario and do not alter the NGO's cost factor; i.e., the NGO's total cost of effort is $c(\epsilon_S^I)^2 + c(\epsilon_S^R)^2$. As shown in Table A.8, the option of targeting both parties has the biggest impact on the NGO's strategy when the NGO is less pragmatic. The largest shifts occur when the NGO attempts to increase the expected percentage of the market receiving the replacement substance. For example, the less pragmatic NGO targets (K_1, D) instead of (D, K_2) and (K_1, K_2) instead of (K_1, D) at the parameter regions that form the boundaries between these equilibria in the base model. In addition, we observe that when the NGO can target both parties, it incurs the highest increase in payoff (as compared to the base model) at the parameter regions that form the thresholds between equilibrium regions under the base model; i.e., at $b_U^*(\theta_1)$, the boundary between (K_1, D) and (D, K_2) , and $b_L^*(\theta_1)$.

Table A.8 Firm Equilibria Shifts When the NGO Targets Both Parties

Orig. EQ	Target Both EQ	No. of Cases	% of All Cases ($\gamma > 0$)	α	γ
(K_1, D)	(K_1, D)	1,315,400	37.1%	1.70	0.59
(K_1, K_2)	(K_1, K_2)	1,128,035	31.8%	2.08	0.23
(D, K_2)	(D, K_2)	834,604	23.5%	1.70	0.71
(D, D)	(D, D)	183,713	5.2%	1.73	0.70
(K_1, D)	(K_1, K_2)	53,420	1.5%	1.25	0.26
(D, K_2)	(K_1, D)	14,656	0.4%	1.42	0.24
Total		3,529,828	99.6%	1.81	0.50

Note: The top six occurring cases are presented. Percentages are with respect to the total number of cases, 3,544,210. Parameter values shown are averages.

The Impact of the NGO's Effort Level: We test how varying the effectiveness of the NGO's effort impacts the NGO's strategy by relaxing three assumptions: (i) the NGO's cost factor c is the same for targeting the industry and the regulatory body; (ii) the NGO's effort is 100% effective; and (iii) the NGO's impact is linear in its effort level. To test these cases we let (i) $c_I \in \{100, 200\}$ and $c_R \in \{100, 200\}$; (ii) $x_S(\epsilon) = w_S \epsilon$ with $w_S \in \{0.50, 0.75, 1.00\}$ for $S \in \{I, R\}$; (iii) $x(\epsilon) = \sqrt{\epsilon}$ and $x(\epsilon) = \epsilon^2$.

First, as shown in Table A.9, when a strategy becomes more costly to the NGO, it is less used by the NGO; i.e., the NGO changes to the other strategy. Nevertheless, the equilibria do not change for 90.3% of all cases tested (over 131 million). Thus, our insights in §4 are robust to possible inaccuracies in estimating the NGO's cost factor.

Table A.9 Equilibria Shifts When the NGO's Strategy Becomes More Costly

Orig. EQ	New EQ	(c_I, c_R)	No. of Cases	% of All Cases
$I(K_1, D)$	$R(K_1, K_2)$	(200, 100)	2,592,200	2.0%
$I(K_1, K_2)$	$R(K_1, K_2)$	(200, 100)	1,130,000	1.0%
$I(K_1, D)$	$R(K_1, D)$	(200, 100)	1,145,040	0.9%
$R(K_1, K_2)$	$I(K_1, D)$	(100, 200)	2,860,050	2.2%
$R(K_1, K_2)$	$I(K_1, K_2)$	(100, 200)	1,997,700	1.5%
$R(K_1, D)$	$I(K_1, D)$	(100, 200)	785,339	0.6%
All Cases			12,773,534	9.8%

Note: The top six occurring cases are presented. Percentages are with respect to the total number of cases, 131,049,407.

When the NGO's effort is not 100% effective, we find that the number of consumers receiving a replacement declines. Specifically, when (w_I, w_R) decreases from (1.0, 1.0) to (0.5, 0.5), we observe a 22.3% increase in the number of $I(D, K_2)$, $R(D, D)$, and $R(D, K_2)$ cases, and a 16.9% decrease in the number of $I(K_1, K_2)$ and $R(K_1, K_2)$ cases. In addition, we observe from Table A.10 a decrease in the NGO's choice of the less effective strategy compared to the base model.

Table A.10 NGO Strategy When Targeting the Industry or the Regulatory Body Becomes Less Effective

w_I	w_R	Target the Industry	% of Cases	Target the Regulatory Body	% of Cases
0.5	1.0	6,080,826	44.6%	7,558,014	55.4%
1.0	0.5	10,923,360	80.1%	2,715,579	19.9%
1.0	1.0	8,615,718	63.2%	5,023,034	36.8%

Note: Parameter values shown are the number of cases.

To analyze how our results change with a nonlinear NGO impact, we first test how $b_U^*(\theta_1)$ and $b_L^*(\theta_1)$ change when the NGO's effort shifts from having a low impact (i.e., $x(\epsilon) = \epsilon^2$) to having a high impact (i.e., $x(\epsilon) = \sqrt{\epsilon}$). For 97.3% of the 253,421 $b_L^*(\theta_1)$ samples, $b_L^*(\theta_1)$ decreases (i.e., the size of the $R(D, D)$ region decreases) as we shift from $x(\epsilon) = \epsilon^2$ to $x(\epsilon) = \sqrt{\epsilon}$. Only when the existing market sensitivity is high, and thus, targeting the industry is less effective in the $(K_1, D)/(D, K_2)$ region, do we observe cases in which $b_L^*(\theta_1)$ increases. For $b_U^*(\theta_1)$, as shown in Table A.11, if the NGO does not significantly incorporate the firms' profits into its decision making, then as the impact of the NGO's effort increases, $b_U^*(\theta_1)$ decreases (in 60.9% of the 373,602 $b_U^*(\theta_1)$ samples). Thus, the less pragmatic NGO induces (K_1, K_2) for lower benefit-to-cost ratios. If instead, the NGO is more pragmatic, then $b_U^*(\theta_1)$ can increase as the NGO does not target both firms to replace when the firms' costs are high.

Table A.11 How Threshold $b_U^*(\theta_1)$ Changes as the Impact of the NGO's Effort Increases

$b_U^*(\theta_1)$	No. of Cases	% of Cases	γ	α	k
Decreasing	227,547	60.9%	0.19	1.84	320.6
Increasing	146,055	39.1%	0.53	2.23	339.5
Total	373,602	100%	0.32	1.99	328.0

Note: Parameter values shown are averages.

Regarding the regions of potential contention, we test how the size of the $I(K_1, D)_A$ and $I(D, K_2)_A$ regions (i.e., the range of b/c values when these equilibria are achieved) change as the impact of the NGO's effort changes. We find that the regions of potential contention are increasing in size as the impact of the NGO's effort increases. Specifically, in 92.7% of the 386,699 $I(D, K_2)_A$ cases, the size

of the region increases when the NGO's effort has a higher impact; similarly, in 95.4% of the 184,075 $I(K_1, D)_A$ cases the size of the region increases.

Finally, we test how a nonlinear impact alters the NGO's optimal strategy. As shown in Table A.12, most changes to the NGO's strategy occur in the $(K_1, D)/(D, K_2)$ region. In particular, when the impact is high (i.e., concave), targeting the industry is almost always the NGO's preferred strategy in this region (98.6% of the 40,786,315 $(K_1, D)/(D, K_2)$ cases). In contrast, when the impact is low (i.e., convex), targeting the regulatory body is used more often (42.5% of the $(K_1, D)/(D, K_2)$ cases). This is especially true when the existing market sensitivity is high and the benefit-to-cost ratio is low.

Table A.12 Equilibrium Comparison for High vs. Low Impact

EQ (High Impact)	EQ (Low Impact)	Cases	b	θ_1	p	α	q	γ	k
$R(K_1, K_2)$	$R(K_1, K_2)$	16,957,000	447.5	0.72	0.23	2.14	0.23	0.22	335.57
$I(K_1, D)$	$I(K_1, D)$	13,467,245	434.4	0.77	0.22	1.67	0.21	0.62	329.1
$I(K_1, D)$	$R(K_1, D)$	8,945,875	290.9	0.80	0.28	1.85	0.42	0.66	317.3
$I(D, K_2)$	$I(D, K_2)$	7,856,003	342.1	0.77	0.12	1.74	0.25	0.74	401.0
$I(D, K_2)$	$R(D, K_2)$	5,015,879	106.5	0.78	0.20	1.75	0.35	0.69	362.7
$R(D, D)$	$R(D, D)$	2,366,459	63.5	0.71	0.18	1.76	0.10	0.73	371.5

Note: Parameter values shown are averages. 54,608,461 of 65,529,524 cases tested are shown.

The Effect of Time Discounting ($\alpha < 1$): To model this scenario we define $\alpha < 1$ as a time discount factor; i.e., firm i 's cost for not being ready for regulation αK_i is less than its cost to proactively replace K_i in net present value terms. As shown in Table A.13, when $\alpha = 2.0$, the NGO targets the regulatory body for 47.7% of all cases tested; when $\alpha = 0.5$, the NGO targets the regulatory body for only 10.8% of all cases. Note that the positioning of the equilibria (i.e., Proposition 1) continues to hold.

Table A.13 The Impact of a Time Discount Factor on the NGO's Strategy

α	$I(D, K_2)$	$I(K_1, D)$	$I(K_1, K_2)$	$R(D, D)$	$R(D, K_2)$	$R(K_1, D)$	$R(K_1, K_2)$	% of Cases	
								Ind	Reg
0.5	4,258,390	4,176,790	412,480	879,404	88,931	101,418	0	89.2%	10.8%
1.0	3,080,280	4,599,000	627,820	565,113	33,456	317,010	551,330	85.0%	15.0%
1.5	1,999,746	3,543,000	368,690	402,010	13,529	203,384	2,464,600	65.7%	34.3%
2.0	1,405,157	2,279,480	41,801	287,534	7,116	91,424	3,013,400	52.3%	47.7%

Note: Values shown are the number of occurrences for each equilibrium given the associated α value.

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