Essays on Environmental NGOs and Clean Technologies Adoption

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Abstract

Chapter 1. — We develop a model of NGO-firm partnerships. An NGO can share environmental expertise with one or two competing firms, and certify their 'clean' production, important for consumers with environmental concerns. The NGO may also obtain funds from a partner firm for an environmental project, important for consumers who derive project participation warm-glow. The NGO benefits from reduced environmental damage and project realization, while firms may gain or avoid loss of profitable custom. This model allows us to understand increasingly common partnerships between firms and NGOs as mutually beneficial in a competitive setting. 'Clean' production and/or the project may be independently viable on the market, supported by consumer preferences. A viable project can then support adoption of a non-viable 'clean' technology, leading to a 'cleaner' market. However, when 'clean' production is viable, we identify a 'dirty' production damage threshold below which the NGO prefers to obtain funds for a non-viable project and partners on production with only one firm, rather than forgo the project and partner on 'clean' production with both firms instead. Moreover, this damage threshold is increasing in consumers' environmental concern, and thus can generate counterintuitive situations : less environmental concern leads to a 'cleaner' market, whereas more concern leads to a 'dirtier' market.

Chapter 2. — Consumers choosing amongst horizontally-differentiated products (brands) that also embody some degree of an environmental attribute, suffer stigma if they make brown choices. The intensity of that stigmatization is declining in the fraction of other

consumers making similarly brown decisions. It is common to suppose that people feeling such stigma would improve environmental outcomes. We show that while the threat of stigma makes it more likely that a consumer will choose the green option *from a given menu*, it can *reduce* the incentives for firms to offer green options in the first place. In an asymmetric duopoly setting social stigma can lower or increase the likelihood of clean technology adoption and in plausible circumstances drives the high-cost firm into a 'brown trap' or the low-cost firm into a 'green trap'. While increased competition reduces the 'green trap', it exacerbates the 'brown trap'.

Chapter 3. — The effect of warm-glow on number of NGOs and welfare is investigated within a charity market with ideologically differentiated public goods. In this setting ideology acts as a warm-glow multiplier on donations, and high enough warm-glow can push welfare into negative territory — welfare would be higher if nobody donated. Under first-best we find that an optimal number of NGOs exists even though NGOs have no costs. Under free-entry we obtain the level of warm-glow that would induce the welfare-maximizing number of NGOs to enter. A social planner can determine donor population to behave overall *as if* they were experiencing the welfare-maximizing level of warm-glow, and thus optimize free-entry welfare, through one of two equivalent and revenue-neutral fiscal policies: by subsidizing/taxing donations either at the source, when the donors make them, or at the destination, when the NGOs receive them.

Declaration

I acknowledge the contribution of Anthony Heyes for the research associated with Chapter 2 and Chapter 3 of this thesis. In both cases, his contribution is equal to my own, although the work in this thesis is in my own words.

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General Introduction

Environmental degradation is an issue that inevitably affects all societies. Environmental quality is therefore a public good, and supportive actions that at least slow down environmental degradation benefit everyone, just like damaging actions are costly to everyone. We are constantly faced with choices of such actions. Do we purchase a green good or a brown good? Do we contribute to a public good or not, and if we do, which one? These choices lie at the intersection of interactions between individuals, firms and non-governmental organizations (NGOs). The incentives that these economic agents are subject to ultimately dictate the menu of available choices, how effective they are in curtailing environmental degradation, and implications for social welfare.

Each of the following three chapters in this thesis analyzes the interactions of a different set of economic agents, as well as resulting market, environmental, and welfare outcomes. First chapter focuses on partnerships between NGOs and firms, and the emerging pattern of green technologies adoption. Second chapter looks at the effect of social stigma experienced by consumers of brown goods on firms' incentives to adopt a green technology. Third chapter analyzes the effect of donors' warm-glow on the number of ideologically differentiated NGOs, as well as how this number can be optimized under free-entry. Given the strategic nature of interactions between firms, between NGOs, and between firms and NGOs, game theory provides the ideal tools for analysis. In each chapter we build a model of these interactions starting from a classic game-theoretic template, and in each model competitive forces that drive interactions between firms, and between NGOs, are essential for understanding environmental and welfare outcomes.

NGOs and firms often cross paths in the economic literature, usually as opponents rather than partners. In the public politics arena NGOs lobby governments for favorable legislation or take firms to court for environmental transgressions in an attempt to force improvements in firms' environmental practices. In the private politics arena NGOs organize boycotts and protests to likewise pressure firms into adopting greener technologies. The last three decades though have witnessed a steady increase in partnerships between firms and NGOs. For example, household names such as WWF and Coca-Cola partnered to improve freshwater use during production and realize various environmental projects together ("WWF Partnerships: Coca-Cola", 2019). Yet few papers address this rise in cooperative private politics (e.g., Baron & Diermeier, 2007; Baron, 2012).

For the first chapter of this thesis we build the first model that focuses exclusively on cooperative private politics, broadly based on the WWF–Coca-Cola partnership. An NGO that has green production expertise and needs funds for a project can partner with one or two competing firms. Of particular interest is how the project — arguably the more controversial component because it is funded by a transfer from firm to NGO — affects NGO's partnering strategy on green production, and implicitly the environmental qualities of the goods available for consumers.

We find that a project that is well liked by consumers can support adoption of costly green practices that would not be adopted at all in its absence. However, we also find that the NGO may withhold cost-efficient green expertise from one of the firms, and offer it only to its competitor, when both firms would be willing to adopt its green practices. NGO's partner thus obtains a competitive advantage that translates into additional profits, which are then funneled towards NGO's project. In this case the project option is detrimental to market adoption of green practices. Welfare analysis shows that it is also detrimental to welfare in a wide range of circumstances.

This chapter contributes to our understanding of increasingly common NGO-firms partnerships. It cautions that when the partnership involves monetary donations from a firm to an NGO, the NGO may be incentivized to keep brown choices available on markets, despite the markets being ready to offer only green goods.

In the absence of environmental NGOs and their ever-diversifying methods of green technologies advancement, consumers can play a major role in firms' voluntary adoption of green practices. Individuals may be motivated to demand green products by altruism or warm-glow, in light of environmental quality as a public good (e.g., Bergstrom, 1995; Andreoni, 1990; Popp, 2001). They may be motivated by environmental concerns about the continued degradation that is costly to everyone (e.g., Eriksson, 2004; Conrad, 2005; Innes, 2006). It is becoming increasingly clear though that consumers can also be motivated by stigma — the social disapproval of others when choosing a brown good instead of a green good. Recent evidence of its transformational capacity is that airlines are devising strategies to overcome polluter stigma, which is advanced by a grassroots European anti-flying movement that even generated new vocabulary (e.g., Swedish "flygskam" which translates as "flight shame") (Rucinski et al., 2019). Despite its growing environmental importance, the economic literature has thus far analyzed stigma in other contexts, such as welfare receipts (Moffitt, 1983; Lindbeck et al., 1999), and criminality (Rasmusen, 1996).

For the second chapter we build the first model on firms' adoption of green technologies that accounts for the stigma experienced by consumers of brown goods, in a horizontally-differentiated asymmetric duopoly setting. Consistent with previous literature, the stigma of making a brown choice is decreasing in the proportion of consumers who likewise make brown choices, in line with the common justification that "everybody does it". Of particular interest is how the social stigma of a brown choice affects the availability of a green choice.

The main insight is that stigma increases price competition when both green goods and brown goods are on offer, making green technology adoption less profitable than in the absence of stigma. Since the level of experienced stigma is sensitive to the proportion of consumers who make similarly brown choices, in a mixed-adoption outcome both firms lower their prices in an attempt to tilt that proportion in their favor. The prospect of lower prices then incentivizes both firms to avoid a mixed-adoption outcome: the high-cost firm requires a lower cost than in the absence of stigma in order to adopt the green technology; the low-cost firm is willing to accept a higher cost than in the absence of stigma in order to "follow" its competitor and also adopt the green technology.

Welfare analysis isolates the circumstances under which stigma is detrimental to welfare in light of its effects on firms' adoption thresholds. Low stigma induces the high-cost firm not to adopt the green technology when it is socially-preferred that it does, while high enough stigma induces the low-cost firm to adopt when it is socially-preferred that it does not. In many settings increased competition is a remedy for these welfare traps, however we find this to be the case only for over-adoption. Increased competition magnifies low-cost firm's cost advantage from brown production, making the high-cost firm more reluctant to adopt and participate in a stigma-inducing mixed-adoption outcome. The high-cost firm requires an even cheaper green technology as a result of increased competition, which exacerbates, rather than correct, its under-adoption.

This chapter contributes to our understanding of increasingly relevant social stigma of brown choices, and how it can impede market availability of green choices to begin with.

Individuals can contribute to environmental quality not only through the product choices they make, but also through the public goods they support. When there is a demand for an environmental public good, but markets fail to provide it efficiently, environmental NGOs often step in, collect donations and realize projects that provide the demanded public good. Apart from the warm-glow motivation for a public good contribution (Andreoni, 1990), donors also care about how that public good is provided (Frey et al., 2004), in other words they have ideological preferences. For example, WWF negotiates with authorities and the industry to save whales and may be supported by a donor who prefers a diplomatic approach, whereas Sea Shepherd intervenes directly on the high seas to stop the hunt, and may be supported by a donor who prefers a more confrontational approach.

In the final chapter we build a model of a charity market where donors have ideological preferences and derive warm-glow utility from their donations. Of particular interest here is whether there is an optimal number of NGOs when donors have ideological preferences. Previous literature found that in the absence of ideology the optimal number of NGOs is zero (Barla & Pestieau, 2005), and when ideology is relevant only for fundraising, but not for how the public good is provided, one NGO suffices (Pestieau & Sato, 2006).

We find that an optimal number of NGOs exists and can be higher than one because donors derive utility from ideological proximity to NGO projects. Under free-entry the main insight is that ideology acts in a sense as a warm-glow multiplier. A warm-glow increase leads to higher donations, so more NGOs enter; this increases ideological proximity between donors and NGOs' projects, which further increases donations, further increases NGO entry, and can lead to over-entry. Too high warm-glow can thus decrease welfare, and there is a level of warm-glow that optimizes welfare under free-entry. A social planner evidently cannot impose a certain level of warm-glow, however it can tax donations such that donors behave overall *as if* they were experiencing the optimal level of warm-glow, and this way the social planner can optimize welfare under free-entry.

This chapter contributes to our understanding of the optimal number of NGOs when they supply ideologically differentiated projects (e.g., WWF and Sea Shepherd), and supports differential tax treatment for different charity markets.

Chapter 1

NGO-Firms Environmental Partnerships: A Theoretical Model

1.1 Introduction

Partnerships are increasingly common between firms and NGOs, organizations better known for their confrontations rather than for working together. The *status quo* started to change in 1990, when McDonald's partnered with Environmental Defense Fund to increase the sustainability of its packaging — the first partnership between an environmental group and a Fortune 500 company ("McDonald's and EDF Mark 20 Years", 2010).

NGO-firm partnerships have since become more numerous and diverse. Sierra Club accepted over $25 million in donations from the gas industry — source undisclosed until learned by the press — to help fund the Club's Beyond Coal campaign (Walsh, 2012). Greenpeace partnered with Coca-Cola, PepsiCo, Red Bull and Unilever to accelerate firms' transition to natural refrigerants ("Mission Accomplished", 2018). Unlike Sierra Club which tried to conceal donations' source, and unlike Greenpeace which does not accept donations, World Wildlife Fund (WWF) publicizes donations, their sources, and the projects they fund. In fact, corporate partners that donate $1 million or more, such as Coca-Cola, GAP Inc., Domtar, etc., receive the designation Million Dollar Panda. At the same time WWF acts as a consultant for some of these companies, with the objective of improving their environmental performance.

Stakeholders' views of NGO-firm partnerships diverge.

On the one hand governments encourage more cooperation between firms and NGOs. "Governments and corporations are rewarding cooperative groups and NGO partners with tax breaks, grants, and seats at the decision-making table" (Dauvergne & LeBaron, 2014, ch. 3 par. 51).

On the other hand grassroots activists accuse NGOs of "selling out". The claim is that instead of putting pressure on firms to change their practices through confrontational strategies, NGOs are partnering with firms to access funding for their projects, which in turn legitimizes rather than challenge business as usual, and perpetuates environmentally damaging modes of production.

> For instance, the WWF/Coca-Cola campaign to 'save' polar bears has driven sales of over one billion cans of Coke adorned with a white polar bear. [...] Efforts such as these may improve the ecological footprint of individual products and bring revenue to cash-strapped environmental organizations — but they are not fundamentally helping the planet, in fact they reinforce unsustainable patterns of production and consumption worldwide. (LeBaron, 2013)

Social activist Naomi Klein even claims "Big green groups are more damaging than climate deniers. [...] It's not, 'sue the bastards'; it's, 'work through corporate partnerships with the bastards.' There is no enemy anymore" (Mark, 2013).

These statements invite the question that we address in this paper.

Do NGO-firm partnerships indeed play a role in reinforcing environmentally damaging means of production, do they, on the contrary, promote adoption of environmentally friendly means of production, or both?

The question is increasingly relevant as the number of NGO-firm partnerships is expected to continue growing to the detriment of confrontational NGO tactics such as boycotts, litigation, and government lobbying.

In the 2018 C&E Corporate-NGO Partnerships Barometer from U.K., close to 90% of both corporate and NGO respondents expected the role of partnerships to become more or much more important over the following three years, and none expected a reversal of the trend (C&E Advisory, 2018). CEO of C&E Advisory, Manny Amadi highlights NGO expertise and consumer attitudes as factors driving this trend: "Consumers are increasingly probing, so the best partnerships with NGOs see brands really drawing on the knowledge of their NGO partners in making those decisions about their supply chains and relationships with consumers" (Tesseras, 2017).

Indeed, consumers are themselves moving away from boycotts and towards rewarding companies using their wallets — a course of action referred to as "buycotting". A 2017 survey of 2,000 consumer activists in the U.S. and U.K. shows a shift towards supportive consumer actions. Consumer activists think it is more important to support companies by buying from them than participating in boycotts, buycotters are more engaged in consumer activism than boycotters, and buycotters skew younger than boycotters ("Battle of the Wallets", 2018).

The shift in attitudes is driven in part by the inefficiency of NGOs' confrontational tactics to incentivize meaningful change. An analysis of U.S. corporate boycotts from 1990 to 2005 shows that boycotts have very little effect on initial market disruption of their targets (King, 2011); based on his boycotts research Brayden King concludes that "the typical boycott doesn't have much impact on sales revenue" ("Do Boycotts Work?", 2017). At the same time lobbying governments and litigation can be very costly in terms of both money and time. NGOs that are always strapped for funds and are trying to address time sensitive issues, such as environmental degradation or labor conditions, find themselves essentially cornered into partnering with firms whose production practices they are trying to improve.

CEO of WWF Canada until 2012, Gerald Butts confirmed the rationale as he justified WWF's partnership with Coca-Cola for The Globe and Mail:

> Coke is the No. 1 purchaser of aluminum on the face of the earth — which is one of the most carbon-intensive commodities. The No. 1 purchaser of sugar cane. The No. 3 purchaser of citrus. The second-largest purchaser of glass, and the fifth-largest purchaser of coffee. We could spend 50 years lobbying 75 national governments to change the regulatory framework for the way these commodities are grown and produced. Or these folks at Coke could make a decision that they're not going to purchase anything that isn't grown or produced in a certain way — and the whole global supply chain changes overnight. And that in a nutshell is why we're in a partnership. (Houpt, 2011)

1.1.1 Literature

The economic literature follows the historical trend of firm-NGO interactions — it is rich in analyses of confrontational politics, with few models addressing the more recent cooperative politics. Given the strategic nature of firm-NGO interactions, game theory has been economists' theoretical tool of choice to model and analyze them.

Indirect confrontations such as NGOs and firms lobbying governments for favorable legislation (e.g., Becker, 1983; Conconi, 2003; Heyes & Liston-Heyes, 2005), and NGOs suing firms over environmental or human rights abuses (e.g., Baik & Shogren, 1994; Hurley & Shogren, 1997; Heyes & Rickman, 1999) are the domain of public politics. Direct confrontations such as boycotts and protests (e.g., Baron, 2001, 2003; Innes, 2006; Heijnen & van der Made, 2012) are the domain of private politics.

While there is a small economic literature that looks at both public and private politics (e.g., Calveras et al., 2007; Reid & Toffel, 2009; Kraft et al., 2013), Baron (2012) points out that many activists and NGOs "have concluded that more progress towards their goals can be achieved by targeting economic agents directly rather than by working through government" (Baron, 2012, p. 1).

Alongside the literature on confrontational private politics there is a substantial literature on labeling and credence goods (e.g., Arora & Gangopadhyay, 1995; Feddersen & Gilligan, 2001; Krautheim & Verdier, 2012). Desirable environmental and labor practices are validated by NGOs with a label and/or publicly praised, however the interactions between firms and NGOs are not explicitly cooperative — certainly not representative of the NGO-firm partnerships exemplified earlier —, and the literature relies on non-cooperative frameworks for analysis.

Baron and Diermeier (2007) bridge confrontational private politics and the labeling and credence goods literature with a model in which an activist targets a firm with a campaign to improve its production practices. The campaign consists of a demand, a reward such as public praise if the firm meets the demand, and a threat of harm such as a boycott if the firm rejects the demand. The firm may be rational, or recalcitrant — non-responsive to campaign on principle. The optimal campaign is more aggressive and more negative — higher demand and larger harm threatened —, the higher the probability the firm is rational.

Baron (2012) introduces explicitly cooperative private politics as he presents a model in which activists select targets and choose a cooperative or confrontational strategy, but not both. Developing each capability is costly, thus activists frequently specialize, and a main "concern about an activist having both confrontational and cooperative capabilities is that the cooperative side of the activist organization could pass to the confrontational side inside information about the firm learned through a cooperative engagement" which "could cause firms to reject participation in cooperative engagements" (Baron, 2012, p. 5).

The cooperative activist has expertise that can help the target discover the benefits of the proposed change through cooperative engagement, and subsequently the firm may accept or reject the proposed change. A cooperative activist may have bargaining power given by the share of social benefits that the target internalizes in its decision to implement the proposed change or not. Greater bargaining power decreases the probability that the firm enters a cooperative engagement, but when it does enter, it increases the likelihood that the firm accepts the proposed change.

Our paper analyzes the interplay between two commonly used tools in NGO-firm partnerships — improvement in production practices and sponsorship of NGO projects —, and thus contributes to this emerging literature on cooperative private politics. Baron (2012) explicitly assumes no corporate donations, while Baron and Diermeier (2007) only address changes in firms' practices. Moreover, our paper focuses on NGO-firm(s) partnerships in a market setting where two competing firms have strategic interactions. Baron and Diermeier (2007) explicitly assume no strategic interactions between firms, while Baron (2012) does not model strategic interactions in the case of two potential targets. Both papers assume that an NGO can only target one firm at a time, whereas in our model the NGO can also partner with both firms — an important distinction since the model supports equilibria in which the NGO can extract more environmental benefits from the market as a result.

1.1.2 Model and Results Summary

The theoretical model we propose is broadly based on the kind of partnership exemplified by WWF and Coca-Cola. Started in 2007, it has as main objective "addressing the natural resource challenges that impact freshwater by measurably improving environmental performance across the company's supply chain" ("WWF Partnerships: Coca-Cola", 2019). WWF uses its unique expertise to advise Coca-Cola on how to reduce environmental damage from production, as acknowledged by the Chairman and CEO of Coca-Cola, Muhtar Kent: "WWF's expertise will be instrumental in reaching our environmental performance goals, some of which they help us set" ("Coca-Cola and WWF Annual Partnership Review", 2013, p. 2).

At the same time Coca-Cola donated $2 million from 2011 to 2016 to fund WWF's effort to protect the polar bear's home ("WWF Press Releases: 'Arctic Home' ", 2012).

The partnership has been extended to 2020, and Coca-Cola continues to fund other WWF environmental projects such as saving the endangered Yangtze finless porpoises (Wells, 2017a), and the reintroduction to its natural environment of the nearly extinct Père David's deer (Wells, 2017b).

In our setting the NGO holds a 'clean' production technology — a simplified representation of NGO's unique expertise in environmental damage reduction —, as well as an unfunded environmental project — such as reintroducing a nearly extinct species or protecting a species' habitat. The NGO enters a horizontally-differentiated symmetric duopoly in which firms only have access to a default 'dirty' production technology that generates environmental damage. Consumers may have environmental concerns and internalize the damage generated by production of a purchased good.[1] They may also derive warm-glow utility[2] from participation in funding NGO's environmental project.[3]

For the coherence of the presentation we first analyze NGO strategies that employ only one of the two tools — either the 'clean' technology or the environmental project, but not both. This allows us to isolate the conditions under which an environmental tool is implementable on its own — it is by definition *viable*.

Definition 1.1. ***(Environmental tool viability)*** *An environmental tool is viable if it is implementable through NGO-firm(s) partnership(s) in isolation, independently of the second environmental tool.*

[1]Environmental concern has been documented as a measurable global phenomenon (e.g., Brechin & Kempton, 1994; Dunlap & Mertig, 1995; Dunlap et al., 2000; Schultz et al., 2005). Empirical studies document the positive impact of environmental concern on environmental behavior intent and environmental behaviors in various domains such as energy use and green energy, tourism and recreation, product packaging, etc. (e.g., Gatersleben et al., 2002; Poortinga et al., 2002, 2004; Hedlund, 2011; Koenig-Lewis et al., 2014; Magnier & Schoormans, 2015). It has also been embedded in many models in industrial organization (e.g., Eriksson, 2004; Innes, 2006; Heyes & Martin, 2017).

[2]Based on the model of impure altruism introduced by Andreoni (1990), in which donors derive utility from the public good, and additional utility — coined "warm-glow" — from contributing to the public good. The impure altruism model is supported by evidence from behavioral experiments (e.g., Palfrey & Prisbrey, 1997; Goeree et al., 2002), and the field of neuroeconomics (e.g., Moll et al., 2006; Harbaugh et al., 2007).

[3]Thus there are four types of consumers: 1) with environmental concerns who do not derive warm-glow; 2) without environmental concerns who derive warm-glow, 3) with both concerns and warm-glow; 4) consumers with none.

Then we analyze NGO strategies that employ both the 'clean' technology and the environmental project.

Wielding two environmental tools enables the NGO to leverage a viable tool in order to implement a non-viable tool. Specifically, a viable project generates a range of circumstances in which the sponsoring firm adopts the 'clean' technology in addition to fully funding the project, even though the technology is not viable. None of the firms would adopt it in the absence of the project. Such a partnership promotes 'clean' technology adoption.

Likewise, a viable 'clean' technology generates a range of circumstances in which both firms adopt 'clean', and the NGO also obtains enough funds for its environmental project even though the project is not viable on its own. The NGO then obtains the maximum payoff in this setting: a fully 'clean' market (both firms) and project realization.

However the NGO can further "stretch" the range of circumstances in which it obtains enough funds for the project by offering the 'clean' technology only to the sponsoring firm, and withholding it from its competitor. The viable 'clean' technology gives NGO's partner firm a competitive advantage that translates into additional profit, which is then partially or fully funneled through the NGO-firm partnership towards NGO's non-viable project.

Such a partnership reinforces 'dirty' production. The competitor that ends up producing 'dirty' would adopt the viable 'clean' technology, but the NGO does not offer it. The NGO opts for such a strategy only when the marginal damage from 'dirty' production is not too high — environmental damage from competitor's 'dirty' production does not outweigh the environmental benefits generated through the project. Beyond a certain threshold the NGO prefers to forgo project realization, and partners with both firms on 'clean' production instead.

Somewhat unexpectedly though, this marginal damage threshold is increasing in consumers' level of environmental concern. A higher level of concern in the population increases demand for the 'clean' good, and reduces demand for the 'dirty' good when both on offer. From NGO's perspective, a more concerned population "cleans up" more of the environmental damage from the market through its product choices. Higher concern thus reduces the environmental cost of the option, incentivizing the NGO to opt for project realization and partly 'clean' market (one firm) at increased levels of marginal damage, rather than forgo the project and opt for a fully 'clean' market (both firms).

This can lead to counterintuitive situations in which higher environmental concern among consumers leads to lower availability of 'clean' products on the market. Although people want to buy them, the NGO limits 'clean' options *because* people want to buy them.

Therefore while our paper shows that NGO-firm partnerships can promote adoption of 'clean' technologies, it also points out the conditions under which the NGO capitalizes on consumers' environmental concerns in a competitive market in order to extract funds for its outside environmental project, which reinforces 'dirty' production.

Welfare outcomes depend upon the extent to which consumers are assumed to internalize the environmental damages that their consumption decisions impose. If all consumers internalize damages, then the market implements the socially efficient pattern of 'clean' technology adoption by firms in the absence of an environmental project, but NGO's project option disturbs that. If only some consumers internalize, things are more nuanced.

The paper proceeds as follows. In Section 1.2 we present the model. Sections 1.2.1 to 1.2.4 present the elements of the game: NGO, firms, consumers, and timing of their moves. Section 1.2.5 presents the analysis of the game. We first focus on NGO partnering strategies that only employ one of the environmental tools, and derive independent viability conditions for each tool. Then we focus on NGO strategies that employ both tools and compare equilibrium outcomes to independent viability benchmarks. Section 1.2.6 summarizes all equilibria in the game. Section 1.3 presents welfare analysis, and Section 1.4 concludes with a discussion of our results and avenues for future research.

1.2 Model

A complete information game comprises an environmental NGO, two symmetric firms and a unit continuum of consumers in a classic Hotelling (1990) setting.

1.2.1 Non-governmental organization

The NGO maximizes environmental benefits, and it holds two tools through which it can generate them.

The first tool is a 'clean' production technology. It can produce the good with zero marginal environmental damage at marginal cost $c > 0$.

The second tool is an environmental project. It is a unique, non-replicable and indivisible project that requires an amount $X > 0$ to generate X environmental benefits. The project generates zero environmental benefits with less than X in funding, and it generates X environmental benefits with more than X in funding. The environmental project does not address the environmental damage generated by firms' default 'dirty' production.

1.2.2 Firms

Firm 1 and firm 2 are located at the ends of the unit continuum of consumers. They are profit-maximizing producers of horizontally differentiated goods, and use the same default 'dirty' technology at zero marginal cost. The 'dirty' production technology generates marginal environmental damage $\delta > 0$. Firms do not have access to a production or offset technology that generates lower damage.

1.2.3 Consumers

Consumers are uniformly distributed on a continuum of unit length and density. Each consumer may purchase only one unit of good from one of the two firms, and derives utility $\overline{u} > 0$ from its consumption; we assume $\overline{u}$ is large enough that all consumers make a purchase (i.e., the market is always "covered"). Consumers incur constant marginal travel cost $t > 0$ times the distance traveled to purchase the good from one of the two firms.[4]

A fraction $\alpha \in (0, 1)$ has environmental concerns, and it fully internalizes production damage from the consumed good as a result. The remaining $(1 - \alpha)$ is not concerned about environmental damage, and it does not internalize damages.

A fraction $\beta \in (0, 1)$ cares about the environmental benefits generated by NGO's project, and derives warm-glow from participation in the provision of project's environmental benefits. If the project is realized, its environmental benefits X are fully and equally enjoyed by all consumers, whether they care about the project or not. Consumers who care about the project and contribute to the project through the price they pay[5] derive total warm-glow $\gamma > 0$ from their contribution and from the contributions of other consumers. For the sake of model tractability we assume environmentally concerned consumers are just as likely to care about NGO's environmental project as unconcerned consumers.[6]

There are thus four types of consumers: $\alpha\beta$, with environmental concerns who derive warm-glow; $\alpha(1 - \beta)$, with environmental concerns who do not derive warm-glow; $(1 - \alpha)\beta$, without environmental concerns who derive warm-glow; $(1-\alpha)(1-\beta)$, without environmental concerns who do not derive warm-glow.

[4]For example, a consumer located halfway between the two firms on the unit segment incurs travel cost $\frac{t}{2}$ to purchase from either firm. Travel cost may be physical and/or ideological, and it may include direct and/or opportunity costs.

[5]The NGO can realize the project only if one or both firms fully fund the project. The only source of revenue from which a firm can donate to fund the project is the price paid by consumers for its good. Thus the only way for consumers to participate in the provision of the environmental benefits generated by the project is by making a purchase from a firm that donates to the project.

[6]While it is reasonable to expect that a consumer with environmental concerns is more likely to care about and derive warm-glow from participation in an environmental project, accounting for this aspect would not have an impact on the qualitative results, and would complicate the model unnecessarily. For example, if the fractions of consumers who derive warm-glow were β_C and β_U for concerned and unconcerned consumers, respectively, where $\beta_C, \beta_U \in (0, 1)$ and $\beta_C > \beta_U$, then the fraction of consumers deriving warm-glow from project participation would be $\alpha\beta_C + (1 - \alpha)\beta_U$ instead of simply $\alpha\beta + (1 - \alpha)\beta = \beta$.

1.2.4 Timing

In Stage 1 the NGO proposes partnership(s) P to one firm, both firms, or none; proposals are common knowledge and the NGO does not propose a partnership if indifferent. A partnership may consist of two parts:

a) adoption of 'clean' technology at marginal cost c;

b) a donation amount — X, ϕX or $(1-\phi)X$ — to fund the environmental project, where $\phi \in (0,1)$ and $(1-\phi)$ are the fractions of X to be funded by firm i and firm j, $i, j \in \{1, 2\}$, respectively, in case both firms sponsor the project.

In Stage 2 firms simultaneously accept (A) or reject (R) a proposed partnership; firms accept when indifferent. Then the NGO implements accepted partnership(s) if feasible[7], consumers update information and make purchases, firms set prices and obtain profits.

1.2.5 Analysis

We solve by backward induction, present full proofs and derivation of payoffs in Appendix A, and here we present the main findings after providing a payoffs derivation example.

Figure 1.1 presents all strategies available to the NGO at Stage 1.

[7]For example, if one firm accepts technology adoption and partial sponsorship, whereas the other firm rejects a partnership that involves partial sponsorship, then the NGO does not have enough funds to realize the project, and implements no partnership. Appendix B presents an extension where the NGO implements only the feasible part of an accepted partnership (i.e., technology adoption) when the partnership is not feasible as proposed (i.e., insufficient funds for project realization).

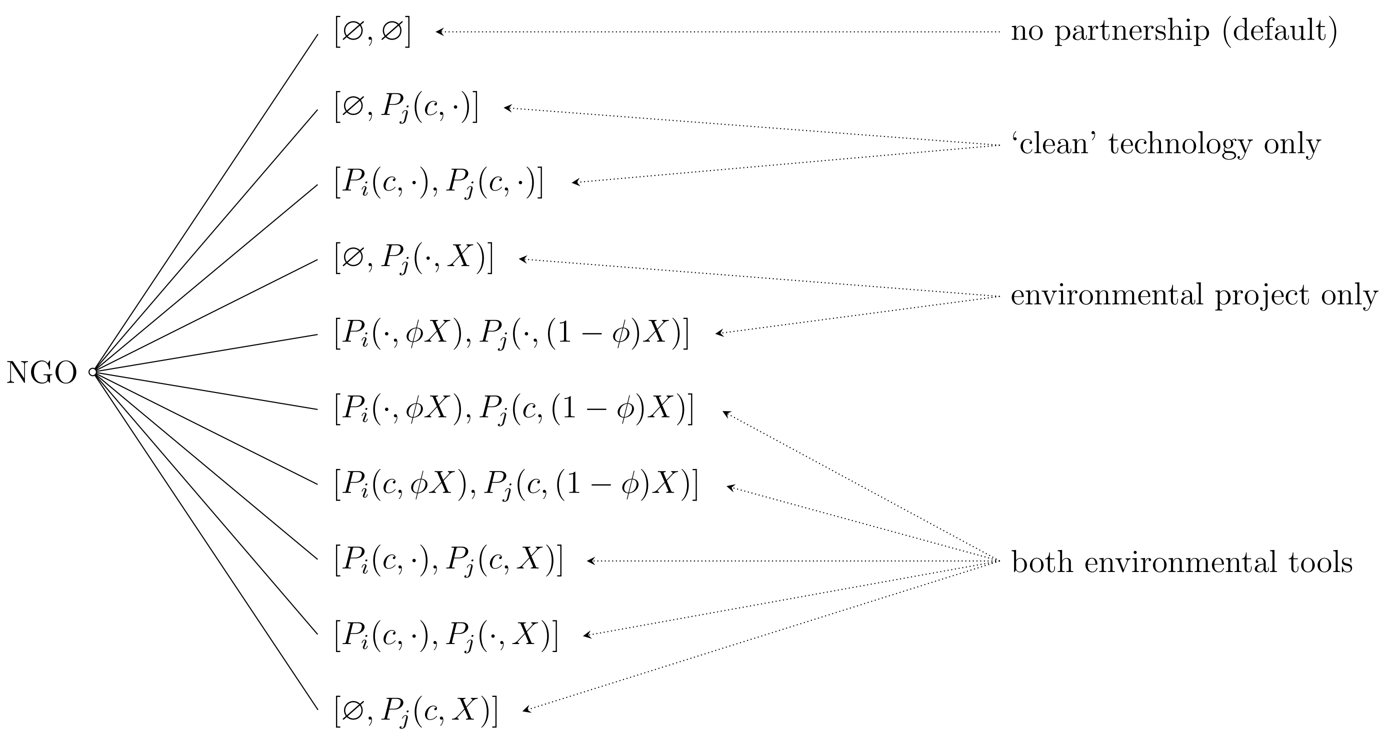

Figure 1.1: NGO's Stage 1 strategies

Starting from the top, first is the default strategy of proposing no partnerships $[\varnothing, \varnothing]$.

Next are two strategies that only employ the 'clean' technology tool. The NGO proposes 'clean' adoption only to one firm $[\varnothing, P_j(c, \cdot)]$, or to both firms $[P_i(c, \cdot), P_j(c, \cdot)]$. In the absence of an environmental project NGO's set of strategies reduces to these two and the default $[\varnothing, \varnothing]$.

The following two strategies only employ the environmental project tool. The NGO proposes full project sponsorship to one firm $[\varnothing, P_j(\cdot, X)]$, or partial project sponsorship to both firms $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$, $\phi \in (0, 1)$. In the absence of a 'clean' technology NGO's set of strategies reduces to these two and the default $[\varnothing, \varnothing]$.

The bottom five strategies employ both the 'clean' technology and the environmental project. In the top two the NGO proposes partial project sponsorship to both firms, and either proposes 'clean' adoption to one firm only $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$, or to both firms $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$. In the bottom three strategies the NGO proposes full project sponsorship to firm j, and proposes 'clean' adoption to both firms $[P_i(c, \cdot), P_j(c, X)]$, or only to firm i $[P_i(c,\cdot), P_j(\cdot, X)]$, or only to firm j $[\varnothing, P_j(c,X)]$, $i,j \in \{1,2\}$.

Without loss of generality we present derivation of firms' payoffs for the case in which firm j adopts the 'clean' technology and fully funds the project while firm i produces 'dirty'. In other words the NGO has a partnership $P_j(c,X)$ with firm j on 'clean' production and project realization, and no partnership with firm i.

In Stage 2 demand for each firm's product is determined by the location of the consumer who is indifferent between purchasing from firm i or firm j, $i,j \in \{1,2\}$, as in the classic Hotelling (1990) solution. Let us assume that firm i is located left on the unit segment (at $\theta = 0$, $\theta \in [0,1]$), and firm j is located right (at $\theta = 1$). Thus those located to the left of the indifferent consumer purchase from firm i, whereas those located to the right of the indifferent consumer purchase from firm j.

In our setting there are four indifferent consumers, corresponding to each of the four categories of consumers in the game.[8] The indifferent consumers within each category are characterized as follows, contingent on the NGO having no partnership with firm i ($\varnothing$), and a partnership on 'clean' production and project realization with firm j ($P_j(c,X)$):

$$\overline{u} + X - t\widehat{\theta}_{\alpha\beta} - p_i - \delta = \overline{u} + X - t(1 - \widehat{\theta}_{\alpha\beta}) - p_j + \gamma \Leftrightarrow \widehat{\theta}_{\alpha\beta} = \frac{1}{2} - \frac{p_i - p_j + \delta + \gamma}{2t}; \tag{1.1}$$

$$\overline{u} + X - t\widehat{\theta}_{\alpha(1-\beta)} - p_i - \delta = \overline{u} + X - t(1 - \widehat{\theta}_{\alpha(1-\beta)}) - p_j \Leftrightarrow \widehat{\theta}_{\alpha(1-\beta)} = \frac{1}{2} - \frac{p_i - p_j + \delta}{2t}; \tag{1.2}$$

$$\begin{aligned} \overline{u} + X - t\widehat{\theta}_{(1-\alpha)\beta} - p_i = \overline{u} + X - t(1 - \widehat{\theta}_{(1-\alpha)\beta}) - p_j + \gamma \Leftrightarrow \widehat{\theta}_{(1-\alpha)\beta} = \frac{1}{2} - \frac{p_i - p_j + \gamma}{2t}; \\ \overline{u} + X - t\widehat{\theta}_{(1-\alpha)(1-\beta)} - p_i = \overline{u} + X - t(1 - \widehat{\theta}_{(1-\alpha)(1-\beta)}) - p_j \Leftrightarrow \widehat{\theta}_{(1-\alpha)(1-\beta)} = \frac{1}{2} - \frac{p_i - p_j}{2t}. \end{aligned} \tag{1.3}$$

Notation is: $\overline{u}$ — individual utility from good consumption; X — utility from project

[8] There are four categories of consumers: environmentally concerned consumers who care about the project (proportion $\alpha\beta$); concerned consumers who do not care about the project ($\alpha(1-\beta)$); unconcerned consumers who care about the project ($(1-\alpha)\beta$); unconcerned consumers who do not care about the project ($(1-\alpha)(1-\beta)$).

realization; p_i and p_j — prices of goods sold by firm i and firm j, respectively; α — proportion of consumers with environmental concerns; δ — marginal damage from 'dirty' production; β — proportion of consumers who care about the project; γ — warm-glow derived by consumers who care about the project and participate in funding it; $\widehat{\theta}_{\alpha\beta}, \widehat{\theta}_{\alpha(1-\beta)}, \widehat{\theta}_{(1-\alpha)\beta}, \widehat{\theta}_{(1-\alpha)(1-\beta)}$ — locations on the unit population segment of the indifferent consumer within each category; t — marginal transport cost.

Demand functions for firm i and firm j are then $\Lambda_i = \alpha\beta\widehat{\theta}_{\alpha\beta} + \alpha(1-\beta)\widehat{\theta}_{\alpha(1-\beta)} + (1-\alpha)\beta\widehat{\theta}_{(1-\alpha)\beta} + (1-\alpha)(1-\beta)\widehat{\theta}_{(1-\alpha)(1-\beta)} = \frac{1}{2} - \frac{p_i - p_j + \alpha\delta + \beta\gamma}{2t}$ and $\Lambda_j = 1 - \Lambda_i$, respectively.[9] Firms maximize profit functions $\Pi_i(p_i, p_j, \alpha, \delta, \beta, \gamma) = p_i\Lambda_i(p_i, p_j, \alpha, \delta, \beta, \gamma)$ and $\Pi_j(p_i, p_j, c, \alpha, \delta, \beta, \gamma, X) = (p_j - c)[1 - \Lambda_i(p_i, p_j, \alpha, \delta, \beta, \gamma)] - X$, respectively, where c is the marginal cost of 'clean' production and X is the amount needed to realize the project. Equilibrium prices are obtained by solving both firms' maximization problems, $\frac{\partial \Pi_i}{\partial p_i} = 0$ and $\frac{\partial \Pi_j}{\partial p_j} = 0$ if and only if:

$$p_i^* = t - \frac{(\alpha\delta - c) + \beta\gamma}{3} \text{ and } p_j^* = t + \frac{\alpha\delta + 2c + \beta\gamma}{3}, \text{ respectively.} \tag{1.4}$$

Plugging these into the earlier demand and profit functions yields equilibrium demand and profit levels:

$$\Lambda_i^* = \frac{1}{2} - \frac{(\alpha\delta - c) + \beta\gamma}{6t} \text{ and } \Lambda_j^* = \frac{1}{2} + \frac{(\alpha\delta - c) + \beta\gamma}{6t}, \text{ respectively;} \tag{1.5}$$

$$\Pi_i^* = \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 \text{ and } \Pi_j^* = \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 - X, \text{ respectively.} \tag{1.6}$$

[9] We assume t is always large enough to generate an interior solution for all categories of consumers. This is in line with the classic Hotelling model which noted the solution is "subject to the limitation that the difference between the prices must not exceed the cost of transportation from A to B" (Hotelling, 1990, p. 56). In our setting A is at $\theta = 0$ and B is at $\theta = 1$ (i.e., the ends of the unit length segment), and the equivalent assumption is $\widehat{\theta}_{(1-\alpha)(1-\beta)} \in (0,1)$: from (1.3), $\frac{1}{2} - \frac{p_i - p_j}{2t} > 0 \Leftrightarrow p_i - p_j < t; \frac{1}{2} - \frac{p_i - p_j}{2t} < 1 \Leftrightarrow p_j - p_i < t$. We extend this assumption to all categories of consumers for model tractability (i.e., $\widehat{\theta}_{\alpha\beta}, \widehat{\theta}_{\alpha(1-\beta)}, \widehat{\theta}_{(1-\alpha)\beta}, \widehat{\theta}_{(1-\alpha)(1-\beta)} \in (0,1)$), for which it is sufficient that t is always large enough. For sufficiently low values of t it becomes possible for one firm to serve all consumers in one or more categories, or even the whole market (demand equals one).

NGO's payoff, which we denote by Ω, is obtained by subtracting 'dirty' production damage $\delta \times \Lambda_i^*$ from environmental benefits X generated through the project:

$$\Omega = X - \delta \left[\frac{1}{2} - \frac{(\alpha\delta - c) + \beta\gamma}{6t} \right]. \tag{1.7}$$

The same method presented above yields payoffs for all other partnering outcomes.

Of the ten Stage 1 strategies available (Fig. 1.1), five are on equilibrium paths, and five are never played by the NGO. The analysis focuses on the former and presents the rationale for ruling out the latter along the way.

Figure 1.2 presents firms' Stage 2 strategies, as well as firms' and NGO's payoffs, for all five Stage 1 strategies that the NGO may play in the game. Firms' and NGO's payoffs from (1.6) and (1.7) appear twice: first when in Stage 1 the NGO proposes partnerships on clean production to firm i, and on clean production and project to firm j ($[P_i(c, \cdot), P_j(c, X)]$), but in Stage 2 firm i rejects whereas firm j accepts (R, A); and second when in Stage 1 the NGO proposes a partnership only to firm j on clean production and project ($[\varnothing, P_j(c, X)]$), and in Stage 2 firm j accepts (A). The NGO ends up implementing partnership on clean production and project with firm j and no partnership with firm i under both sequences of players' moves, as in the example above.

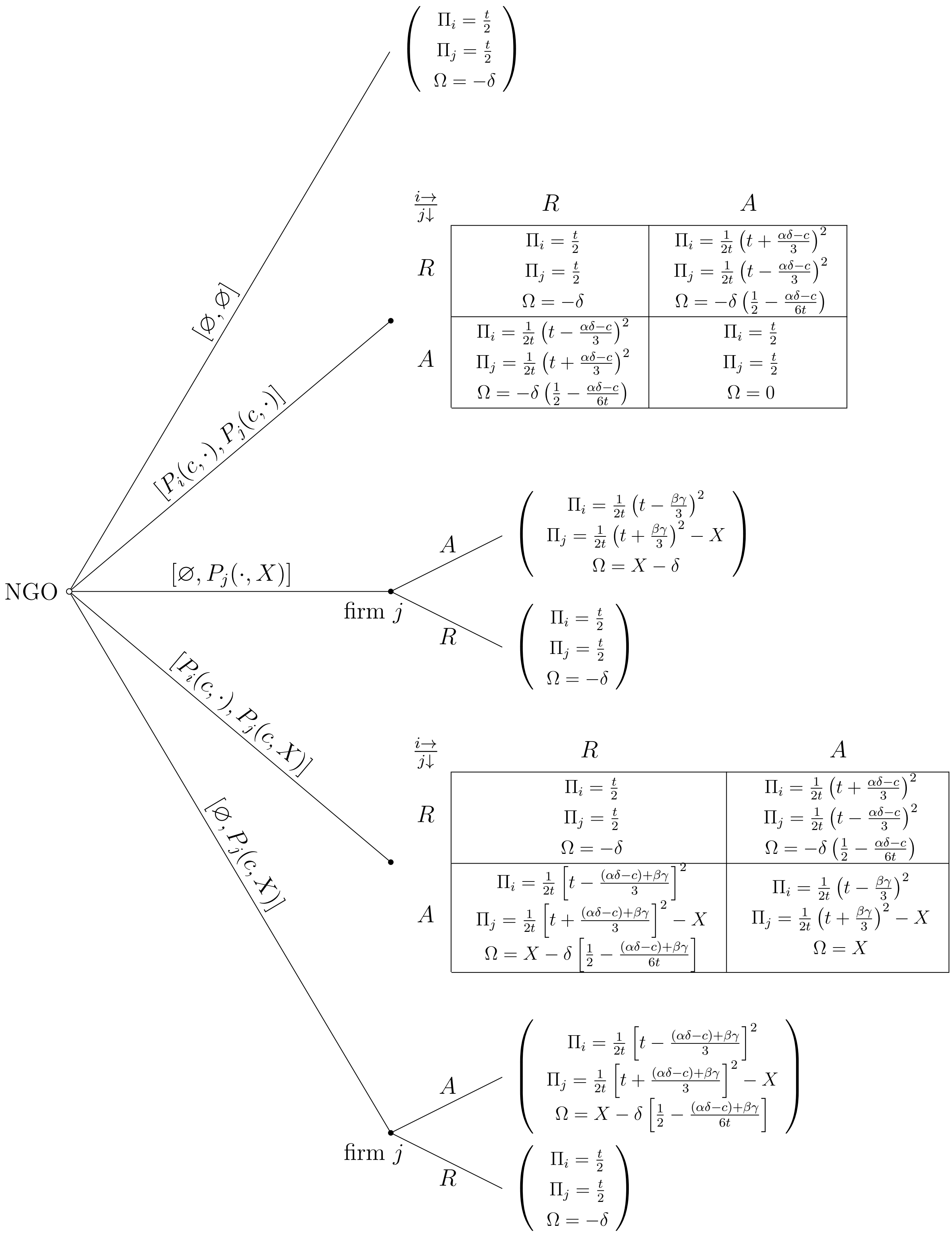

Figure 1.2: Two-stage game (omits NGO's unplayed strategies)

No partnerships

Starting again from the top, first in Figure 1.2 is NGO's strategy of not proposing any partnerships $[\varnothing, \varnothing]$; firms and NGO obtain default payoffs. Firms produce using the existing 'dirty' technology and split the market equally $\Pi_i = \Pi_j = \frac{t}{2}$. The NGO does not generate any environmental benefits and obtains the minimum payoff in this game $\Omega = -\delta$ from total environmental damage generated by the two firms.

Partnerships on 'clean' production with both firms

Second in Figure 1.2 is NGO's strategy of proposing 'clean' adoption to both firms $[P_i(c,\cdot), P_j(c,\cdot)]$ in Stage 1. Then in Stage 2 firms play the corresponding partnership acceptance game that we present in Table 1.1.

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$
A	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$

Table 1.1: Firms' Stage 2 acceptance game of $[P_i(c,\cdot), P_j(c,\cdot)]$

It is a strictly dominant strategy for each firm to accept (reject) for $c < \alpha\delta$ ($c > \alpha\delta$).[10] Elimination of strictly dominated strategies at each cost level leads to two Nash equilibria: $(A, A)^{NE}$ for $c < \alpha\delta$, $(R, R)^{NE}$ for $c > \alpha\delta$.

Moreover, given the dominant strategies above, it follows that a firm would accept to unilaterally adopt 'clean' under same cost conditions if the NGO provided that opportunity in Stage 1 ($[\varnothing, P_j(c,\cdot)]$, 2nd NGO strategy in Fig. 1.1).

In Stage 1 the NGO knows that each firm is willing to adopt 'clean' production for $c < \alpha\delta$, whether its competitor also adopts or not. Partnering on 'clean' production with only one

[10] $\Pi_i(A,R) > \Pi_i(R,R) \Leftrightarrow c < \alpha\delta$ and $\Pi_i(A,A) > \Pi_i(R,A) \Leftrightarrow c < \alpha\delta$; $\Pi_j(R,A) > \Pi_j(R,R) \Leftrightarrow c < \alpha\delta$ and $\Pi_j(A,A) > \Pi_j(A,R) \Leftrightarrow c < \alpha\delta$.

firm is strictly dominated by partnering with both firms, for any $c < \alpha\delta$: the NGO prefers a fully 'clean' market to a partly 'clean' market.

Therefore $[\varnothing, P_j(c, \cdot)]$ is the first NGO strategy we rule out as strictly dominated by $[P_i(c, \cdot), P_j(c, \cdot)]$ for any $c < \alpha\delta$.

In the absence of an environmental project tool, $[\varnothing, P_j(c, \cdot)]$ and $[P_i(c, \cdot), P_j(c, \cdot)]$ would be the only strategies available to the NGO besides the default strategy $[\varnothing, \varnothing]$. Then the NGO would propose $[P_i(c, \cdot), P_j(c, \cdot)]$ in Stage 1, and both firms would accept $(A, A)^{NE}$ in Stage 2 for any $c < \alpha\delta$. The NGO would not propose any partnership $[\varnothing, \varnothing]$, and firms and NGO would obtain default payoffs for any $c > \alpha\delta$. Thus the 'clean' technology is viable if and only if $c < \alpha\delta$.

Proposition 1.1. *The 'clean' production technology is viable if its marginal cost is sufficiently low relative to environmental concern and marginal damage from 'dirty' production,* $c < \alpha\delta$.

Partnership on environmental project with one firm

Third in Figure 1.2 is NGO's strategy of proposing full project sponsorship to one firm $[\varnothing, P_j(\cdot, X)]$. In Stage 2 firm j accepts if its payoff is higher than the default payoff obtained if it rejects;

$$[\varnothing, P_j(\cdot, X)] : \Pi_j(A) > \Pi_j(R) \Leftrightarrow \frac{1}{2t}\left(t + \frac{\beta\gamma}{3}\right)^2 - X > \frac{t}{2} \Leftrightarrow \tag{1.8}$$

$$\Leftrightarrow \gamma > \widetilde{\gamma}(\beta, X), \text{ where } \widetilde{\gamma}(\beta, X) \equiv \frac{1}{\beta}\left[\sqrt{(3t)^2 + 18tX} - 3t\right]. \tag{1.9}$$

A firm accepts to fully fund the environmental project as long as the level of participation warm-glow γ it elicits is high enough ($\gamma > \widetilde{\gamma}$) given the proportion of consumers who care about it β, and the amount needed for its realization X. This level of warm-glow gives the sponsoring firm a large enough competitive advantage that it can fully fund the project from the additional profit obtained as a result. The firm rejects otherwise ($\gamma < \widetilde{\gamma}$).

The strategy of partnering on the project with one firm $[\varnothing, P_j(\cdot, X)]$ is followed in Figure 1.1 by three strategies that propose to both firms partial project sponsorships ϕX and $(1-\phi)X$, respectively, for a total of X. None of these appear in Figure 1.2 because the two firms never accept to fund the project together. Table 1.2 presents firms' payoffs from accepting (A, A) such partnerships for all three strategies.[11]

firm $i \longrightarrow$ firm $j \downarrow$	$P_i(\cdot, \phi X)$	$P_i(c, \phi X)$
$P_j(\cdot, (1-\phi)X)$	$\Pi_i = \frac{t}{2} - \phi X$ $\Pi_j = \frac{t}{2} - (1-\phi)X$	$\Pi_i = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2 - \phi X$ $\Pi_j = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2 - (1-\phi)X$
$P_j(c, (1-\phi)X)$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2 - \phi X$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2 - (1-\phi)X$	$\Pi_i = \frac{t}{2} - \phi X$ $\Pi_j = \frac{t}{2} - (1-\phi)X$

Table 1.2: Firms' payoffs if both accept partial sponsorships

One firm's rejection of such a partnership is sufficient for the firms to obtain default payoffs $\Pi_i = \Pi_j = \frac{t}{2}$ instead.[12] It is immediately obvious for pairs of partnerships $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$ and $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$ that both firms are better off with default payoffs rather than sponsoring the project together ($\frac{t}{2} - \phi X < \frac{t}{2}$ and $\frac{t}{2} - (1-\phi)X < \frac{t}{2}$, $\forall \phi \in (0, 1)$, $\forall X > 0$).

In case of the former ($[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$) none of the firms would obtain a competitive advantage from project sponsorships because consumers who care about the project would derive participation warm-glow regardless of which firm they would buy from. Nevertheless firms would have to make strictly positive donations, leaving them worse off.

In case of the latter ($[P_i(c, \phi X), P_j(c, (1-\phi)X)]$) none of the firms would obtain a competitive advantage from symmetric 'clean' technology adoption, nor from project sponsorship, yet they would still have to make strictly positive donations, leaving them

[11]Firms' Stage 2 acceptance games for Stage 1 partnerships proposals $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$, $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$ and $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$ are presented in full (inclusive of (A, R), (R, A) and (R, R) outcomes) in Appendix A Tables 1.6 and 1.7.

[12]By assumption the project is indivisible and generates zero environmental benefits with less than X in funding. If one firm accepts, but the other one rejects, the NGO cannot realize the project. The partnership with the accepting firm falls through because the NGO fails to deliver on its side of the deal (project realization).

worse off. It follows that (A, A) is never a Nash equilibrium in these cases because it is in the interest of each firm to deviate, reject, and obtain the higher default payoff.

In case of asymmetric 'clean' adoption[13] $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$ at least one firm is better off with the default payoff rather than sponsoring the project together with its competitor. If the 'clean' technology is viable ($c < \alpha\delta$), then non-adopting firm i would be at a competitive disadvantage from 'dirty' production, would not get a competitive advantage from project sponsorship, and would have to make strictly positive donation ϕX, leaving it worse off. If the 'clean' technology is not viable ($c > \alpha\delta$), then adopting firm j would be at a competitive disadvantage from 'clean' production, would not get a competitive advantage from project sponsorship, and would have to make strictly positive donation $(1-\phi)X$, leaving it worse off. It follows that (A, A) cannot be a Nash equilibrium because it is in the interest of at least one firm to deviate, reject, and obtain the higher default payoff.

Thus there is always at least one firm that rejects a partnership proposal to sponsor NGO's project together with its competitor, and therefore in Stage 1 the NGO never proposes such partnerships to the firms.[14]

Remark 1.1. *Firms do not fund NGO's environmental project together.*

In the absence of a 'clean' technology, $[\varnothing, P_j(\cdot, X)]$ and $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X]$ would be the only strategies available to the NGO besides the default strategy $[\varnothing, \varnothing]$. Remark 1.1 rules out sponsorship by both firms. This leaves single firm sponsorship $[\varnothing, P_j(\cdot, X)]$ as the only way in which the NGO can realize the project in isolation, provided warm-glow is high enough $\gamma > \widetilde{\gamma}(\beta, X)$ (1.8).

Then in the absence of a 'clean' technology tool, the NGO would propose $[\varnothing, P_j(\cdot, X)]$ in Stage 1 and firm j would accept (A) in Stage 2 for any $\gamma > \widetilde{\gamma}(\beta, X)$. The NGO would not

[13]Asymmetric 'clean' technology adoption case $[P_i(c, \phi X), P_j(\cdot, (1-\phi)X)]$ in Table 1.2 is equivalent to $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$, $i, j \in \{1, 2\}$.

[14]The NGO cannot implement partnership plan $P_i(c, \phi X)$ or $P_j(c, (1-\phi)X)$ on its own because it does not have enough funds to realize the project. In an Appendix B extension we assume the NGO implements the feasible portion of an accepted partnership when it does not obtain enough funds for its project (e.g., implements $P_i(c, \cdot)$ if in Stage 1 it offers $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$ and in Stage 2 firms (A, R)). We identify conditions under which both firms accept to fund NGO's project together under this assumption.

propose any partnership $[\varnothing, \varnothing]$, and firms and NGO would obtain default payoffs for any $\gamma < \widetilde{\gamma}(\beta, X)$. Thus the environmental project is viable if and only if $\gamma > \widetilde{\gamma}(\beta, X)$.

Proposition 1.2. *The environmental project is viable if the level of participation warm-glow it elicits is sufficiently high given the proportion β of consumers who care about the project and the amount X needed to realize the project, $\gamma > \widetilde{\gamma}(\beta, X)$.*

Partnerships on 'clean' production with both firms and on project with one firm

Fourth in Figure 1.2 is NGO's strategy of proposing 'clean' production adoption and full project sponsorship to one firm, and just 'clean' production adoption to its competitor $[P_i(c, \cdot), P_j(c, X)]$. Then in Stage 2 firms play the corresponding partnership acceptance game from Figure 1.2, which we present in Table 1.3.

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$
A	$\Pi_i = \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2$ $\Pi_j = \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 - X$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\beta\gamma}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\beta\gamma}{3}\right)^2 - X$

Table 1.3: Firms' Stage 2 acceptance game of $[P_i(c, \cdot), P_j(c, X)]$

Accepting (rejecting) the partnership is a strictly dominant strategy for firm i if and only if the 'clean' technology is viable (not viable).[15] Thus (A, A) can be a Nash equilibrium if and only if the 'clean' technology is viable.

Provided $c < \alpha\delta$, firm j has no incentive to deviate from (A, A) if and only if participation

[15] $[P_i(c, \cdot), P_j(c, X)]$: $\Pi_i(A, R) > \Pi_i(R, R) \Leftrightarrow \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2 > \frac{t}{2} \Leftrightarrow c < \alpha\delta$; $\Pi_i(A, A) > \Pi_i(R, A) \Leftrightarrow \frac{1}{2t}\left(t - \frac{\beta\gamma}{3}\right)^2 > \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 \Leftrightarrow c < \alpha\delta$; $\Pi_i(R, R) > \Pi_i(A, R) \Leftrightarrow c > \alpha\delta$; $\Pi_i(R, A) > \Pi_i(A, A) \Leftrightarrow c > \alpha\delta$.

warm-glow is high enough:

$$[P_i(c,\cdot),P_j(c,X)] : \Pi_j(A,A) > \Pi_j(A,R) \Leftrightarrow \gamma > \underline{\gamma},$$
$$\text{where } \underline{\gamma}(\alpha,\beta,\delta,c,X) \equiv \frac{1}{\beta}\left\{\sqrt{[3t-(\alpha\delta-c)]^2+18tX}-3t\right\}.$$

Thus both firms accept if and only if the 'clean' technology is viable and $\gamma > \underline{\gamma}$. The following relationship holds between $\underline{\gamma}(\alpha,\beta,\delta,c,X)$ and project's independent viability threshold $\widetilde{\gamma}(\beta,X)$ (1.9):

$$\underline{\gamma}(\alpha,\beta,\delta,c,X) < \widetilde{\gamma}(\beta,X), \forall c < \alpha\delta.$$

In Stage 1 the NGO always proposes $[P_i(c,\cdot),P_j(c,X)]$ if $c < \alpha\delta$ and $\gamma > \underline{\gamma}$, and firms accept $(A,A)^{NE}$ in Stage 2, because it is the only way the NGO obtains the maximum payoff in the game: project realization and 'clean' technology adoption by both firms.

Proposition 1.3. *For any viable 'clean' technology ($c < \alpha\delta$), a warm-glow interval $[\underline{\gamma},\widetilde{\gamma})$ exists over which the NGO implements a fully 'clean' market and realizes the environmental project, despite the project not being viable.*

As long as the 'clean' technology is viable firm j is willing to accept the dual partnership with the NGO on project and production at levels of warm-glow $\gamma \in [\underline{\gamma},\widetilde{\gamma})$ at which the project is not viable. Firm j knows that firm i accepts the viable 'clean' technology regardless of firm j's action. This would give firm i a competitive advantage and leave firm j at a competitive disadvantage if firm j rejects. Thus firm j accepts to fully sponsor the project in order to obtain the viable 'clean' technology as well. This way it avoids the loss of profit entailed by 'dirty' production, and uses some or all of the avoided loss to subsidize the full sponsorship of NGO's non-viable project.

Over the interval $[\underline{\gamma},\widetilde{\gamma})$ the NGO leverages the viable 'clean' technology into an implicit threat. It knows firm j will not reject in order to avoid the competitive disadvantage from firm i's sole adoption of the 'clean' technology. Thus although the NGO does not make an overt threat to firm j, it uses market competition to make a covert threat and obtain enough funds for its project.

We can eliminate here the fifth and last[16] Stage 1 strategy that the NGO never plays, $[P_i(c,\cdot), P_j(\cdot, X)]$. In Stage 2 firms would play a partnership acceptance game that we detail in Appendix A. As has been the case throughout the analysis, firm i accepts adoption if and only if the 'clean' technology is viable, which gives it a competitive advantage from 'clean' production in this case.

This implies that if firm j is willing to accept $P_j(\cdot, X)$, then it is necessarily willing to accept $P_j(c, X)$ because it would eliminate its competitive disadvantage from 'dirty' production. Then the NGO proposing $[P_i(c,\cdot), P_j(\cdot, X)]$ instead of $[P_i(c,\cdot), P_j(c, X)]$ in Stage 1, when in Stage 2 both firms accept either, would contradict the initial assumption that the NGO maximizes environmental benefits.

Therefore the NGO never plays $[P_i(c,\cdot), P_j(\cdot, X)]$ because under the same conditions under which both firms accept those partnerships, they are willing to accept $[P_i(c,\cdot), P_j(c, X)]$ instead, which gives the NGO a higher payoff, the maximum in the game.

Partnership on 'clean' production and project with one firm

Last of NGO's strategies both in Figure 1.1 and Figure 1.2 is that of offering a partnership on 'clean' production and environmental project to one firm only, and no partnership to its competitor $[\varnothing, P_j(c, X)]$. Then in Stage 2 firm j accepts if its profit is higher than if it rejects.

One and only one environmental tool has to be viable for the NGO to use this strategy. If both are viable, then the NGO offers $[P_i(c,\cdot), P_j(c, X)]$ instead, both firms accept and the NGO obtains maximum payoff. If none is viable then firm j rejects $P_j(c, X)$.

In keeping with the analysis so far, we first assume the 'clean' technology is viable ($c <$

[16] We have already eliminated $[\varnothing, P_j(c,\cdot)]$ as strictly dominated by $[P_i(c,\cdot), P_j(c,\cdot)]$, as well as $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$, $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$ and $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$, $\phi \in (0, 1)$, by Remark 1.1.

$\alpha\delta$), whereas the environmental project is not ($\gamma < \underline{\gamma}$)[17]. Then firm j accepts $P_j(c, X)$ if and only if participation warm-glow is high enough:

$$[\varnothing, P_j(c,X)] : \Pi_j(A) > \Pi_j(R) \Leftrightarrow \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 - X > \frac{t}{2} \Leftrightarrow \tag{1.10}$$

$$\Leftrightarrow \gamma > \underline{\underline{\gamma}}, \text{ where } \underline{\underline{\gamma}}(\alpha, \beta, \delta, c, X) \equiv \widetilde{\gamma}(\beta, X) - \frac{\alpha\delta - c}{\beta}. \tag{1.11}$$

We can establish the following relationships between $\underline{\underline{\gamma}}$, $\underline{\gamma}$ — above which the NGO uses the viable 'clean' technology as an implicit threat to obtain enough project funds, and $\widetilde{\gamma}$ — project's independent viability threshold:

$$\underline{\underline{\gamma}} < \underline{\gamma} < \widetilde{\gamma}, \forall c < \alpha\delta.$$

Incentivized by the competitive advantage from exclusive adoption of the viable 'clean' technology, firm j is willing to fully fund NGO's project at lower levels than $\underline{\gamma}$. The firm uses some or all of the additional profit from exclusive 'clean' production to subsidize the full sponsorship of NGO's project. This further increases the warm-glow interval over which the NGO can realize the project despite it being non-viable.

In Stage 1 the NGO knows that a warm-glow interval $[\underline{\underline{\gamma}}, \underline{\gamma})$ exists over which it can obtain enough funds for its project by offering the 'clean' technology only to sponsoring firm j and withholding it from its competitor. However the NGO also knows that since the technology is viable, it can forgo the project, offer 'clean' adoption to both firms, and obtain a fully 'clean' market instead.

In case of the latter NGO's payoff is simply zero as it eliminates environmental damage from the market. If it opts for project realization $[\varnothing, P_j(c, X)]$, its payoff is given by the generated environmental benefits X minus total damage from firm i's 'dirty' production.

[17] For $c < \alpha\delta$ and $\gamma > \underline{\gamma}$ the NGO proposes $[P_i(c, \cdot), P_j(c, X)]$ and obtains maximum payoff by Proposition 1.3.

As per Figure 1.2, $\Omega[\varnothing, P_j(c,X)] > \Omega[P_i(c,\cdot), P_j(c,\cdot)]$ if and only if:

$$X - \delta\left[\frac{1}{2} - \frac{(\alpha\delta - c) + \beta\gamma}{6t}\right] > 0 \Leftrightarrow \delta < \overline{\delta}, \tag{1.12}$$

$$\text{where } \overline{\delta}(\alpha,\beta,\gamma,c,X) \equiv \frac{1}{2\alpha}\left[(3t + c - \beta\gamma) - \sqrt{(3t + c - \beta\gamma)^2 - 24\alpha t X}\right]. \tag{1.13}$$

Provided the marginal damage is not too high ($\delta < \overline{\delta}$), the environmental benefits generated through the project outweigh total damage from 'dirty' production — which the NGO retains on the market for project funding purposes in this case. Thus in Stage 1 the NGO proposes $[\varnothing, P_j(c,X)]$, and firm j accepts (A) in Stage 2, if the 'clean' technology is viable, $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$, and $\delta < \overline{\delta}$.

Proposition 1.4. *For any viable 'clean' technology, and any project participation warm-glow $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$, a marginal damage level $\overline{\delta}$ exists, below which the NGO implements a partly 'clean' market and realizes the environmental project rather than implement a fully 'clean' market and not realize the project.*

Over the interval $[\underline{\underline{\gamma}}, \underline{\gamma})$, and provided damage is low enough ($\delta < \overline{\delta}$), the NGO leverages the viable 'clean' technology into an implicit incentive. It knows firm j will accept to fully fund NGO's non-viable project in order to gain the competitive advantage from exclusive adoption of the 'clean' technology. By withholding the viable 'clean' technology from firm i the NGO uses market competition to "sweeten up the deal" for firm j and obtain enough funds for its project.

An increase in environmental concern α in the population increases demand for firm j's 'clean' good and decreases demand for firm i's 'dirty' good, which means that total damage on the market decreases (from (1.12):$\frac{\partial\left[\left(\frac{1}{2} - \frac{\alpha\delta - c + \beta\gamma}{6t}\right)\delta\right]}{\partial\alpha} = -\frac{\delta^2}{6t}$). There are more concerned consumers who are inclined to purchase the 'clean' good, and thus "clean up" the market. This in turn reduces the environmental cost of the project option $[\varnothing, P_j(c,X)]$ for the NGO. It ultimately incentivizes the NGO to increase the damage threshold $\overline{\delta}$ below which it is willing to implement only a partly 'clean' market and realize the project, instead of a fully ‘clean’ market and forgo the project. Indeed, we find that $\frac{\partial\overline{\delta}(\alpha,\beta,\gamma,c,X)}{\partial\alpha} > 0$.

Proposition 1.5. *The marginal damage threshold $\overline{\delta}$ is increasing in the level of environmental concern α in the population.*

This can generate counterintuitive situations in which a more environmentally concerned population leads to fewer ‘clean’ options and higher environmental damage on the market. An increase in concern α leads to an increase in the marginal damage threshold $\overline{\delta}$, so some levels of damage at which the NGO preferred to implement a fully ‘clean’ market may become damage levels at which the NGO prefers to realize the project and implement only a partly ‘clean’ market instead.

Although it is true that the NGO does so in order to maximize environmental benefits, it is also true that under the specific conditions presented above the existence of an environmental project option has a negative impact on ‘clean’ technology adoption. The NGO and its partner firm capitalize on consumers’ environmental concerns to generate additional gross profit for the firm, which is then funneled towards NGO’s non-viable project.

If marginal damage is too high ($\delta > \overline{\delta}$), then the NGO implements a fully ‘clean’ market and forgoes the project ($\forall c < \alpha\delta, \gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$). The same applies if $\gamma < \underline{\underline{\gamma}}$ — there are no strategies under which the NGO can obtain enough funds for its project.

Assuming now that the project is viable, whereas the ‘clean’ technology is not ($\gamma > \widetilde{\gamma},\ c > \alpha\delta$), firm j accepts $[\varnothing, P_j(c,X)]$ in Stage 2 under the same condition derived at (1.10): if and only if participation warm-glow is high enough $\gamma > \underline{\underline{\gamma}}$. By re-arranging terms, $\underline{\underline{\gamma}}(\alpha,\beta,\delta,c,X) = \widetilde{\gamma}(\beta,X) + \frac{c-\alpha\delta}{\beta}$, it becomes obvious that

$$\underline{\underline{\gamma}} > \widetilde{\gamma}, \forall c > \alpha\delta.$$

In Stage 1 the NGO knows that firm j is willing to fully fund its project and adopt the ‘clean’ technology if $\gamma > \underline{\underline{\gamma}}$. Thus the NGO proposes $[\varnothing, P_j(c,X)]$ in Stage 1, and firm j accepts (A) in Stage 2, for any $c > \alpha\delta$ and $\gamma > \underline{\underline{\gamma}}$.

Proposition 1.6. *For any $c > \alpha\delta$ and any warm-glow level $\gamma > \underline{\underline{\gamma}}$ the NGO realizes the project and implements a partly 'clean' market despite the 'clean' technology not being viable.*

The NGO leverages the viable project into an incentive for the firm to adopt the non-viable 'clean' technology. Exclusive sponsorship gives firm j a competitive advantage. Provided $\gamma > \underline{\underline{\gamma}}$, it translates into enough additional profit to fully fund NGO's project and also subsidize adoption of the non-viable 'clean' technology.

The existence of a project option promotes 'clean' technology adoption in this case. In the absence of the viable project, the NGO would only have a non-viable 'clean' technology that none of the firms would want to adopt. Thus while the project option can generate circumstances under which the NGO reinforces 'dirty' production — by withholding the 'clean' technology from a firm that is willing to adopt it (Prop. 1.4) —, it can also generate circumstances under which the NGO promotes 'clean' technology adoption (Prop. 1.6).

We finalize the game analysis section with two remaining strategies the NGO may play if the 'clean' technology is not viable: project sponsorship only $[\varnothing, P_j(\cdot, X)]$, and default strategy $[\varnothing, \varnothing]$.

If the 'clean' technology is not viable and $\gamma \in [\widetilde{\gamma}, \underline{\underline{\gamma}})$, the competitive advantage from project sponsorship is not enough to fully fund the project and also subsidize 'clean' technology adoption. The environmental project is nonetheless viable ($\gamma > \widetilde{\gamma}$), so the NGO proposes $[\varnothing, P_j(\cdot, X)]$ in Stage 1, firm j accepts (A) and the NGO realizes the project in Stage 2.

The NGO does not offer any partnerships $[\varnothing, \varnothing]$ if and only if none of the environmental tools is viable ($c > \alpha\delta$, $\gamma < \widetilde{\gamma}$). None of the firms would accept 'clean' adoption and/or full project sponsorship, and the NGO has no leverage.

This concludes the analysis of all sequential equilibria in the game. We recapitulate all of them before we continue with welfare analysis.

1.2.6 Equilibria

Figure 1.3 presents an overview of all equilibrium outcomes in $c-\gamma$ space.

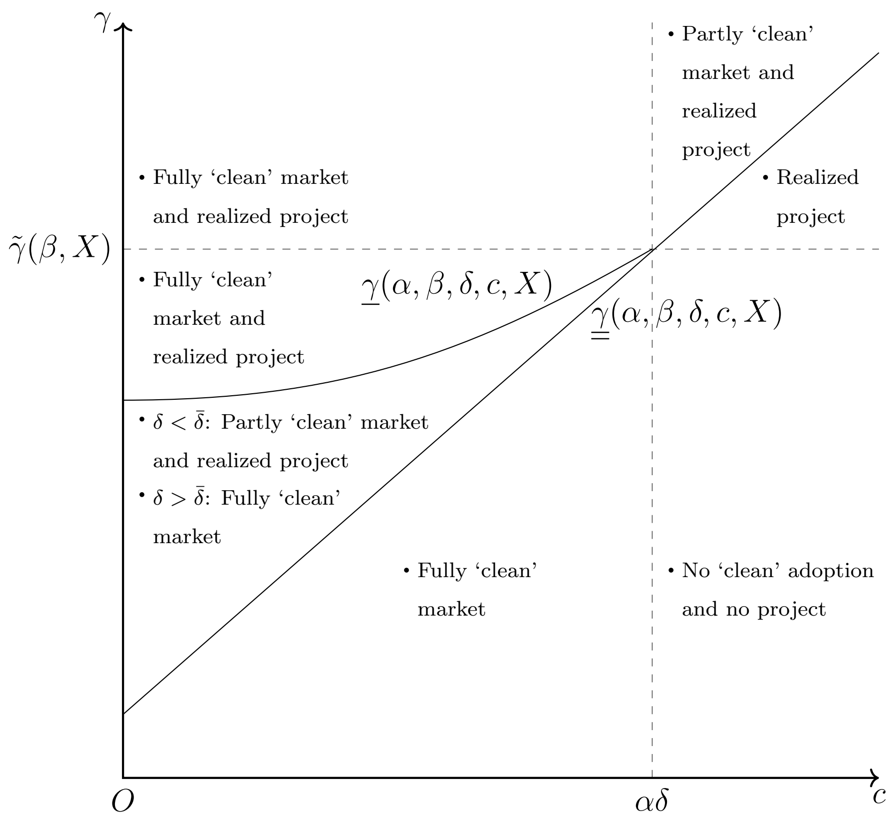

Figure 1.3: All equilibrium outcomes in $c-\gamma$ space

To the left of $c = \alpha\delta$ the 'clean' technology is viable, whereas to the right of $\alpha\delta$ it is not. In the absence of the environmental project, the 'clean' technology would get implemented if and only if $c < \alpha\delta$.

Above $\gamma = \widetilde{\gamma}(\beta, X)$ the environmental project is viable, whereas below $\widetilde{\gamma}(\beta, X)$ it is not. In the absence of the 'clean' technology, the environmental project would be realized if and only if $\gamma > \widetilde{\gamma}(\beta, X)$.

Wielding both environmental tools enables the NGO to "carve" in the graph areas over which it extracts more environmental benefits from the market.

Below $\widetilde{\gamma}$ on the $\gamma-$axis starts $\underline{\gamma}(\alpha, \beta, \delta, c, X)$, increases in c, and ends at coordinates $(\alpha\delta, \widetilde{\gamma})$. Above $\underline{\gamma}$ and below $\widetilde{\gamma}$ ($c < \alpha\delta$, $\gamma \in [\underline{\gamma}, \widetilde{\gamma})$) the NGO proposes $[P_i(c, \cdot), P_j(c, X)]$, both firms accept $(A, A)^{NE}$, and the NGO implements a fully ‘clean’ market and realizes the environmental project, despite the project not being viable (Prop. 1.3). Firm j accepts in order to avoid a competitive disadvantage from ‘dirty’ production, and uses some or all of the avoided profit loss to subsidize NGO’s non-viable project. Same sequential equilibrium applies when both tools are viable ($c < \alpha\delta$, $\gamma > \widetilde{\gamma}$).

Below $\underline{\gamma}$ on the $\gamma-$axis starts $\underline{\underline{\gamma}}(\alpha, \beta, \delta, c, X)$, increases in c, passes through coordinates $(\alpha\delta, \widetilde{\gamma})$, and extends to the right of $\alpha\delta$ and above $\widetilde{\gamma}(\beta, X)$. Above $\underline{\underline{\gamma}}$ and below $\underline{\gamma}$ ($c < \alpha\delta$, $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$), provided marginal damage is not too high ($\delta < \overline{\delta}$), the NGO proposes $[\varnothing, P_j(c, X)]$, firm j accepts (A), and the NGO implements a partly ‘clean’ market and realizes the environmental project rather than implement a fully ‘clean’ market and not realize the project (Prop. 1.4). Incentivized by exclusive use of the viable ‘clean’ technology, firm j uses some or all of the additional profit to subsidize NGO’s non-viable project.

Under the same conditions ($c < \alpha\delta$, $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$), but provided marginal damage is high ($\delta > \overline{\delta}$), the NGO prefers to forgo the non-viable project and proposes $[P_i(c, \cdot), P_j(c, \cdot)]$, both firms accept, and the NGO implements a fully ‘clean’ market. Same applies for $\gamma < \underline{\underline{\gamma}}$ and $c < \alpha\delta$, regardless of where marginal damage stands in relation to $\overline{\delta}$. There are no strategies under which the NGO can realize the project, but the ‘clean’ technology is nonetheless viable.

Above $\underline{\underline{\gamma}}$ and right of $\alpha\delta$ ($c > \alpha\delta$, $\gamma > \underline{\underline{\gamma}}$) the NGO proposes $[\varnothing, P_j(c, X)]$, firm j accepts (A), and the NGO realizes the project and implements a partly ‘clean’ market despite the ‘clean’ technology not being viable (Prop. 1.6). The firm uses some of the additional profit from exclusive project sponsorship to subsidize adoption of the non-viable ‘clean’ technology.

Below $\underline{\underline{\gamma}}$ and above $\widetilde{\gamma}$ ($c > \alpha\delta$, $\gamma \in [\widetilde{\gamma}, \underline{\underline{\gamma}})$) the NGO proposes $[\varnothing, P_j(\cdot, X)]$, firm j accepts (A), and the NGO realizes the project. The environmental project is viable, but the level of warm-glow is not high enough, and the sponsoring firm does not make enough additional profit to subsidize ‘clean’ adoption on top of fully funding the project.

Below $\widetilde{\gamma}$ and right of $\alpha\delta$ ($c > \alpha\delta$, $\gamma < \widetilde{\gamma}$) none of the tools is viable and the NGO has no leverage. Firms and NGO obtain default payoffs.

1.3 Welfare

A benevolent central planner evaluates the welfare-preferred pattern of NGO-firms partnerships. Total welfare comprises: consumers' utility from consumption ($\overline{u}$) and NGO's project if realized (X), net of transport costs (marginal cost t) and purchase prices (p_i, p_j); firms' revenues, net of production costs (marginal cost c if 'clean', 0 if 'dirty'), environmental costs (marginal damage δ if 'dirty', 0 if 'clean') and project funding costs (X total if realized). Purchase prices paid by consumers are revenues for the firms, so these terms cancel each other out. Consumers' utility from NGO's project equals total funding costs for firms, so these terms likewise cancel out ($X - X = 0$).[18]

The planner takes into account how environmental concern and warm-glow affect decisions of individuals and firms because their effects inform decisions regarding policy design. However it is not within planner's attributes to "manage" environmental concern and warm-glow, and thus they are not explicitly included in the welfare function, but their effects, on demand levels and travel costs for example, are.[19]

Given that consumption utility is fixed at $\overline{u}$, social planner's objective function reduces to minimizing total remaining costs in the model — production, environmental, and transport. To isolate the impact on welfare of a firm's monetary donation to fund NGO's project, which is arguably the more controversial component of a partnership, we fix the level of environmental concern in the population at $\alpha = 1$, such that all consumers internalize

[18]This stems from our assumption that the project requires X in funding to generate X environmental benefits. Welfare analysis becomes more nuanced if environmental benefits generated through the project are higher or lower than the funding costs. We will point out what difference alternative assumptions can make.

[19]With respect to warm-glow we follow Andreoni (2006), Diamond (2006), and Heyes and Kapur (2011), for examples. Andreoni (2006) concludes that "it is most prudent and most informative to first recognize that behavior is chosen by people seeking warm-glows, but then to set the social welfare maximizing goals that makes no adjustment for warm-glow in aggregating welfare. That is, all social welfare prescriptions should be made without counting warm-glow, but should be constrained by behavior that is dictated by seeking warm-glow" (p. 1227).

With respect to environmentally concerned consumers, they treat marginal production damage *as if* incident upon themselves when making decisions, but none actually is. Given that the social planner already accounts for environmental damage costs to society, taking into account consumers' environmental concerns would lead to double counting some or all (if $\alpha = 1$) of the damage.

damages. The $\alpha = 1$ case corresponds to what Heyes and Martin (2017) call 'fully-conscient' consumers; consumers are assumed fully-conscient throughout this welfare section.

Let us denote the aforementioned total remaining costs by Γ. It can then be shown that[20]:

$$\Gamma[\varnothing, \varnothing] = \delta + \left(\frac{t}{2}\right)^2; \tag{1.14}$$

$$\Gamma[P_i(c, \cdot), P_j(c, \cdot)] = c + \left(\frac{t}{2}\right)^2; \tag{1.15}$$

$$\Gamma[\varnothing, P_j(\cdot, X)] = \delta + \left(\frac{t}{2}\right)^2 + \beta\left[\frac{(3-2\beta)\gamma}{6}\right]^2 + (1-\beta)\left(\frac{2\beta\gamma}{6}\right)^2; \tag{1.16}$$

$$\Gamma[P_i(c, \cdot), P_j(c, X)] = c + \left(\frac{t}{2}\right)^2 + \beta\left[\frac{(3-2\beta)\gamma}{6}\right]^2 + (1-\beta)\left(\frac{2\beta\gamma}{6}\right)^2; \tag{1.17}$$

$$\Gamma[\varnothing, P_j(c, X)] = \delta\left(\frac{1}{2} - \frac{\delta - c + \beta\gamma}{6t}\right) + c\left(\frac{1}{2} + \frac{\delta - c + \beta\gamma}{6t}\right) + \left(\frac{t}{2}\right)^2 + \tag{1.18}$$

$$+ \beta\left[\frac{(\delta - c) + (3-2\beta)\gamma}{6}\right]^2 + (1-\beta)\left[\frac{(\delta - c) - 2\beta\gamma}{6}\right]^2. \tag{1.19}$$

We can then establish the following relationships:

$$c < \delta : [P_i(c, \cdot), P_j(c, \cdot)] \text{ is the lowest cost partnering outcome;} \tag{1.20}$$

$$c > \delta : \Gamma[\varnothing, \varnothing] \text{ is the lowest cost partnering outcome (no partnerships).} \tag{1.21}$$

A fully 'clean' market and no project is the welfare-preferred outcome when marginal cost of 'clean' production is lower than marginal damage of 'dirty' production. No adoption and no project is the welfare-preferred outcome when marginal cost of 'clean' production is higher than marginal damage of 'dirty' production.

[20]Using again outcome $[\varnothing, P_j(c, X)]$ as an example, total environmental costs are $\delta \times \Lambda_i$, and total production costs are $c \times \Lambda_j$, where demand levels Λ_i and Λ_j for firms' 'dirty' and 'clean' products, respectively, are obtained from (1.5) by setting $\alpha = 1$. Plugging equilibrium prices from (1.4) into locations of indifferent consumers from (1.1) and (1.2), and likewise setting $\alpha = 1$, yields $\widehat{\theta}_\beta = \frac{1}{2} - \frac{(\delta-c)+(3-2\beta)\gamma}{6t}$ and $\widehat{\theta}_{(1-\beta)} = \frac{1}{2} - \frac{(\delta-c)-2\beta\gamma}{6t}$. Then total travel costs are: $\beta\left(\int_0^{t\widehat{\theta}_\beta} \theta d\theta + \int_0^{t(1-\widehat{\theta}_\beta)} \theta d\theta\right) + (1-\beta)\left(\int_0^{t\widehat{\theta}_{(1-\beta)}} \theta d\theta + \int_0^{t(1-\widehat{\theta}_{(1-\beta)})} \theta d\theta\right)$.

Absent a project option the NGO implements the welfare-preferred outcome. With fully-conscient consumers the 'clean' technology is viable for any $c < \delta$ (Prop. 1.1). Then the NGO partners with both firms on 'clean' production if $c < \delta$, and partners with none if $c > \delta$.

The environmental project option can incentivize the NGO to deviate from the welfare-preferred outcome. Project realization in partnership with one of the firms when firms use symmetric production technologies increases consumers' transport costs (see (1.16) and (1.17) compared to (1.14) and (1.15), respectively).

Deviation from the welfare-preferred outcome is likewise welfare decreasing when firms end up using different production technologies (1.18). If the 'clean' technology is viable ($c < \delta$), the NGO withholds it from firm i, and offers it only to firm j in order to obtain enough project funding from it (Prop. 1.4), then costs to society increase through two channels. First, firm i produces 'dirty' when 'clean' production is socially-preferred. Second, consumers' travel costs increase. If the 'clean' technology is not viable ($c > \delta$), and the NGO incentivizes firm j to adopt it with exclusive sponsorship of its viable project (Prop. 1.6), then costs to society increase because firm j produces 'clean' when 'dirty' production is socially-preferred, and due to higher travel costs incurred by consumers.

Proposition 1.7. *NGO project realization in partnership with one firm is detrimental to welfare.*

This result is sensitive to the assumption that the project generates exactly X environmental benefits with X in funding. If benefits were lower while the cost remained the same, then the added net cost of the project only strengthens the result above. However, if benefits were higher, while the cost remained the same, it becomes a question of how high are the net benefits. If they are high enough to offset the increase in costs to society discussed above, then project realization in partnership with one firm increases welfare.

The result nonetheless cautions that NGO-firm partnerships which involve a project sponsorship by one of the firms can reduce welfare under multiple partnering outcomes.

1.4 Conclusions

The number of NGO-firm partnerships has been increasing over the past three decades, and is expected to grow to the detriment of confrontational NGO tactics such as boycotts, litigation, and government lobbying. Litigation and government lobbying tend to be costly and can take a long time, whereas boycotts rarely impact targets enough to determine them to make a meaningful change in practices. This trend is driven not only by firms and NGOs, but also by consumers, as consumer activists tend to be younger, and more active and engaged in supportive actions rather than boycott actions.

We provide the first model of cooperative private politics that captures the main elements of these increasingly common NGO-firm(s) partnerships, while also accounting for firms' strategic interactions. Within its framework an NGO can partner with one or two firms with the help of two environmental tools: 'clean' production and an environmental project.

As long as one tool is independently viable, the NGO can use it as leverage when it partners with one or both firms, and thus also implement a non-viable tool. In essence the NGO uses the competition between the two firms to extract more environmental benefits from the market.

The NGO can use a viable environmental project as an incentive to determine the sponsoring firm to also adopt a non-viable 'clean' technology. In this case the NGO has a positive impact on 'clean' technology adoption. Absent the environmental project, none of the firms would adopt the 'clean' technology.

Likewise, the NGO can use a viable 'clean' technology as a threat or as a reward to determine an adopting firm to also fully fund a non-viable project.

The implicit threat comes from NGO's strategy of offering the 'clean' technology on its own to a firm's competitor. At the same time the NGO offers to the firm a partnership on both 'clean' production and project sponsorship. In order to avoid a competitive disadvantage from 'dirty' production and obtain the viable 'clean' technology as well, the firm accepts NGO's partnership offer and uses some or all of the avoided profit loss to subsidize

NGO's non-viable project.

The NGO can further increase the set of circumstances under which it obtains enough funds for its non-viable project. It can reward the sponsoring firm by withholding the viable 'clean' technology from its competitor. Incentivized by the competitive advantage from exclusive 'clean' adoption, the firm accepts and uses some or all of the additional profit to subsidize full project sponsorship. Thus the NGO may prefer a partly 'clean' market (one firm) to a fully 'clean' market (both firms) if it can obtain enough funds to realize its environmental project.

Of course, the NGO prefers this outcome only if the marginal environmental damage is low enough, such that the environmental benefits generated through the project outweigh the environmental damage remaining on the market. However, this marginal environmental damage threshold is increasing in population's level of environmental concern. This can generate circumstances under which a more concerned population has access to fewer 'clean' options than a less concerned population.

By creating a 'clean'–'dirty' mixed-production market through its partnership strategy, the NGO utilizes consumers' environmental concerns to shift more custom towards the firm it partners with, and the additional profit is partly or fully funneled towards the environmental project. In this case the project option has a negative impact on 'clean' technology adoption. Absent the environmental project, the NGO would partner with both firms on 'clean' production.

Welfare analysis shows that the project option can be detrimental to welfare under multiple partnering outcomes. While the analysis is sensitive to assumptions about the output of the project relative to its funding costs, and about consumers' level of environmental concern, this possibility is best underscored by NGO's strategy of withholding a viable 'clean' technology from a firm in order to obtain full project sponsorship from the second firm. If consumers are less than fully-conscient (some do not have environmental concerns), firms are ready to adopt 'clean' production at lower costs than socially desirable, so the market already under-adopts it. By withholding the technology from one of the firms the NGO exacerbates under-adoption in order to realize the project. The project is then detrimental to welfare unless the benefits it generates fully offset the costs imposed on society by its realization.

Therefore our model provides arguments for both camps on the issue of partnerships between NGOs and firms. There are circumstances under which a viable project incentivizes a firm to adopt a non-viable 'clean' technology. There are also circumstances under which an NGO withholds a viable 'clean' production from a firm in order to obtain enough project funding from its competitor, which reduces 'clean' adoption and can be detrimental to welfare.

The issue is further complicated by the fact that in both cases the sequential equilibrium looks the same: the NGO offers partnership on 'clean' production and environmental project to one firm, and makes no offer to firm's competitor; the firm accepts and the NGO implements. These interactions take place in a perfect information setting in the model, but in reality sponsorships and projects are usually widely publicized, whereas cost considerations remain private information.

Consequently we would likely not know whether 'clean' adoption is made possible by the project, or whether the project is made possible by the NGO withholding the 'clean' technology from firm's competitor. To an outside observer they both look the same.

In the short-run these results point out that partnerships between firms and NGOs need to be more transparent in order to understand whether they are beneficial or detrimental to market adoption of 'clean' practices. Some governments already reward NGOs and firms that form partnerships. This raises questions on how government involvement affects firms' and NGOs' partnering strategies, how many and what kind of partnerships occur in equilibrium, what are the implications for NGOs that refuse to partner with firms or governments, and others.

In the long-run they raise questions for further research on whether such activities by

NGOs are desirable in our economies. If the NGO competes with other firms to produce 'clean' technologies, or as a 'clean' production consultant, how does this affect the market for 'clean' technologies? Since NGOs benefit from subsidies, what are the effects of these subsidies on competition in the 'clean' technologies sector, on the 'clean' technologies and services that are generated and implemented, and is this an NGO activity that should be subsidized?

With growing and diversifying partnerships between firms and NGOs it becomes increasingly useful to understand how they affect interactions between firms and NGOs, and how they influence generation and adoption of 'clean' technologies. As this paper points out, sometimes it is not as much what the NGO does, but rather what the NGO does not do.

1.5 Appendix A

The game unfolds as follows. Stage 1: NGO chooses a partnering strategy from the following: $[\varnothing,\varnothing]$, $[\cdot, P_j(c,\cdot)]$, $[P_i(c,\cdot), P_j(c,\cdot)]$, $[\varnothing, P_j(\cdot, X)]$, $[P_i(\cdot,\phi X), P_j(\cdot,(1-\phi)X)]$, $[P_i(\cdot,\phi X), P_j(c,(1-\phi)X)]$, $[P_i(c,\phi X), P_j(c,(1-\phi)X)]$, $[P_i(c,\cdot), P_j(c,X)]$, $[P_i(c,\cdot), P_j(\cdot,X)]$, $[\varnothing, P_j(c,X)]$, $\phi \in (0,1)$, $i,j \in \{1,2\}$. Stage 2: firms accept (A) or reject (R) and NGO implements accepted partnership(s), firms set prices and obtain profits, consumers update information and make purchases.

Solve by backward induction starting with Stage 2. Without loss of generality we solve as example for the case in which firm j adopts the 'clean' technology and fully funds the project while firm i produces 'dirty'. We obtain payoffs for all other cases employing the same method. The indifferent consumers within each category[21] are characterized by the

[21]There are four categories of consumers: environmentally concerned consumers who care about the project (proportion $\alpha\beta$); concerned consumers who do not care about the project ($\alpha(1-\beta)$); unconcerned consumers who care about the project ($(1-\alpha)\beta$); unconcerned consumers who do not care about the project ($(1-\alpha)(1-\beta)$).

following equations for implemented outcome $[\varnothing, P_j(c, X)]$:

$$\overline{u} + X - t\widehat{\theta}_{\alpha\beta} - p_i - \delta = \overline{u} + X - t(1 - \widehat{\theta}_{\alpha\beta}) - p_j + \gamma \Leftrightarrow \widehat{\theta}_{\alpha\beta} = \frac{1}{2} - \frac{p_i - p_j + \delta + \gamma}{2t};$$

$$\overline{u} + X - t\widehat{\theta}_{\alpha(1-\beta)} - p_i - \delta = \overline{u} + X - t(1 - \widehat{\theta}_{\alpha(1-\beta)}) - p_j \Leftrightarrow \widehat{\theta}_{\alpha(1-\beta)} = \frac{1}{2} - \frac{p_i - p_j + \delta}{2t};$$

$$\overline{u} + X - t\widehat{\theta}_{(1-\alpha)\beta} - p_i = \overline{u} + X - t(1 - \widehat{\theta}_{(1-\alpha)\beta}) - p_j + \gamma \Leftrightarrow \widehat{\theta}_{(1-\alpha)\beta} = \frac{1}{2} - \frac{p_i - p_j + \gamma}{2t};$$

$$\overline{u} + X - t\widehat{\theta}_{(1-\alpha)(1-\beta)} - p_i = \overline{u} + X - t(1 - \widehat{\theta}_{(1-\alpha)(1-\beta)}) - p_j \Leftrightarrow \widehat{\theta}_{(1-\alpha)(1-\beta)} = \frac{1}{2} - \frac{p_i - p_j}{2t}.$$

Notation: $\overline{u}$ — individual utility from good consumption; X — individual utility from project realization; p_i and p_j — prices of goods sold by firm i and firm j, respectively; α — proportion of consumers with environmental concerns; δ — marginal damage from 'dirty' production; β — proportion of consumers who care about the project; γ — warm-glow derived by consumers who care about the project and participate in funding it; $\widehat{\theta}_{\alpha\beta}, \widehat{\theta}_{\alpha(1-\beta)}, \widehat{\theta}_{(1-\alpha)\beta}, \widehat{\theta}_{(1-\alpha)(1-\beta)}$ — locations on the unit population segment of the indifferent consumer within each category; t — marginal transport cost.

Demand functions are: $\Lambda_i(p_i, p_j, \alpha, \delta, \beta, \gamma) = \alpha\beta\widehat{\theta}_{\alpha\beta} + \alpha(1-\beta)\widehat{\theta}_{\alpha(1-\beta)} + (1-\alpha)\beta\widehat{\theta}_{(1-\alpha)\beta} + (1-\alpha)(1-\beta)\widehat{\theta}_{(1-\alpha)(1-\beta)} = \frac{1}{2} - \frac{p_i - p_j + \alpha\delta + \beta\gamma}{2t}$ and $\Lambda_j = 1 - \Lambda_i$, respectively. Firms maximize profit functions $\Pi_i(p_i, p_j, \alpha, \delta, \beta, \gamma) = p_i\Lambda_i(p_i, p_j, \alpha, \delta, \beta, \gamma)$and $\Pi_j(p_i, p_j, c, \alpha, \delta, \beta, \gamma, X) = (p_j - c)[1 - \Lambda_i(p_i, p_j, \alpha, \delta, \beta, \gamma)] - X$, respectively, where c is the marginal cost of 'clean' production and X is the amount needed to realize the project. Equilibrium prices are: $\frac{\partial \Pi_i}{\partial p_i} = 0$ and $\frac{\partial \Pi_j}{\partial p_j} = 0 \Leftrightarrow p_i^* = t - \frac{(\alpha\delta - c) + \beta\gamma}{3}$ and $p_j^* = t + \frac{\alpha\delta + 2c + \beta\gamma}{3}$, respectively. Plugging these into the earlier demand and profit functions yields equilibrium demand and profit levels $\Lambda_i^* = \frac{1}{2} - \frac{(\alpha\delta - c) + \beta\gamma}{6t}$ and $\Lambda_j^* = \frac{1}{2} + \frac{(\alpha\delta - c) + \beta\gamma}{6t}$, respectively, and $\Pi_i^* = \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2$ and $\Pi_j^* = \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 - X$, respectively.

NGO's payoff is obtained by subtracting 'dirty' production damage $\delta \times \Lambda_i^*$ from environmental benefits X generated through the project: $\Omega = X - \delta\left[\frac{1}{2} - \frac{(\alpha\delta - c) + \beta\gamma}{6t}\right]$.

Table 1.4 presents firms and NGO payoffs for all possible outcomes implemented by NGO in Stage 2, with the exception of three that involve partial project sponsorships

$[P_i(\cdot,\phi X), P_j(\cdot,(1-\phi)X)]$, $[P_i(\cdot,\phi X), P_j(c,(1-\phi)X)]$, $[P_i(c,\phi X), P_j(c,(1-\phi)X)]$, which are addressed separately in the proof of Remark 1.1.

firm $i \longrightarrow$ firm $j \downarrow$	$\varnothing$	$P_i(c,\cdot)$
$\varnothing$	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$ $\Omega = -\delta$	$\Pi_i = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$ $\Omega = -\delta\left(\frac{1}{2} - \frac{\alpha\delta - c}{6t}\right)$
$P_j(c,\cdot)$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$ $\Omega = -\delta\left(\frac{1}{2} - \frac{\alpha\delta - c}{6t}\right)$	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$ $\Omega = 0$
$P_j(\cdot,X)$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\beta\gamma}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\beta\gamma}{3}\right)^2 - X$ $\Omega = X - \delta$	$\Pi_i = \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) - \beta\gamma}{3}\right]^2$ $\Pi_j = \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) - \beta\gamma}{3}\right]^2 - X$ $\Omega = X - \delta\left[\frac{1}{2} + \frac{(\alpha\delta - c) - \beta\gamma}{6t}\right]$
$P_j(c,X)$	$\Pi_i = \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2$ $\Pi_j = \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 - X$ $\Omega = X - \delta\left[\frac{1}{2} - \frac{(\alpha\delta - c) + \beta\gamma}{6t}\right]$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\beta\gamma}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\beta\gamma}{3}\right)^2 - X$ $\Omega = X$

Table 1.4: Firms' and NGO's payoffs

Proposition 1.1 proof: Assuming the NGO does not have an environmental project, its set of Stage 1 strategies reduces to: $[\varnothing,\varnothing]$, $[\varnothing, P_j(c,\cdot)]$, $[P_i(c,\cdot), P_j(c,\cdot)]$. In Stage 2 firms i and/or j accept (A) or reject (R) an NGO offer, $i,j \in \{1,2\}$; then NGO implements accepted partnerships, firms set prices and obtain profits, consumers update information and make purchases.

If NGO proposes $[\varnothing, P_j(c,\cdot)]$ in Stage 1, then in Stage 2 firm j accepts iff $\Pi_j(A) > \Pi_j(R) \Leftrightarrow \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2 > \frac{t}{2} \Leftrightarrow c < \alpha\delta$.

If NGO proposes $[P_i(c,\cdot), P_j(c,\cdot)]$ in Stage 1, then in Stage 2 firms play the partnership acceptance game presented in Table 1.5.

(A) is a strictly dominant strategy for each firm, $\forall\, c < \alpha\delta$, while (R) is a strictly dominant strategy for each firm, $\forall\, c > \alpha\delta$: $\Pi_i(A,A) > \Pi_i(R,A) \Leftrightarrow c < \alpha\delta$; $\Pi_i(A,R) > \Pi_i(R,R) \Leftrightarrow c < \alpha\delta$; $\Pi_j(A,A) > \Pi_j(A,R) \Leftrightarrow c < \alpha\delta$; $\Pi_j(R,A) > \Pi_j(R,R) \Leftrightarrow c < \alpha\delta$.

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$
A	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$

Table 1.5: Firms' Stage 2 acceptance game of $[P_i(c,\cdot), P_j(c,\cdot)]$

By elimination of strictly dominated strategies: $(A,A)^{NE} \Leftrightarrow c < \alpha\delta$, $(R,R)^{NE} \Leftrightarrow c > \alpha\delta$.

In Stage 1 NGO knows each firm accepts 'clean' adoption iff $c < \alpha\delta$. $[\varnothing, P_j(c,\cdot)]$ is strictly dominated by $[P_i(c,\cdot), P_j(c,\cdot)]$, and therefore the NGO never plays it: $\Omega[P_i(c,\cdot), P_j(c,\cdot)] > \Omega[\varnothing, P_j(c,\cdot)] > \Omega[\varnothing,\varnothing]$, $\forall c < \alpha\delta$.

Remark 1.2. *NGO strategy* $[\varnothing, P_j(c,\cdot)]$ *is strictly dominated by* $[P_i(c,\cdot), P_j(c,\cdot)]$.

In the absence of an environmental project, in Stage 1: NGO $[P_i(c,\cdot), P_j(c,\cdot)] \Leftrightarrow c < \alpha\delta$; NGO $[\varnothing,\varnothing] \Leftrightarrow c > \alpha\delta$.

Conclusion: The 'clean' production technology is viable if its marginal cost is sufficiently low relative to environmental concern and marginal damage from 'dirty' production, $c < \alpha\delta$.

Remark 1.1 proof: There are three Stage 1 strategies that propose partial project funding to the firms: $[P_i(\cdot,\phi X), P_j(\cdot,(1-\phi)X)]$, $[P_i(\cdot,\phi X), P_j(c,(1-\phi)X)]$, $[P_i(c,\phi X), P_j(c,(1-\phi)X)]$, $\phi \in (0,1)$, $i,j \in \{1,2\}$.

If NGO proposes $[P_i(\cdot,\phi X), P_j(\cdot,(1-\phi)X)]$ or $[P_i(c,\phi X), P_j(c,(1-\phi)X)]$ in Stage 1, then in Stage 2 firms play the partnership acceptance game presented in Table 1.6.[22]

(A,A) is never a Nash equilibrium: $\Pi_i(A,A) < \Pi_i(R,A)$ and $\Pi_j(A,A) < \Pi_j(A,R)$, $\forall \phi \in (0,1)$, $X > 0$. $(R,R)^{NE}$, $(R,A)^{NE}$ and $(A,R)^{NE}$ as none of the firms can make itself better off by deviating: $\Pi_{i/j}(R,R) = \Pi_{i/j}(R,A) = \Pi_{i/j}(A,R) > \Pi_{i/j}(R,R)$.

If NGO proposes $[P_i(\cdot,\phi X), P_j(c,(1-\phi)X)]$ in Stage 1, then in Stage 2 firms play the partnership acceptance game presented in Table 1.7.

[22]It is sufficient for one firm to reject for the NGO not to be able to realize the project. If the competing firm accepts, the NGO cannot deliver on project realization and therefore the partnership falls through. Firms and NGO obtain default payoffs $\Pi_i = \Pi_j = \frac{t}{2}$, $\Omega = -\delta$.

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$
A	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{t}{2} - \phi X$ $\Pi_j = \frac{t}{2} - (1-\phi)X$

Table 1.6: Firms' Stage 2 acceptance game of $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$ or $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$
A	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2 - \phi X$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2 - (1-\phi)X$

Table 1.7: Firms' Stage 2 acceptance game of $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$

(A, A) is never a Nash equilibrium: $\Pi_i(A, A) < \Pi_i(R, A)$, $\forall c < \alpha\delta$, $\phi \in (0, 1)$, $X > 0$; $\Pi_j(A, A) < \Pi_j(A, R)$, $\forall c > \alpha\delta$, $\phi \in (0, 1)$, $X > 0$. $(R, R)^{NE}$ as none of the firms can make itself better off by deviating: $\Pi_{i/j}(R, R) = \Pi_{i/j}(R, A) = \Pi_{i/j}(A, R)$. (A, R) and/or (R, A) may or may not be Nash equilibria, depending on the values of α, δ, c, ϕ, X, however that is irrelevant for our analysis. It is relevant that whenever (A, R) and/or (R, A) are Nash equilibria, firms' payoffs are same as for $(R, R)^{NE}$, and that (A, A) is never a Nash equilibrium.

Thus (A, A) is never a Nash equilibrium for any of the three Stage 1 partnering strategies that propose partial project funding.

In Stage 1 NGO knows this. By assumption the NGO does not make a partnership offer if indifferent, and therefore the NGO never plays $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$, $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$, $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$, $\phi \in (0, 1)$, $i, j \in \{1, 2\}$.

Remark 1.3. *NGO never plays strategies* $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$, $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$, $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$ *as* (A, A) *is never a Nash equilibrium, and the NGO does not offer partnerships* ($[\varnothing, \varnothing]$) *if indifferent.*

Conclusion: Firms never fund NGO's environmental project together.

Proposition 1.2 proof: Assuming the NGO does not have a 'clean' technology, its set of Stage 1 strategies reduces to: $[\varnothing, \varnothing]$, $[\varnothing, P_j(\cdot, X)]$, $[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$. In Stage 2 firms i and/or j accept (A) or reject (R) an NGO offer, $i, j \in \{1, 2\}$; then NGO implements accepted partnerships, firms set prices and obtain profits, consumers update information and make purchases.

$[P_i(\cdot, \phi X), P_j(\cdot, (1-\phi)X)]$ is ruled out by Remark 1.1.

If NGO proposes $[\varnothing, P_j(\cdot, X)]$, firm j accepts iff $\Pi_j(A) > \Pi_j(R) \Leftrightarrow \frac{1}{2t}\left(t + \frac{\beta\gamma}{3}\right)^2 - X > \frac{t}{2} \Leftrightarrow \gamma > \widetilde{\gamma}(\beta, X)$, where:

$$\widetilde{\gamma}(\beta, X) \equiv \frac{1}{\beta}\left[\sqrt{(3t)^2 + 18tX} - 3t\right]. \tag{1.22}$$

In Stage 1 the NGO knows it can only realize the project if fully funded by one firm.

In the absence of a 'clean' technology, in Stage 1: NGO $[\varnothing, P_j(\cdot, X)] \Leftrightarrow \gamma > \widetilde{\gamma}$; NGO $[\varnothing, \varnothing] \Leftrightarrow \gamma < \widetilde{\gamma}$.

Conclusion: The environmental project is viable if the level of participation warm-glow it elicits is sufficiently high given the proportion β of consumers who care about the project and the amount X needed to realize the project, $\gamma > \widetilde{\gamma}(\beta, X)$.

Proposition 1.3 proof: If NGO offers $[P_i(c, \cdot), P_j(c, X)]$ in Stage 1, then in Stage 2 firms play the partnership acceptance game presented in Table 1.8.

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$
A	$\Pi_i = \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2$ $\Pi_j = \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 - X$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\beta\gamma}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\beta\gamma}{3}\right)^2 - X$

Table 1.8: Firms' Stage 2 acceptance game of $[P_i(c, \cdot), P_j(c, X)]$

(A) is a strictly dominant strategy for firm i, $\forall\ c < \alpha\delta$, while ($R$) is a strictly dominant strategy for firm i, $\forall\, c > \alpha\delta$: $\Pi_i(A,A) > \Pi_i(R,A) \Leftrightarrow c < \alpha\delta$; $\Pi_i(A,R) > \Pi_i(R,R) \Leftrightarrow c < \alpha\delta$.

If $c < \alpha\delta$, firm i accepts, while firm j accepts iff $\Pi_j(A,A) > \Pi_j(A,R) \Leftrightarrow \gamma > \underline{\gamma}(\alpha,\beta,\delta,c,X)$, where:

$$\underline{\gamma}(\alpha,\beta,\delta,c,X) \equiv \frac{1}{\beta}\left\{\sqrt{[3t-(\alpha\delta-c)]^2+18tX}-3t\right\},$$

and where $\underline{\gamma}(\alpha,\beta,\delta,c,X) < \frac{1}{\beta}\left[\sqrt{(3t)^2+18tX}-3t\right]$, $\forall c < \alpha\delta$, and therefore:

$$\underline{\gamma}(\alpha,\beta,\delta,c,X) < \widetilde{\gamma}(\beta,X), \forall c < \alpha\delta. \tag{1.23}$$

In Stage 1 the NGO knows it can obtain maximum payoff in the game iff $c < \alpha\delta$ and $\gamma > \underline{\gamma}$, and thus in Stage 1: NGO $[P_i(c,\cdot), P_j(c,X)]$, $\forall c < \alpha\delta$ and $\gamma > \underline{\gamma}$.

Remark 1.4. *Stage 1: NGO* $[P_i(c,\cdot), P_j(c,X)]$, $\forall c < \alpha\delta$, $\gamma > \underline{\gamma}$. *Stage 2: firms* $(A,A)^{NE}$. *Payoffs:* $\Pi_i = \frac{1}{2t}\left(t-\frac{\beta\gamma}{3}\right)^2$, $\Pi_j = \frac{1}{2t}\left(t+\frac{\beta\gamma}{3}\right)^2 - X$, $\Omega = X$.

Conclusion: For any viable 'clean' technology ($c < \alpha\delta$), a warm-glow interval $[\underline{\gamma}, \widetilde{\gamma})$ exists over which the NGO implements a fully 'clean' market and realizes the environmental project, despite the project not being viable.

If NGO offers $[P_i(c,\cdot), P_j(\cdot,X)]$ in Stage 1, then in Stage 2 firms play the partnership acceptance game presented in Table 1.9.

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{1}{2t}\left(t+\frac{\alpha\delta-c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t-\frac{\alpha\delta-c}{3}\right)^2$
A	$\Pi_i = \frac{1}{2t}\left(t-\frac{\beta\gamma}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t+\frac{\beta\gamma}{3}\right)^2 - X$	$\Pi_i = \frac{1}{2t}\left[t+\frac{(\alpha\delta-c)-\beta\gamma}{3}\right]^2$ $\Pi_j = \frac{1}{2t}\left[t-\frac{(\alpha\delta-c)-\beta\gamma}{3}\right]^2 - X$

Table 1.9: Firms' Stage 2 acceptance game of $[P_i(c,\cdot), P_j(\cdot,X)]$

(A) is a strictly dominant strategy for firm i, $\forall c < \alpha\delta$: $\Pi_i(A,A) > \Pi_i(R,A) \Leftrightarrow c < \alpha\delta$

and $\Pi_i(A,R) > \Pi_i(R,R) \Leftrightarrow c < \alpha\delta$.

Firm j has no incentive to deviate from (A,A) iff $\Pi_j(A,A) > \Pi_j(A,R) \Leftrightarrow$

$\Leftrightarrow \gamma > \frac{1}{\beta}\left\{\sqrt{[3t-(\alpha\delta-c)]^2+18tX}-[3t-(\alpha\delta-c)]\right\}$, which is higher than $\widetilde{\gamma}(\beta,X)$ (from 1.22), $\forall c < \alpha\delta$.

In Stage 1 the NGO knows that under the conditions under which both firms accept $[P_i(c,\cdot),P_j(\cdot,X)]$, they would accept $[P_i(c,\cdot),P_j(c,X)]$ instead ($c<\alpha\delta$, $\gamma>\underline{\gamma}$, where $\underline{\gamma}<\widetilde{\gamma}$, $\forall c<\alpha\delta$). $[P_i(c,\cdot),P_j(\cdot,X)]$ is strictly dominated by $[P_i(c,\cdot),P_j(c,X)]$: $\Omega[P_i(c,\cdot),P_j(c,X)] > \Omega[P_i(c,\cdot),P_j(\cdot,X)]$.

Remark 1.5. *NGO strategy* $[P_i(c,\cdot),P_j(\cdot,X)]$ *is strictly dominated by* $[P_i(c,\cdot),P_j(c,X)]$.

Remark 1.6. $[P_i(c,\cdot),P_j(\cdot,X)]$ *is the fifth and final NGO strategy we can eliminate, together with* $[\varnothing,P_j(c,\cdot)]$ *(Prop. 1.1 proof) and* $[P_i(\cdot,\phi X),P_j(\cdot,(1-\phi)X)]$, $[P_i(\cdot,\phi X),P_j(c,(1-\phi)X)]$, $[P_i(c,\phi X),P_j(c,(1-\phi)X)]$ *(Remark 1.1 proof).*

Remark 1.7. *This leaves five strategies that the NGO may play:* $[P_i(c,\cdot),P_j(c,X)]$ *(solved in Prop. 1.3 proof), and* $[\varnothing,P_j(c,X)]$, $[P_i(c,\cdot),P_j(c,\cdot)]$, $[\varnothing,P_j(\cdot,X)]$, $[\varnothing,\varnothing]$ *for which we solve below.*

Proposition 1.4 proof: Assuming $c<\alpha\delta$, if NGO proposes $[\varnothing,P_j(c,X)]$ in Stage 1, then in Stage 2 firm j accepts iff $\Pi_j(A) > \Pi_j(R) \Leftrightarrow \frac{1}{2t}\left[t+\frac{(\alpha\delta-c)+\beta\gamma}{3}\right]^2 - X > \frac{t}{2} \Leftrightarrow \gamma > \underline{\underline{\gamma}}(\alpha,\beta,\delta,c,X)$, where:

$$\underline{\underline{\gamma}}(\alpha,\beta,\delta,c,X) \equiv \widetilde{\gamma}(\beta,X) - \frac{\alpha\delta-c}{\beta}.$$

Moreover, $\widetilde{\gamma}(\beta,X)-\frac{\alpha\delta-c}{\beta} < \underline{\gamma}(\alpha,\beta,\delta,c,X)$, $\forall c<\alpha\delta$, and using (1.23) it follows that:

$$\underline{\underline{\gamma}}(\alpha,\beta,\delta,c,X) < \underline{\gamma}(\alpha,\beta,\delta,c,X) < \widetilde{\gamma}(\beta,X), \forall c<\alpha\delta. \tag{1.24}$$

In Stage 1 the NGO knows firm j accepts $[\varnothing,P_j(c,X)]$ if $c<\alpha\delta$ and $\gamma>\underline{\underline{\gamma}}$, and that firms accept $[P_i(c,\cdot),P_j(c,\cdot)]$ if $c<\alpha\delta$ (Prop. 1.1 proof). The NGO prefers the former over the latter iff $\Omega[\varnothing,P_j(c,X)] > \Omega[P_i(c,\cdot),P_j(c,\cdot)] \Leftrightarrow X-\delta\left[\frac{1}{2}-\frac{(\alpha\delta-c)+\beta\gamma}{6t}\right] > 0 \Leftrightarrow \delta < \overline{\delta}$, where:

$$\overline{\delta}(\alpha,\beta,\gamma,c,X) \equiv \frac{1}{2\alpha}\left[(3t+c-\beta\gamma)-\sqrt{(3t+c-\beta\gamma)^2-24\alpha tX}\right]. \tag{1.25}$$

In Stage 1 NGO proposes $[\varnothing, P_j(c,X)]$ if $\delta < \overline{\delta}$, $c < \alpha\delta$, $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$. We have already established that for $\gamma > \underline{\gamma}$ NGO proposes $[P_i(c,\cdot), P_j(c,X)]$ (Prop. 1.3 proof).

Conclusion: For any viable 'clean' technology, and any project participation warm-glow $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$, a marginal damage level $\overline{\delta}$ exists, below which the NGO implements a partly 'clean' market and realizes the environmental project rather than implement a fully 'clean' market and not realize the project.

Proposition 1.5 proof: $\frac{\partial\overline{\delta}(\alpha,\beta,\gamma,c,X)}{\partial\alpha} > 0 \Leftrightarrow$

$\Leftrightarrow \frac{1}{2\alpha^2}\left[\sqrt{(3t+c-\beta\gamma)^2-24\alpha tX}-(3t+c-\beta\gamma)+\frac{12\alpha tX}{\sqrt{(3t+c-\beta\gamma)^2-24\alpha tX}}\right] > 0 \Leftrightarrow$

$\Leftrightarrow \frac{(3t+c-\beta\gamma)^2-12\alpha tX-(3t+c-\beta\gamma)\sqrt{(3t+c-\beta\gamma)^2-24\alpha tX}}{2\alpha^2\sqrt{(3t+c-\beta\gamma)^2-24\alpha tX}} > 0 \Leftrightarrow (3t+c-\beta\gamma)^2-12\alpha tX > (3t+c-\beta\gamma)\sqrt{(3t+c-\beta\gamma)^2-24\alpha tX} \Leftrightarrow$

$\Leftrightarrow \quad [(3t+c-\beta\gamma)^2-12\alpha tX]^2 \quad > \quad \left[(3t+c-\beta\gamma)\sqrt{(3t+c-\beta\gamma)^2-24\alpha tX}\right]^2 \quad \Leftrightarrow$ $(12\alpha tX)^2 > 0, (T), \forall\alpha > 0, t > 0, X > 0.$

Conclusion: The marginal damage threshold $\overline{\delta}$ is increasing in the level of environmental concern in the population α.

Proposition 1.6 proof: Assuming $c > \alpha\delta$, if NGO proposes $[\varnothing, P_j(c,X)]$ in Stage 1, then in Stage 2 firm j accepts iff $\Pi_j(A) > \Pi_j(R) \Leftrightarrow \frac{1}{2t}\left[t+\frac{(\alpha\delta-c)+\beta\gamma}{3}\right]^2 - X > \frac{t}{2} \Leftrightarrow \gamma > \underline{\underline{\gamma}}(\alpha,\beta,\delta,c,X)$, where $\underline{\underline{\gamma}} = \widetilde{\gamma}(\beta,X) - \frac{\alpha\delta-c}{\beta} > \widetilde{\gamma}(\beta,X)$, $\forall c > \alpha\delta$:

$$\underline{\underline{\gamma}}(\alpha,\beta,\delta,c,X) > \widetilde{\gamma}(\beta,X), \forall c > \alpha\delta.$$

In Stage 1 NGO proposes $[\varnothing, P_j(c,X)]$ if $c > \alpha\delta$ and $\gamma > \underline{\underline{\gamma}}$. If $c > \alpha\delta$, then (A,A) cannot be a Nash equilibrium for strategies $[P_i(c,\cdot), P_j(c,X)]$ (Prop. 1.3 proof) and $[P_i(c,\cdot), P_j(c,\cdot)]$ (Prop. 1.1 proof). Strategy $[\varnothing, P_j(\cdot,X)]$ is strictly dominated here as $\Omega[\varnothing, P_j(c,X)] > \Omega[\varnothing, P_j(\cdot,X)]$.

Conclusion: For any $c > \alpha\delta$ a participation warm-glow threshold $\underline{\underline{\gamma}} > \widetilde{\gamma}$ exists, such that if $\gamma > \underline{\underline{\gamma}}$ then the NGO realizes the project and implements a partly 'clean' market despite the 'clean' technology not being viable.

Propositions 1.4 and 1.6 isolate the second sequential equilibrium below.

Remark 1.8. *Stage 1: NGO* $[\varnothing, P_j(c,X)]$*,* $\forall \delta < \overline{\delta}$*,* $c < \alpha\delta$*,* $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$*; and* $\forall c > \alpha\delta$*,* $\gamma > \underline{\underline{\gamma}}$*. Stage 2: firm* j (A)*. Payoffs:* $\Pi_i = \frac{1}{2t}\left[t - \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2$, $\Pi_j = \frac{1}{2t}\left[t + \frac{(\alpha\delta - c) + \beta\gamma}{3}\right]^2 - X$*,* $\Omega = X - \delta\left[\frac{1}{2} - \frac{(\alpha\delta - c) + \beta\gamma}{6t}\right]$*.*

In Stage 1 NGO proposes $[P_i(c,\cdot), P_j(c,\cdot)]$ if $\delta > \overline{\delta}$, $c < \alpha\delta$, $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$ as $\Omega[\varnothing, P_j(c,X)] < \Omega[P_i(c,\cdot), P_j(c,\cdot)] \Leftrightarrow \delta > \overline{\delta}$. It likewise proposes $[P_i(c,\cdot), P_j(c,\cdot)]$ if $c < \alpha\delta$ and $\gamma < \underline{\underline{\gamma}}$. If $\gamma < \underline{\underline{\gamma}}$, $\forall c < \alpha\delta$, then (A, A) cannot be a Nash equilibrium for $[P_i(c,\cdot), P_j(c,X)]$ (requires $\gamma > \underline{\gamma}$ per Prop. 1.3 proof, where $\underline{\gamma} > \underline{\underline{\gamma}}$, $\forall c < \alpha\delta$, per (1.24)) and firm j rejects $[\varnothing, P_j(c,X)]$ (Prop. 1.4 proof) or $[\varnothing, P_j(\cdot,X)]$ (Prop. 1.2 proof).

Remark 1.9. *Stage 1: NGO* $[P_i(c,\cdot), P_j(c,\cdot)]$*,* $\forall \delta > \overline{\delta}$*,* $c < \alpha\delta$*,* $\gamma \in [\underline{\underline{\gamma}}, \underline{\gamma})$*; and* $\forall c < \alpha\delta$*,* $\gamma < \underline{\underline{\gamma}}$*. Stage 2: firms* $(A, A)^{NE}$*. Payoffs:* $\Pi_i = \Pi_j = \frac{t}{2}$, $\Omega = 0$*.*

In Stage 1 NGO proposes $[\varnothing, P_j(\cdot,X)]$ if $c > \alpha\delta$, $\gamma \in [\widetilde{\gamma}, \underline{\underline{\gamma}})$. If $c > \alpha\delta$, then (A, A) cannot be a Nash equilibrium for $[P_i(c,\cdot), P_j(c,X)]$ (Prop. 1.3 proof) or $[P_i(c,\cdot), P_j(c,\cdot)]$ (Prop. 1.1 proof). If $\gamma < \underline{\underline{\gamma}}$, $\forall c > \alpha\delta$, firm j rejects $[\varnothing, P_j(c,X)]$ (Prop. 1.6 proof).

Remark 1.10. *Stage 1: NGO* $[\varnothing, P_j(\cdot,X)]$*,* $\forall c > \alpha\delta$*,* $\gamma \in [\widetilde{\gamma}, \underline{\underline{\gamma}})$*. Stage 2: firm* j (A)*. Payoffs:* $\Pi_i = \frac{1}{2t}\left(t - \frac{\beta\gamma}{3}\right)^2$, $\Pi_j = \frac{1}{2t}\left(t + \frac{\beta\gamma}{3}\right)^2 - X$*,* $\Omega = X - \delta$*.*

In Stage 1 NGO does not propose partnerships $[\varnothing, \varnothing]$ if $c > \alpha\delta$, $\gamma < \widetilde{\gamma}$ as the 'clean' technology is not viable (Prop. 1.1) and the environmental project is not viable (Prop. 1.2).

Remark 1.11. *Stage 1: NGO* $[\varnothing, \varnothing]$*,* $\forall c > \alpha\delta$*,* $\gamma < \widetilde{\gamma}$*. Stage 2: default payoffs* $\Pi_i = \Pi_j = \frac{t}{2}$*,* $\Omega = -\delta$*.*

Proposition 1.7 proof: We employ the same example from the beginning of the Analysis section to calculate total welfare costs for outcome $[\varnothing, P_j(c,X)]$. Assuming $\alpha = 1$, there are two types of consumers: consumers with environmental concerns who care about the project (proportion β), and consumers with environmental concerns who do not care about the project (proportion $(1-\beta)$). Then total welfare $TW = \overline{u} + X - p_i\Lambda_i - p_j\Lambda_j - \left[\beta\left(\int\limits_0^{t\widehat{\theta}_\beta}\theta d\theta + \int\limits_0^{t(1-\widehat{\theta}_\beta)}\theta d\theta\right) + (1-\beta)\left(\int\limits_0^{t\widehat{\theta}_{(1-\beta)}}\theta d\theta + \int\limits_0^{t(1-\widehat{\theta}_{(1-\beta)})}\theta d\theta\right)\right] + (p_i-\delta)\Lambda_i + (p_j-c)\Lambda_j - X$, where: $\overline{u}$ — individual utility from good consumption; X — utility from project realization, and cost of fully funding the project; Λ_i and Λ_j — demand for the good of firm i and firm j, respectively; p_i and p_j — prices of goods sold by firm i and firm j, respectively; t — marginal travel cost; $\widehat{\theta}_\beta, \widehat{\theta}_{(1-\beta)}$ — locations on the unit population segment of the indifferent consumer within each category; δ — marginal damage from 'dirty' production; c — marginal cost of 'clean' production.

Social planner's equivalent objective function is to minimize total net costs Γ, where in this case $([\varnothing, P_j(c, X)])$:

$$\Gamma = \delta \times \Lambda_i + c \times \Lambda_j + \left[\beta\left(\int\limits_0^{t\widehat{\theta}_\beta}\theta d\theta + \int\limits_0^{t(1-\widehat{\theta}_\beta)}\theta d\theta\right) + (1-\beta)\left(\int\limits_0^{t\widehat{\theta}_{(1-\beta)}}\theta d\theta + \int\limits_0^{t(1-\widehat{\theta}_{(1-\beta)})}\theta d\theta\right)\right].$$

Demand levels Λ_i and Λ_j for firms' 'dirty' and 'clean' products, respectively, are obtained from (1.5) by setting $\alpha = 1$. Plugging equilibrium prices from (1.4) into locations of indifferent consumers from (1.1) and (1.2), and likewise setting $\alpha = 1$, yields $\widehat{\theta}_\beta = \frac{1}{2} - \frac{(\delta-c)+(3-2\beta)\gamma}{6t}$ and $\widehat{\theta}_{(1-\beta)} = \frac{1}{2} - \frac{(\delta-c)-2\beta\gamma}{6t}$. Calculating yields total net costs.

Employing the same method for each outcome on an equilibrium path yields:

$$\begin{aligned}
\Gamma[\varnothing,\varnothing] &= \delta + \left(\frac{t}{2}\right)^2; \\
\Gamma[P_i(c,\cdot),P_j(c,\cdot)] &= c + \left(\frac{t}{2}\right)^2; \\
\Gamma[\varnothing,P_j(\cdot,X)] &= \delta + \left(\frac{t}{2}\right)^2 + \beta\left[\frac{(3-2\beta)\gamma}{6}\right]^2 + (1-\beta)\left(\frac{2\beta\gamma}{6}\right)^2; \\
\Gamma[P_i(c,\cdot),P_j(c,X)] &= c + \left(\frac{t}{2}\right)^2 + \beta\left[\frac{(3-2\beta)\gamma}{6}\right]^2 + (1-\beta)\left(\frac{2\beta\gamma}{6}\right)^2; \\
\Gamma[\varnothing,P_j(c,X)] &= \delta\left(\frac{1}{2} - \frac{\delta-c+\beta\gamma}{6t}\right) + c\left(\frac{1}{2} + \frac{\delta-c+\beta\gamma}{6t}\right) + \left(\frac{t}{2}\right)^2 + \\
&\quad + \beta\left[\frac{(\delta-c)+(3-2\beta)\gamma}{6}\right]^2 + (1-\beta)\left[\frac{(\delta-c)-2\beta\gamma}{6}\right]^2.
\end{aligned}$$

For any $c < \delta$: $\Gamma[P_i(c,\cdot),P_j(c,\cdot)] < \Gamma[\varnothing,\varnothing] < \Gamma[\varnothing,P_j(\cdot,X)]$; $\Gamma[P_i(c,\cdot),P_j(c,\cdot)] < \Gamma[P_i(c,\cdot),P_j(c,X)]$; $\Gamma[P_i(c,\cdot),P_j(c,\cdot)] < \Gamma[\varnothing,P_j(c,X)]$.

For any $c > \delta$: $\Gamma[\varnothing,\varnothing] < \Gamma[P_i(c,\cdot),P_j(c,\cdot)] < \Gamma[P_i(c,\cdot),P_j(c,X)]$; $\Gamma[\varnothing,\varnothing] < \Gamma[\varnothing,P_j(\cdot,X)]$; $\Gamma[\varnothing,\varnothing] < \Gamma[\varnothing,P_j(c,X)]$.

Conclusion: $[P_i(c,\cdot),P_j(c,\cdot)]$ is socially-preferred, $\forall c < \delta$, $[\varnothing,\varnothing]$ is socially-preferred, $\forall c > \delta$, and thus realizing the project in partnership with one firm ($[\varnothing,P_j(\cdot,X)]$ or $[P_i(c,\cdot),P_j(c,X)]$ or $[\varnothing,P_j(c,X)]$) reduces welfare.

1.6 Appendix B

We assume here that the NGO implements the feasible part of a partnership if it cannot implement the partnership as accepted by the firm. This applies only to NGO strategies $[P_i(\cdot,\phi X),P_j(c,(1-\phi)X]$ and $[P_i(c,\phi X),P_j(c,(1-\phi)X]$.

In the case of the former firms' Stage 2 acceptance game from Table 1.7 changes to:

(R) is a strictly dominant strategy for firm j, $\forall c > \alpha\delta$: $\Pi_j(A,R) > \Pi_j(A,A)$ and $\Pi_j(R,R) > \Pi_j(R,A)$, $\forall c > \alpha\delta, \phi \in (0,1), X > 0$. Thus for any $c > \alpha\delta$, (A,A) and (R,A)

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$
A	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2 - \phi X$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2 - (1-\phi)X$

Table 1.10: Firms' Stage 2 acceptance game of $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$

are not NE.

For any $c < \alpha\delta$ (A, A) cannot be a NE because $\Pi_i(R, A) > \Pi_i(A, A)$, but $(R, A)^{NE}$ because $\Pi_i(R, A) > \Pi_i(A, A)$ and $\Pi_j(R, A) > \Pi_j(R, R)$, $\forall c < \alpha\delta, \phi \in (0, 1), X > 0$.

In Stage 1 the NGO knows that the most it can implement is $[\varnothing, P_j(c, \cdot)]$ if it offers $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$ and $c < \alpha\delta$. Then $[P_i(\cdot, \phi X), P_j(c, (1-\phi)X)]$ is strictly dominated by $[P_i(c, \cdot), P_j(c, \cdot)]$, $\forall c < \alpha\delta$, because firms $(A, A)^{NE}$ in Stage 2 and $\Omega[P_i(c, \cdot), P_j(c, \cdot)] > \Omega[\varnothing, P_j(c, \cdot)]$.

In the case of $[P_i(c, \phi X), P_j(c, (1-\phi)X]$ firms' Stage 2 acceptance game from Table 1.6 changes to:

firm $i \longrightarrow$ firm $j \downarrow$	R	A
R	$\Pi_i = \frac{t}{2}$ $\Pi_j = \frac{t}{2}$	$\Pi_i = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$
A	$\Pi_i = \frac{1}{2t}\left(t - \frac{\alpha\delta - c}{3}\right)^2$ $\Pi_j = \frac{1}{2t}\left(t + \frac{\alpha\delta - c}{3}\right)^2$	$\Pi_i = \frac{t}{2} - \phi X$ $\Pi_j = \frac{t}{2} - (1-\phi)X$

Table 1.11: Firms' Stage 2 acceptance game of $[P_i(c, \phi X), P_j(c, (1-\phi)X)]$

(R) is a strictly dominant strategy for each firm, $\forall c > \alpha\delta$: $\Pi_i(R, R) > \Pi_i(A, R) \Leftrightarrow c > \alpha\delta$; $\Pi_i(R, A) > \Pi_i(A, A)$, $\forall c > \alpha\delta, \phi \in (0, 1), X > 0$; $\Pi_j(R, R) > \Pi_j(R, A) \Leftrightarrow c > \alpha\delta$; $\Pi_j(A, R) > \Pi_j(A, A)$, $\forall c > \alpha\delta, \phi \in (0, 1), X > 0$. By elimination of strictly dominated strategies $(R, R)^{NE}$, $\forall c > \alpha\delta$.

$(A,A)^{NE}$ if $\Pi_i(A,A) > \Pi_i(R,A) \Leftrightarrow c < \alpha\delta - \left[3t - \sqrt{(3t)^2 - 18t\phi X}\right]$ and $\Pi_j(A,A) > \Pi_j(A,R) \Leftrightarrow c < \alpha\delta - \left[3t - \sqrt{(3t)^2 - 18t(1-\phi)X}\right]$, thus if and only if:

$$c < \min\left\{\alpha\delta - \left[3t - \sqrt{(3t)^2 - 18t\phi X}\right], \alpha\delta - \left[3t - \sqrt{(3t)^2 - 18t(1-\phi)X}\right]\right\}.$$

The fraction ϕ that maximizes the minimum c is $\phi = \frac{1}{2}$, and we assume the NGO always proposes an even sponsorship split.[23] Thus:

$$[P_i(c, X/2), P_j(c, X/2)] : (A,A)^{NE} \Leftrightarrow c < \widetilde{c}(\alpha, \delta, X),$$
$$\text{where } \widetilde{c}(\alpha, \delta, X) \equiv \alpha\delta - \left[3t - \sqrt{(3t)^2 - 9tX}\right].$$

Derive cost c at which firms accept $[P_i(c,\cdot), P_j(c,X)]$ for a given level of warm-glow γ. Firm i accepts iff $c < \alpha\delta$ (Prop. 1.3 proof), and therefore:

$$[P_i(c,\cdot), P_j(c,X)] : (A,A)^{NE} \Leftrightarrow c < \overline{c}(\alpha, \delta, \beta, \gamma, X),$$
$$\text{where } \overline{c}(\alpha, \delta, \beta, \gamma, X) \equiv \alpha\delta - \left[3t - \sqrt{(3t+\beta\gamma)^2 - 18tX}\right].$$

Derive cost c at which firm j accepts $[\varnothing, P_j(c,X)]$ for a given level of warm-glow γ:

$$[\varnothing, P_j(c,X)] : \Pi_j(A) > \Pi_j(R) \Leftrightarrow c < \overline{\overline{c}}(\alpha, \delta, \beta, \gamma, X),$$
$$\text{where } \overline{\overline{c}}(\alpha, \delta, \beta, \gamma, X) \equiv \alpha\delta - \beta(\widetilde{\gamma} - \gamma).$$

[23] This means that for low enough c the NGO may propose and firms may accept uneven sponsorship splits, however it is the maximum c at which firms accept to sponsor the project together that is most relevant for the analysis.

The relationship between $\bar{c}$ and $\bar{\bar{c}}$ is[24]:

$$\bar{\bar{c}}(\alpha, \delta, \beta, \gamma, X) > \bar{c}(\alpha, \delta, \beta, \gamma, X).$$

Compare $\widetilde{c}$ to $\bar{c}$ and $\bar{\bar{c}}$:

$$\widetilde{c} > \bar{c} \Leftrightarrow \gamma < \frac{1}{\beta}\left[\sqrt{(3t)^2 + 9tX} - 3t\right];$$
$$\widetilde{c} > \bar{\bar{c}} \Leftrightarrow \gamma < \widetilde{\gamma} - \frac{1}{\beta}\left[3t - \sqrt{(3t)^2 - 9tX}\right].$$

For any $\gamma > \frac{1}{\beta}\left[\sqrt{(3t)^2 + 9tX} - 3t\right]$, the relationship between cost thresholds is:

$$\widetilde{c} < \bar{c} < \bar{\bar{c}}.$$

If $c < \widetilde{c}$, then in Stage 1 the NGO is indifferent between $[P_i(c, X/2), P_j(c, X/2)]$ and $[P_i(c, \cdot), P_j(c, X)]$, in Stage 2 firms accept $(A, A)^{NE}$ either offer and NGO implements; the former is socially-preferred to the latter because the market is evenly split and thus travel costs are minimized.

If $\widetilde{c} < c < \bar{c}$, then in Stage 1 the NGO proposes $[P_i(c, \cdot), P_j(c, X)]$, in Stage 2 firms accept $(A, A)^{NE}$ and NGO implements.

If $\bar{c} < c < \bar{\bar{c}}$ and $\delta < \bar{\delta}$ (1.25), then in Stage 1 the NGO proposes $[\varnothing, P_j(c, X)]$, in Stage 2 firm j accepts (A) and NGO implements.

If $\bar{c} < c < \bar{\bar{c}}$ and $\delta > \bar{\delta}$, then in Stage 1 the NGO proposes $[P_i(c, \cdot), P_j(c, \cdot)]$, in Stage 2 firms accept $(A, A)^{NE}$ and NGO implements fully 'clean' market.

If $\bar{\bar{c}} < c < \alpha\delta$, then the previous sequential equilibrium likewise applies and NGO

[24] $\lim_{\gamma \to 0}(\bar{\bar{c}} - \bar{c}) = \left[3t - \sqrt{(3t)^2 - 18tX}\right] - \left[\sqrt{(3t)^2 + 18tX} - 3t\right] = 0 \Leftrightarrow X = 0$ and $\frac{\partial\left[\lim_{\gamma \to 0}(\bar{\bar{c}} - \bar{c})\right]}{\partial X} = 3t\left[\frac{1}{\sqrt{t(t-2X)}} - \frac{1}{\sqrt{t(t+2X)}}\right] > 0$, thus $\lim_{\gamma \to 0}(\bar{\bar{c}} - \bar{c}) > 0$. $\frac{\partial\left[\lim_{\gamma \to 0}(\bar{\bar{c}} - \bar{c})\right]}{\partial \gamma} = \beta\left[1 - \frac{3t + \beta\gamma}{\sqrt{(3t+\beta\gamma)^2 - 18tX}}\right] < 0$ and $\lim_{\gamma \to \widetilde{\gamma}}(\bar{\bar{c}} - \bar{c}) = 0$. Thus $\bar{\bar{c}} > \bar{c}$ for any $\gamma < \widetilde{\gamma}$, which is sufficient given that $[\varnothing, P_j(c, X)]$ is strictly dominated by $[P_i(c, \cdot), P_j(c, X)]$ when both of NGO's tools are viable $(c < \alpha\delta, \gamma > \widetilde{\gamma})$.

implements fully 'clean' market.

For any $\widetilde{\gamma} - \frac{1}{\beta}\left[3t - \sqrt{(3t)^2 - 9tX}\right] < \gamma < \frac{1}{\beta}\left[\sqrt{(3t)^2 + 9tX} - 3t\right]$, the relationship between cost thresholds is:

$$\overline{c} < \widetilde{c} < \overline{\overline{c}}.$$

If $c < \overline{c}$, then the NGO is indifferent between $[P_i(c, X/2), P_j(c, X/2)]$ and $[P_i(c, \cdot), P_j(c, X)]$, but the former is socially-preferred.

If $\overline{c} < c < \widetilde{c}$, then the NGO proposes $[P_i(c, X/2), P_j(c, X/2)]$.

If $\widetilde{c} < c < \overline{\overline{c}}$, then the NGO proposes $[\varnothing, P_j(c, X)]$ if $\delta < \overline{\delta}$, proposes $[P_i(c, \cdot), P_j(c, \cdot)]$ if $\delta > \overline{\delta}$.

If $\overline{\overline{c}} < c < \alpha\delta$, then the NGO proposes $[P_i(c, \cdot), P_j(c, \cdot)]$.

Finally, for any $\gamma < \widetilde{\gamma} - \frac{1}{\beta}\left[3t - \sqrt{(3t)^2 - 9tX}\right]$, the relationship between cost thresholds is:

$$\overline{c} < \overline{\overline{c}} < \widetilde{c}.$$

If $c < \overline{c}$, then the NGO is indifferent between $[P_i(c, X/2), P_j(c, X/2)]$ and $[P_i(c, \cdot), P_j(c, X)]$, but the former is socially-preferred.

If $\overline{c} < c < \widetilde{c}$, then the NGO proposes $[P_i(c, X/2), P_j(c, X/2)]$.

If $\widetilde{c} < c < \alpha\delta$, then the NGO proposes $[P_i(c, \cdot), P_j(c, \cdot)]$.

In general the strategy $[P_i(c, X/2), P_j(c, X/2)]$ in which the NGO follows through with implementing the feasible part of an accepted environmental plan ('clean' production, provided it is viable) is more likely to be employed when the level of project participation warm-glow is relatively low. Under both NGO strategies $[P_i(c, X/2), P_j(c, X/2)]$ and $[P_i(c, \cdot), P_j(c, X)]$ firm j is incentivized to avoid a competitive disadvantage from 'dirty' production. If warm-glow is low then the small competitive advantage from sole project sponsorship may cause firm j to reject full sponsorship, and the firm may be better off with a lower contribution to the project (half) and no competitive advantage from the sponsorship.

Chapter 2

Stigma and the Market for Green Products: Some Surprising Results

2.1 Introduction

Mitchell Pritchett: "I drive a Prius ... I think you'll find I am pretty nice to the environment."

Pritchett neighbor: "I have a car that runs on recycled vegetable oil. Loads of people do now, you know."

(Pritchett turns to camera looking chastened)

Modern Family (Season 5, Episode 12)

There is lots of evidence that how a consumer feels about the choices they make is sensitive to the choices of others (e.g., Leibenstein, 1950; Banerjee, 1992; Çelen & Kariv, 2004). This is particularly true in the case of purchases that have important environmental or social impacts (e.g., Vermeir & Verbeke, 2008; Salazar et al., 2013, Costa Pinto et al., 2014).

We model the effect on market outcomes by recognizing that in settings where decisions have important environmental implications, people making brown[1] choices may suffer stigma or social disapproval, but that such stigmatization is less pronounced when many others in the community make similarly brown choices. We characterize (a) demand behavior when individual choices are linked through this channel, and (b) the incentives for firms to supply new green products in markets where the demand side has this character.

The notion of stigma has been incorporated into economic models on several occasions and we can usefully identify two strands. In Moffitt (1983), Lindbeck et al. (1999) and Rasmusen (1996), for examples, it is a *behavior* that is stigmatized, such as accepting welfare handouts, or committing a crime. In each case the behavior is less stigmatizing when the behavior is more prevalent. Differently, in Bernheim (1994), Bénabou and Tirole (2006) and others, it is an agent's *type* that is subject to stigma, and behavior only matters insofar as it might cause observers of the behavior to update their beliefs about that type.

The two types of model have different mechanics but deliver broadly similar results. That which is most appropriate in any particular context — whether stigma attached to behavior, believed type or (most likely) some combination of the two — is an empirical question.[2] We follow the first, our operationalization of stigma is closest in spirit to that of Lindbeck et al. (1999).

The concept of stigma is closely related to that of social norms, but with a notion of directionality. It is not simply behaving differently from the crowd that might induce stigma. The definition of 'good' and 'bad' behavior, here making green or brown choices, is determined exogenously. There can never be stigma to behaving well (making a green choice), however the extent of stigma associated with bad behavior (making a brown choice) is endogenous and dependent on the fraction of the rest of the community also behaving badly.

[1]The terms "brown"/"dirty" and "green"/"clean" are used throughout to describe the polluting choice and the environmentally-friendly choice, respectively.

[2]For example, one national poll of adults in the United States "... found that environmentally unfriendly behaviors — such as littering or driving a gas guzzler — are emerging as a new definition of what's socially unacceptable in America" (Shelton Group, 2013). The reference to behavior here would be consistent with behavior-based stigma, as we model it.

For example, driving a gas guzzler or taking frequent flights is less stigmatizing when lots of other people are doing it. Similarly, in their analysis of welfare systems and the incentives to work Lindbeck et al. (1999) assumed that "when the population share of transfer recipients is large (small), the individual's discomfort from such a lifestyle is relatively weak (strong)" (p. 3). This assumption was motivated by the laboratory experiments of Gächter and Fehr (1997), and has been confirmed more generally in a number of other studies. In an empirical study on the role of social norms in explaining unemployment Åberg et al. (2003) conclude that "the social and psychological costs of being unemployed ... are likely to be inversely related to the unemployment level among others" (p. 28). More generally, individuals have been observed to "exhibit greater compliance with a norm when they observe greater numbers of others doing so" (Krupka & Weber, 2009, p. 309).[3]

In this paper we present the first model on the adoption of green technology by firms in a competitive setting that accounts for the stigmatization of consumers that make brown choices. In a horizontally-differentiated asymmetric duopoly framework in which consumers may be sensitive to stigma, we show that the possibility of stigmatization intensifies price competition between firms, making adoption of environmentally-friendly technologies *less* profitable than in a setting absent stigma.

In the baseline version of the model consumers do not experience social stigma of brown choices. Firms are motivated to adopt a green technology solely by cost considerations. The low-cost (zero) firm never adopts, whereas the high-cost firm adopts the green technology only if it is cheaper than the brown technology it holds.

Accounting for stigma increases the range of circumstances under which both firms adopt, but also the range under which neither adopts. We provide conditions under which the high-cost firm falls into a 'brown trap' — circumstances in which in the absence of stigma it would choose welfare-improving adoption, but under stigma opts against. However, there are also parameter values for which stigma causes the low-cost firm to fall into a 'green trap', one in

[3]The directionality is in both cases plausible. *Not* littering can never generate social disapproval, just as in Lindbeck et al. (1999) working rather than living off benefits never can.

which the low-cost firm is more likely to adopt the green technology than is socially-desirable but where that excess would not arise absent consideration of stigma.

While in most economic models increasingly robust competition serves to mitigate inefficiency, the role of competition here is more subtle. Increased competition shrinks the green trap, but makes the brown trap wider — the high-cost firm falls into it for a wider range of clean technology costs.

We are the first to model how stigmatization of brown goods consumption impacts green technology decisions. Our analysis complements and extends the large existing literature on the adoption of clean production practices in strategic settings (space precludes anything more than a cursory summary here). Galasso and Tombak (2014) build a model that combines vertical and horizontal differentiation in which consumers derive a private benefit from contributing to the public good (such as environmental protection), with a focus on the timing of the switch from dirty to clean. Deltas et al. (2013) model oligopoly with environmentally-conscious consumers. Chen (2001) presents a model of competitive product design in which the market divides into green and brown segments. While in this paper we will not consider the role of policy interventions, other papers have addressed the question of how policy interventions can influence adoption of cleaner production practices (e.g., McGinty & de Vries, 2009; Gil-Moltó & Varvarigos, 2013; Cohen et al., 2016).

The paper proceeds as follows. In Section 2.2 we present the model. In 2.2.1 consumers do not experience stigmatization of brown choices, while in 2.2.2 we introduce stigma and analyze its market effects. After presenting a series of positive results we investigate welfare implications in Section 2.2.3. Section 2.3 concludes.

2.2 Model

The model comprises:

- Two competing firms that produce horizontally differentiated goods ('brands'). They have asymmetric costs of dirty production. Each decides whether to adopt a clean technology or produce with the existing dirty technology, and then firms compete in prices.

- A population of consumers that have horizontal preferences.

Their actions unfold in two stages:

- Stage 1 (the technology adoption stage):
  - Firms simultaneously choose whether to adopt a clean technology that does not impact the environment or to continue with their existing dirty technology that implies environmental damage. Technology choices are irrevocable and publicly observed.
- Stage 2 (the market stage):
  - Firms announce prices.
  - Consumers decide which firm to buy from.

2.2.1 Base model (no stigma)

In order to highlight the role of stigmatization we will first set-up a base model with no considerations of stigmatization. Then we add stigma into the mix, and see what difference it makes.

We model consumers in the manner of Innes (2006). There are N consumers, each with unit demand, and for notational simplicity we assume $N = 1$. The products offered by the two firms — firm 1 and firm 2 — are horizontally-differentiated and consumers have brand preferences. In particular consumers are assumed uniformly distributed on $(-\overline{\theta}, \overline{\theta})$, $\overline{\theta} > 0$, where θ measures the consumer's preference for the product of firm 2 over the product of firm 1 other things being equal.[4] $\overline{\theta}$ is assumed large enough to support an interior solution.[5] The symmetry of the distribution implies that there is no overall preference for the goods of one firm or the other in the population taken as a whole. Absent social considerations a consumer characterized by $\theta = \theta_i$ buys from firm 2 if $p_1 + \theta > p_2$, from firm 1 otherwise.

Firms already have installed a dirty production technology, and they differ in the costliness of their pre-existing dirty production practices. More concretely we will let c_i denote the cost of a unit of dirty production by firm i, and without loss of generality assume that $c_2 > c_1$ and $c_1 = 0$.[6] This technology generates environmental damage $\Delta > 0$ per unit of production.

There is also a clean technology, available off-the-shelf to all, that generates no environmental damage but implies a marginal cost $\gamma > 0$. Each firm has to decide whether it adopts the clean technology or uses the existing dirty alternative; firms adopt when indifferent.

The sequence of moves is as sketched above. Firms simultaneously and non-cooperatively choose a technology (clean or dirty). They then price compete for sales to the population of consumers just described.

Solving the game backwards[7] yields the intuitive solution: the low-cost firm ($c_1 = 0$) never adopts the clean technology because it costs too much ($\gamma > 0$), while the high-cost firm ($c_2 > 0$) adopts only if the cost is lower than that of its existing dirty technology ($\gamma < c_2$).

Proposition 2.1. *Absent stigma, firm 1 never adopts clean production, while firm 2 adopts if it is cheaper than its dirty technology,* $\gamma \leq c_2$.

[4]The parameter θ can equally be seen as the consumer's location on a line between two firms at pre-fixed locations as in Hotelling (1929).

[5]We follow Innes (2006) by assuming that "parameter values support an interior partition of consumption. (Sufficient for an interior partition [...] is that $\overline{\theta}$ be sufficiently large.)" (p. 376, par. 5)

[6]If we think of the dirty technology being the established one that the firm already has installed then our formulation makes it best to think of the clean technology totally replacing the dirty, not as the addition of an end-of-pipe technology to a dirty plant that remains in use.

[7]A detailed solution follows for the stigma set-up of the game.

Adoption of clean practices is motivated solely by cost considerations in the absence of stigma.

2.2.2 Introducing stigma

We have already identified avoidance of stigma as having the potential to influence decisions. An individual consumer might make a green choice (for example pay a premium for a green product), even if they themselves do not particularly value the additional environmental attribute, in order to avoid the *social* penalty that might come from stigmatization. We introduce the possibility of stigmatization of brown behavior into the baseline model and examine its implications for the technology choices of the firms.

Following Lindbeck et al. (1999) we conceive of stigma as the disgrace or shame an individual feels when behaving "badly" (in their case feeding family by means of welfare benefits rather than one's own toil, in ours buying a brown rather than green product) and make the intensity of disgrace decreasing in the proportion of the community engaged in the same behavior.

For ease of analysis we will denote the stigma penalty an individual feels upon purchase of brown as $\sigma > 0$, multiplied by the proportion of consumers in the population choosing green. The linearity assumed here is a simplification, but since we seek to establish the characteristics of possible equilibria it should not overly concern the reader. The results can be shown to hold for a class of (not too) concave functions. The stigma penalty from behaving badly approaches zero as the fraction of people in the population engaged in good behavior approaches zero, consistent with the everyday defense that "everyone does it".

If technology choices are symmetric, that is if both firms adopt clean or if none adopts, the equilibrium price levels, demand levels and profit levels are the same in the stigma set-up and in the basic set-up. Stigma is irrelevant in these cases: if both adopt clean no consumer experiences stigma because none chooses dirty (there is no dirty product on the market); if both produce dirty no consumer experiences stigma because the proportion of consumers buying clean is zero (there is no clean product on the market).

The interest, then, is going to be what happens to the consumer's problem when one firm adopts the clean technology, the other does not. In that case there is a clear green and brown choice, and the scope for stigmatization of the latter arises.

Assume that firm 1 adopts the clean technology (C) and firm 2 opts to produce dirty (D), such that the outcome to the technology-game is (C, D). The location $\widehat{\theta}$ of the consumer who is indifferent between purchasing from firm 1 or firm 2 is characterized as follows, where Λ_1 is demand for the good of firm 1:

$$p_1 + \widehat{\theta} = p_2 + \sigma\Lambda_1 \Leftrightarrow \widehat{\theta} = p_2 - p_1 + \sigma\Lambda_1. \tag{2.1}$$

We have to account for the fact that while the demand for the clean (green) good offered by firm 1 is determined by the location of the indifferent consumer, the location of that indifferent consumer is itself sensitive to the demand for the clean good. This runs through stigmatization. If a marginal consumer switches from clean to dirty that switch makes the clean product marginally less attractive (or, more correctly, the dirty product less unattractive) to the next consumer on the line. We derive the following expressions for demands for the products offered by firms 1 (clean) and 2 (dirty) respectively:

$$\Lambda_1(p_1, p_2, \sigma) = \frac{\overline{\theta} + \widehat{\theta}}{2\overline{\theta}} \Leftrightarrow \Lambda_1 = \frac{\frac{1}{2} + \frac{p_2 - p_1}{2\overline{\theta}}}{1 - \frac{\sigma}{2\overline{\theta}}}; \Lambda_2 = 1 - \Lambda_1.$$

Using these we can characterize how the two firms will set prices under the current assumption about technology choices (that is (C, D)). By solving firms' maximization problems of $\Pi_1(p_1, p_2, \sigma, \gamma) = (p_1 - \gamma)\Lambda_1(p_1, p_2, \sigma)$ and $\Pi_2(p_1, p_2, \sigma, c_2) = (p_2 - c_2)[1 -$

$\Lambda_1(p_1, p_2, \sigma)]$ respectively, we obtain equilibrium prices, demand levels and profit levels:

$$p_1^* = \overline{\theta} + \frac{2\gamma + c_2 - \sigma}{3}, p_2^* = \overline{\theta} + \frac{\gamma + 2c_2 - 2\sigma}{3}; \tag{2.2}$$

$$\Lambda_1^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{c_2 - \gamma - \sigma}{3}\right), \Lambda_2^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{\gamma - c_2 - 2\sigma}{3}\right); \tag{2.3}$$

$$\Pi_1^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{c_2 - \gamma - \sigma}{3}\right)^2, \Pi_2^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{\gamma - c_2 - 2\sigma}{3}\right)^2. \tag{2.4}$$

Note how the prices of both firms (2.2) are negatively impacted by stigma: $\frac{\partial p_1^*}{\partial \sigma} = -\frac{1}{3}$ and $\frac{\partial p_2^*}{\partial \sigma} = -\frac{2}{3}$. The presence of stigma induces a tug-of-war on the market played by the two competitors through their price choices, with the continuum of consumers as the rope. On the one hand clean firm 1 lowers the price to attract consumers, which increases the stigma of purchasing the dirty good, and thus attracts even more consumers. On the other hand dirty firm 2 lowers the price to retain consumers, which decreases the stigma of purchasing the dirty good, and thus retains even more consumers. In equilibrium the negative impact of stigma on the price of the dirty good is twice as much as that on the price of the clean good: $\frac{\partial p_2^*}{\partial \sigma} = 2\frac{\partial p_1^*}{\partial \sigma}$.

We can similarly calculate the payoffs for the (D, C) case. This allows us to summarize (Table 2.1) equilibrium payoffs in the market conditional on the technology choices made by the firms in Stage 1.

firm 1→ firm 2 ↓	D	C
D	$\Pi_1 = \frac{1}{2\overline{\theta}}\left(\overline{\theta} + \frac{c_2}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}}\left(\overline{\theta} - \frac{c_2}{3}\right)^2$	$\Pi_1 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{c_2-\gamma-\sigma}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma-c_2-2\sigma}{3}\right)^2$
C	$\Pi_1 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma-2\sigma}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} - \frac{\gamma+\sigma}{3}\right)^2$	$\Pi_1 = \frac{\overline{\theta}}{2}$ $\Pi_2 = \frac{\overline{\theta}}{2}$

Table 2.1: Payoffs (with stigma)

This allows us to think about the technology choices of forward-looking firms. We obtain the cost thresholds below which each firm would wish to adopt the clean technology, and begin with each firm's unilateral adoption threshold — the cost below which a firm would wish to be the sole adopter of clean if given the opportunity. For convenience we denote them $\overline{\gamma}_1$ and $\overline{\gamma}_2$ for firm 1 and firm 2, respectively. To be explicit,

$$\Pi_1(C,D) > \Pi_1(D,D) \Leftrightarrow \gamma < \overline{\gamma}_1, \overline{\gamma}_1 \equiv (3\overline{\theta} + c_2)\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) - \sigma; \tag{2.5}$$

$$\Pi_2(D,C) > \Pi_2(D,D) \Leftrightarrow \gamma < \overline{\gamma}_2, \overline{\gamma}_2 \equiv c_2 + (3\overline{\theta} - c_2)\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) - \sigma. \tag{2.6}$$

Comparing (2.5) with (2.6) we find that $\overline{\gamma}_1 < \overline{\gamma}_2$ — firm 1 finds dirty production less costly than does firm 2 so is less ready to change.

With a slight abuse of notation, let us denote adoption thresholds $\overline{\gamma}_{1R}$ and $\overline{\gamma}_{2R}$ as those levels below which firm 1 and firm 2, respectively, would adopt clean production *conditional on* the adoption of clean by its competitor, firm 2 and firm 1, respectively.

$$\Pi_1(C,C) > \Pi_1(D,C) \Leftrightarrow \gamma < \overline{\gamma}_{1R}, \overline{\gamma}_{1R} \equiv 2\sigma - 3\overline{\theta}\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right); \tag{2.7}$$

$$\Pi_2(C,C) > \Pi_2(C,D) \Leftrightarrow \gamma < \overline{\gamma}_{2R}, \overline{\gamma}_{2R} \equiv c_2 + 2\sigma - 3\overline{\theta}\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right). \tag{2.8}$$

It is immediately obvious that $\overline{\gamma}_{1R} < \overline{\gamma}_{2R}$ for any strictly positive c_2. We can then establish the following relationships between all the thresholds:

$$\overline{\gamma}_1 < \overline{\gamma}_2 < \overline{\gamma}_{2R}, \text{ and } \overline{\gamma}_1 < \overline{\gamma}_{1R} < \overline{\gamma}_{2R}. \tag{2.9}$$

Firm 1's unilateral adoption threshold $\overline{\gamma}_1$ is the lowest, meaning that firm 2 is always willing to adopt clean — unilaterally or conditional on competitor's adoption — at higher costs than $\overline{\gamma}_1$ ($\overline{\gamma}_1 < \overline{\gamma}_2 < \overline{\gamma}_{2R}$). At the same time firm 1 is willing to adopt conditional on firm 2 adoption at higher costs than $\overline{\gamma}_1$ as well ($\overline{\gamma}_1 < \overline{\gamma}_{1R}$). This makes the actual value of firm 1's unilateral adoption threshold $\overline{\gamma}_1$ irrelevant because firm 1 never adopts unilaterally in equilibrium.

Firm 2's threshold conditional on firm 1 adoption $\overline{\gamma}_{2R}$ is the highest, meaning that whenever firm 2 is willing to adopt unilaterally it is automatically willing to adopt conditional on firm 1 adoption ($\overline{\gamma}_2 < \overline{\gamma}_{2R}$). At the same time firm 1 is willing to adopt conditional on firm 2 adoption at lower costs than $\overline{\gamma}_{2R}$ ($\overline{\gamma}_{1R} < \overline{\gamma}_{2R}$). This makes the actual value of firm 2's threshold conditional on firm 1 adoption $\overline{\gamma}_{2R}$ irrelevant because firm 1 is never willing to adopt clean at higher costs than $\overline{\gamma}_{1R}$.

The clean production cost levels that determine the equilibria in this setting are then firm 2's unilateral adoption threshold $\overline{\gamma}_2$ and firm 1's threshold conditional on firm 2 adoption $\overline{\gamma}_{1R}$. For firm 1 producing dirty (D) is a strictly dominant strategy at costs above $\overline{\gamma}_{1R}$ ($\gamma > \overline{\gamma}_{1R} > \overline{\gamma}_1$). For firm 2 adopting clean (C) is a strictly dominant strategy at costs lower than $\overline{\gamma}_2$ ($\gamma < \overline{\gamma}_2 < \overline{\gamma}_{2R}$).

The counterparts of these relevant thresholds in the baseline set-up without stigma are 0 and c_2 for firm 1 and firm 2, respectively. Thus the impact of stigma on patterns of adoption depends on how the $\overline{\gamma}_2$ and $\overline{\gamma}_{1R}$ thresholds for $\sigma > 0$ compare to the thresholds without stigma $\overline{\gamma}_{2|\sigma=0} = c_2$ and $\overline{\gamma}_{1R|\sigma=0} = 0$. We establish in Appendix A that over the whole support of σ,

$$\overline{\gamma}_2 < c_2 \text{ and } \overline{\gamma}_{1R} > 0.$$

This implies the following.

Proposition 2.2. ***(Stigma influences clean technology adoption)*** *The introduction of stigma serves to (a) reduce $\overline{\gamma}_2$, the clean technology cost threshold below which firm 2 would wish to adopt unilaterally clean production and, (b) increase $\overline{\gamma}_{1R}$, the cost threshold below which firm 1 would wish to adopt clean conditional on firm 2 having adopted clean.*

Stigma lowers firm 2's unilateral adoption threshold, but increases firm 1's adoption threshold conditional on firm 2 adoption. As highlighted above, in a mixed-adoption scenario price competition intensifies. Firm 2 requires a lower cost for unilateral adoption than in the absence of stigma in order to compensate for the increased price competition. Firm 1 is willing to incur a higher cost for clean adoption conditional on competitor's adoption in order to likewise avoid the increased price competition of a mixed-adoption scenario.

Basically stigma shifts firms' relevant adoption thresholds towards one another as both firms are reluctant to engage in a stigma tug-of-war induced by mixed-adoption. The relationship between $\overline{\gamma}_2$ and $\overline{\gamma}_{1R}$, and implicitly the resulting market adoption of the clean technology, are dictated by the intensity of the stigma effect:

$$\overline{\gamma}_{1R} < \overline{\gamma}_2 \Leftrightarrow \sigma < \widetilde{\sigma}, \text{where } \widetilde{\sigma}(c_2) \equiv \frac{\left(12\overline{\theta} - c_2\right)}{18\overline{\theta}} c_2. \tag{2.10}$$

For stigma intensity below some threshold $\widetilde{\sigma}$ it is the case that $\overline{\gamma}_{1R} < \overline{\gamma}_2$. Over the interval of lower costs $(0, \overline{\gamma}_{1R}]$ both firms adopt clean; for intermediary costs $(\overline{\gamma}_{1R}, \overline{\gamma}_2]$ only firm 2 adopts clean; at higher costs $\gamma > \overline{\gamma}_2$ no firm adopts clean.[8]

Going forward we will refer to stigma levels $\sigma < \widetilde{\sigma}$ as "low stigma", and stigma levels $\sigma > \widetilde{\sigma}$ as "high stigma". The results obtained so far in the stigma set-up are summarized below.

Proposition 2.3. ***(Low stigma and technology adoption)*** *A stigma critical level $\widetilde{\sigma} = \frac{\left(12\overline{\theta} - c_2\right)}{18\overline{\theta}} c_2$ exists such that if $\sigma < \widetilde{\sigma}$ then $\overline{\gamma}_{1R} < \overline{\gamma}_2$, and for $\gamma \in (0, \overline{\gamma}_{1R}]$ both firms adopt the clean technology, for $\gamma \in (\overline{\gamma}_{1R}, \overline{\gamma}_2]$ only firm 2 adopts, while for $\gamma > \overline{\gamma}_2$ no firm adopts.*

Figure 2.1 shows how stigma shifts firms' adoption thresholds towards one another as each firm is reluctant to engage in a stigma tug-of-war. Firm 2's threshold shifts left from its no-stigma value c_2 to the lower $\overline{\gamma}_2$. Firm 1's threshold conditional on firm 2 adoption increases from zero in the absence of stigma to the higher $\overline{\gamma}_{1R}$.

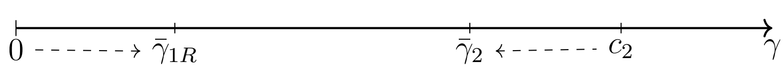

Figure 2.1: Low stigma ($\sigma < \tilde{\sigma}$, Prop. 2.3)

[8] $\gamma \in (0, \overline{\gamma}_{1R}]$: $(C, C)^{NE}$ by successive elimination of firm 2's and then firm 1's strictly dominated strategy D. $\gamma \in (\overline{\gamma}_{1R}, \overline{\gamma}_2]$: $(D, C)^{NE}$ by elimination of strictly dominated strategies C for firm 1 and D for firm 2. $\gamma > \overline{\gamma}_2$: $(D, D)^{NE}$ by successive elimination of firm 1's and then firm 2's strictly dominated strategy C.

Provided stigma is not too high ($\sigma < \widetilde{\sigma}$) firms' adoption thresholds do not shift past each other. Mixed-adoption is the equilibrium within the cost interval they bound $(\overline{\gamma}_{1R}, \overline{\gamma}_2]$. Firm 2 adopts because the cost is low enough to compensate for the stigma-induced price competition. Firm 1 does not "follow" its competitor because stigma is not high enough to completely erode its cost advantage from dirty production. If the cost of clean production drops below $\overline{\gamma}_{1R}$, then its cost advantage from dirty production would be too low to withstand a mixed-adoption stigma tug-of-war, reason for which both firms adopt within the cost interval $(0, \overline{\gamma}_{1R}]$.

At sufficiently high levels of stigma ($\sigma > \widetilde{\sigma}$) firms' adoption thresholds do shift past each other, and their relationship from (2.10) changes to:

$$\overline{\gamma}_2 < \overline{\gamma}_{1R} \Leftrightarrow \sigma > \widetilde{\sigma}.$$

Figure 2.2 shows how firms' adoption thresholds shift past one another in the presence of high stigma.

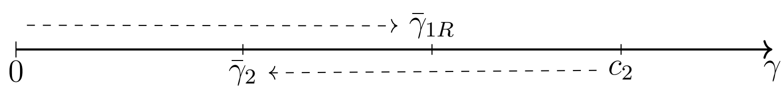

Figure 2.2: High stigma ($\sigma > \tilde{\sigma}$, Prop. 2.4)

Similarly to the low stigma case, over an interval of lower costs $(0, \overline{\gamma}_2]$ both firms adopt clean, and at higher costs $\gamma > \overline{\gamma}_{1R}$ no firm adopts clean.[9] The notable difference is that over the interval of intermediary costs bounded by firms' thresholds $(\overline{\gamma}_2, \overline{\gamma}_{1R}]$ there are now two Nash equilibria: either both firms adopt or none adopts.[10]

[9] $\gamma \in (0, \overline{\gamma}_2]$: $(C,C)^{NE}$ by successive elimination of firm 2's and then firm 1's strictly dominated strategy D; $\gamma > \overline{\gamma}_{1R}$: $(D,D)^{NE}$ by successive elimination of firm 1's and then firm 2's strictly dominated strategy C.

[10] Using payoffs from Table 2.1, $\Pi_1(C,C) > \Pi_1(D,C)$ and $\Pi_2(C,C) > \Pi_2(C,D) \Leftrightarrow \overline{\gamma}_2 < \gamma < \overline{\gamma}_{1R}$; $\Pi_1(D,D) > \Pi_1(C,D)$ and $\Pi_2(D,D) > \Pi_2(D,C) \Leftrightarrow \overline{\gamma}_2 < \gamma < \overline{\gamma}_{1R}$. Thus $(C,C)^{NE}$ and $(D,D)^{NE}$ for $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R}]$

Firm 1 prefers the dirty production Nash equilibrium because it maintains a cost advantage over its competitor, as per Table 2.1 ($\Pi_1(D, D) > \Pi_1(C, C)$). By contrast, firm 2 prefers the clean production Nash equilibrium because adoption by both firms at the same cost γ eliminates its competitor's cost advantage ($\Pi_2(D, D) < \Pi_2(C, C)$). Both firms want to avoid intensified price competition from mixed-adoption in the presence of high stigma, but each firm prefers a different technology choice.[11] Proposition 2.4 summarizes.

Proposition 2.4. ***(High stigma and technology adoption)*** *If $\sigma > \widetilde{\sigma}$ then $\overline{\gamma}_2 < \overline{\gamma}_{1R}$, and for $\gamma \in (0, \overline{\gamma}_2]$ both firms adopt clean, for $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R}]$ either both firms adopt clean or none of them does, while for $\gamma > \overline{\gamma}_{1R}$ no firm adopts clean.*

High stigma rules out the intermediary costs interval over which mixed-adoption was the equilibrium under low stigma, and in its place gives rise to an intermediary costs interval over which the equilibrium is anything but mixed-adoption. Although firms do not agree on the technology choice, they do agree it should be symmetric. Even ending up at the symmetric Nash equilibrium preferred by its competitor leaves each firm better off than if they engaged in a mixed-adoption stigma tug-of-war.

In light of the varied outcomes induced by stigma, it may be of interest what happens in case firms have symmetric costs of dirty production ($c_1 = c_2 = 0$). With the initial cost asymmetry eliminated, firm 2 faces the same incentives as firm 1 does[12], and the two firms behave much like in the high stigma case just discussed. For lower costs $\gamma < \overline{\gamma}_1|_{c_2=0}$ both firms adopt, for intermediary costs $\overline{\gamma}_1|_{c_2=0} < \gamma < \overline{\gamma}_{1R}$ either both firms adopt clean or none of them does, while for $\gamma > \overline{\gamma}_{1R}$ no firm adopts clean. The minor difference is that for intermediary costs both firms are indifferent between the two symmetric technology equilibria, and by assumption firms adopt clean when indifferent.[13] Therefore both firms

[11] Absent some form of coordination, each firm may mix strategies. We analyze mixed strategies when $(C, C)^{NE}$ and $(D, D)^{NE}$ in Appendix B, and identify the mixed-strategy Nash equilibrium. We find that an increase in stigma σ increases the likelihood that each firm chooses dirty. An increase in c_2 increases the probabilities with which firm 1 and firm 2 choose dirty and clean, respectively.

[12] Each firm is willing to solely adopt clean for $\gamma < \overline{\gamma}_1|_{c_2=0}$ (2.5), and each firm is willing to adopt conditional on competitor's adoption for $\gamma < \overline{\gamma}_{1R}$ (2.7).

[13] Using payoffs from Table 2.1, $\Pi_1(C, C) = \Pi_2(C, C) = \Pi_1(D, D)|_{c_2=0} = \Pi_2(D, D)|_{c_2=0} = \frac{\overline{\theta}}{2}$.

adopt for $\gamma \in (0, \overline{\gamma}_{1R}]$, and none of them does at higher costs $\gamma > \overline{\gamma}_{1R}$.

All of the results so far in the paper have been positive. In the next section we turn to the welfare implications of stigmatization.

2.2.3 Welfare analysis

The objective function of the social planner is to minimize total costs in the model — production, environmental and to consumer surplus. They take into account how social stigma affects decisions of individuals and firms because their effects inform decisions regarding policy design. However it is not within their attributes to "manage" social stigma, and thus they are not explicitly included in the objective function, but their effects are taken into account.[14]

We have established in the game analysis that three types of equilibria are possible: full adoption (C, C), partial adoption (D, C), and no adoption (D, D). That which results for a particular configuration of parameter values depends critically on how the marginal cost of production under the clean technology γ compares to firms' adoption thresholds.

We denote total welfare costs with Γ and it can be shown that:

$$
\begin{aligned}
\Gamma(C, C) &= \gamma; \\
\Gamma(D, C) &= \Delta + (\gamma - \Delta)\left(\frac{1}{2} - \frac{\gamma - \Delta}{9\overline{\theta}}\right); \\
\Gamma(D, D) &= \Delta + c_2\left(\frac{1}{2} - \frac{c_2}{9\overline{\theta}}\right).
\end{aligned}
$$

[14]The better known concept of warm-glow is treated in a similar manner. Andreoni (1990) introduced a model of impure altruism in which contributors to a public good derive additional utility, coined "warm-glow", from their contributions. Within the context of this paper, an individual may experience warm-glow from an action that improves the environment (e.g., donating to, or volunteering for an environmental project), but may experience stigma from an action that damages the environment (e.g., creating demand for, and purchasing a product that entails environmental damage). Warm-glow and stigma have the same direction, experienced as a result of an action that affects the state of the environment, they only differ in sense: one is an added utility, the other is a disutility. We therefore apply to stigma the recommendation made by Andreoni (2006) that "it is most prudent and most informative to first recognize that behavior is chosen by people seeking warm-glows, but then to set the social welfare maximizing goals that makes no adjustment for warm-glow in aggregating welfare" (p. 1227).

Comparison of these yields critical values of γ for which each of the potential equilibria is socially-desirable.

$$0 < \gamma < \Delta : \Gamma(C,C) < \Gamma(D,C) \text{ and } \Gamma(C,C) < \Gamma(D,D); \tag{2.11}$$

$$\Delta < \gamma < \Delta + c_2 : \Gamma(D,C) < \Gamma(C,C) \text{ and } \Gamma(D,C) < \Gamma(D,D); \tag{2.12}$$

$$\gamma > \Delta + c_2 : \Gamma(D,D) < \Gamma(D,C) \text{ and } \Gamma(D,D) < \Gamma(C,C). \tag{2.13}$$

Over an interval of low costs relative to marginal damage from dirty production ($\gamma < \Delta$) the welfare-motivated planner prefers full adoption of the clean technology; over an intermediate interval ($\Delta < \gamma < \Delta + c_2$) partial adoption (firm 2 only)[15]; for sufficiently high costs ($\gamma > \Delta + c_2$) no adoption. Otherwise put, it is socially-preferred that firm 1 adopts only if $\gamma < \Delta$, and that firm 2 adopts only if $\gamma < \Delta + c_2$.

To simplify the exposition and maintain comparability with the symmetric costs alternative ($c_1 = c_2 = 0$), we assume $c_2 < \Delta$ such that costs of dirty production are always lower than marginal damage[16], and we also assume that when both firms adopting and none adopting are Nash equilibria (Prop. 2.4), firms implement the clean equilibrium as they do with symmetric costs. This allows us to capture the more interesting welfare effects of stigma, and we point out along the way what difference alternative assumptions would have made.

To understand the impact of accounting for stigma on welfare we need to examine its impact on firms' adoption thresholds.

In the absence of stigma firm 1 does not adopt the clean technology, whereas firm 2 adopts if $\gamma < c_2$ (Prop. 2.1). Given that $c_2 < \Delta$, both firms under-adopt clean. The planner

[15] We also include partial adoption by firm 1 only (C,D) in the proof provided in Appendix A, however it is never socially-preferred. Total costs of adoption by firm 1 only $\Gamma(C,D)$ are always higher than total costs of adoption by firm 2 only $\Gamma(D,C)$. Given that (C,D) is never a market equilibrium, we exclude it from consideration in order to simplify the exposition.

[16] This assumption is especially suitable for cost competitive markets that fail to internalize environmental damages, and these damages escalate over time (e.g., social cost of carbon (Greenstone et al., 2013)). It is then only a matter of time for the relationship to hold.

would prefer that firm 1 adopts if $\gamma < \Delta$, but it does not adopt at all. They would also prefer that firm 2 adopts if $\gamma < \Delta + c_2$, but it does not adopt for $\gamma \in (c_2, \Delta + c_2]$.

Stigma decreases firm 2's adoption threshold from c_2 to $\overline{\gamma}_2 < c_2$. At the same time stigma increases firm 1's adoption threshold from 0 to $\overline{\gamma}_{1R} > 0$ (Prop. 2.2). Provided stigma is relatively low ($\sigma < \widetilde{\sigma}$), firms' two thresholds do not shift past each other, and firm 1's adoption threshold remains lower than firm 2's adoption threshold ($\overline{\gamma}_{1R} < \overline{\gamma}_2$, Prop. 2.3).

Before proceeding to our welfare results, we introduce the notion of "brown trap".

Definition 2.1. ***(Brown trap, under-adoption of clean technology)*** *A firm is said to be in a brown trap if (a) absent stigma a firm would adopt clean production and that would be socially-preferred but (b) accounting for stigma the firm chooses dirty production, which reduces welfare.*

We can then establish the following.

Proposition 2.5. ***(Low stigma welfare effects)*** *Low stigma $\sigma < \widetilde{\sigma}$ generates a brown trap for the high-cost firm, but also generates a clean adoption interval for the low-cost firm.*

(a) Firm 2 falls into a brown trap for clean technology costs $\gamma \in (\overline{\gamma}_2, c_2]$. In that interval absent stigma firm 2 would adopt clean production and that would be socially-preferred, but accounting for stigma it chooses dirty.

(b) Firm 1 adopts for clean technology costs $\gamma \in (0, \overline{\gamma}_{1R}]$. In that interval absent stigma firm 1 would not adopt clean production although it would be socially-preferred, but accounting for stigma it chooses clean.

Low stigma welfare effects are mixed. It delays arrival of the clean technology on the market, but increases market diffusion when it arrives. Figure 2.3 captures the welfare effects of low stigma.

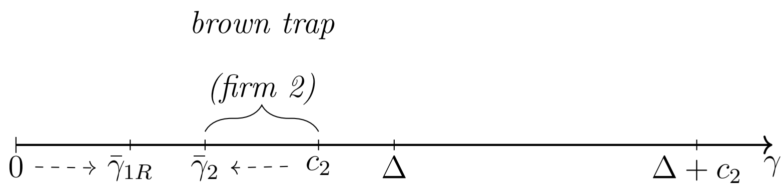

Figure 2.3: Low stigma welfare effects ($\sigma < \tilde{\sigma}$, Prop. 2.5)

Stigma reduces here the likelihood that the market adopts the clean technology at all because it puts downward pressure on the adoption threshold of firm 2, the firm with the higher cost of dirty production and hence the firm which is more ready to adopt. In the absence of stigma the firm would adopt for costs below c_2, but stigma further lowers its adoption threshold to $\overline{\gamma}_2$ when from a social perspective the firm is already under-adopting. Thus low stigma generates a brown trap $(\overline{\gamma}_2, c_2]$ for firm 2.

Moreover, note that this brown trap does not depend on the assumption made in this section that $c_2 < \Delta$. As detailed above, it is socially-preferred that firm 2 adopts clean for costs under $\Delta + c_2$, and $c_2 < \Delta + c_2$ holds for any strictly positive marginal damage Δ. Thus even under the alternative assumption $\Delta < c_2$, low stigma generates a similar brown trap $(\overline{\gamma}_2, c_2]$ for firm 2.

Once firm 2 adopts clean though, stigma increases the likelihood that firm 1 adopts as well. In the absence of stigma firm 1 would never adopt clean, but stigma puts upward pressure on its threshold (from 0 to $\overline{\gamma}_{1R}$) as the firm is incentivized to avoid a stigma tug-of-war. Thus low stigma generates the interval $(0, \overline{\gamma}_{1R}]$ over which firm 1 adopts clean conditional on competitor's adoption when it is socially-preferred that it does adopt.[17]

While low stigma ($\sigma < \widetilde{\sigma}$) induces under-adoption of the clean technology by firm 2, high stigma ($\sigma > \widetilde{\sigma}$) may induce over-adoption by firm 1 or even both firms. High stigma eliminates the possibility of mixed-adoption as both firms seek to avoid a stigma tug-of-war altogether. Firms' thresholds shift past each other, and within the interval they bound

[17] Under the alternative assumption that $\Delta < c_2$ (instead of $c_2 < \Delta$), the outcome is more nuanced for firm 1 than for firm 2. If stigma does not push $\overline{\gamma}_{1R}$ above Δ, then the result from Proposition 2.5 stands for firm 1 as well. However, if stigma pushes $\overline{\gamma}_{1R}$ above Δ, then it induces firm 1 over-adoption, a possibility we address in the paragraphs that follow.

$(\overline{\gamma}_2, \overline{\gamma}_{1R}]$ both firms adopting and none adopting are Nash equilibria (Prop. 2.4).

Given the assumption in this section that firms always implement the former Nash equilibrium and not the latter when indifferent, it follows that both firms adopt clean for $\gamma \in (0, \overline{\gamma}_{1R}]$, and none adopts for $\gamma > \overline{\gamma}_{1R}$, in the presence of high stigma. Provided stigma is sufficiently high, $\overline{\gamma}_{1R}$ may not only shift past firm 2's threshold, but also past firm 2's no-stigma threshold c_2, and even past socially-preferred adoption thresholds Δ and $\Delta + c_2$ (for firm 1 and firm 2, respectively). The corresponding stigma thresholds are as follows.

$$\begin{aligned}
&\overline{\gamma}_{1R} > c_2 \Leftrightarrow \sigma > \overline{\sigma}, \overline{\sigma}(c_2) \equiv \frac{c_2}{2} + \frac{3}{16}\left[5\overline{\theta} - \sqrt{(5\overline{\theta})^2 - 16c_2\overline{\theta}}\right];\\
&\overline{\gamma}_{1R} > \Delta \Leftrightarrow \sigma > \overline{\overline{\sigma}}, \overline{\overline{\sigma}}(\Delta) \equiv \frac{\Delta}{2} + \frac{3}{16}\left[5\overline{\theta} - \sqrt{(5\overline{\theta})^2 - 16\Delta\overline{\theta}}\right];\\
&\overline{\gamma}_{1R} > \Delta + c_2 \Leftrightarrow \sigma > \overline{\overline{\overline{\sigma}}}, \overline{\overline{\overline{\sigma}}}(\Delta, c_2) \equiv \frac{\Delta + c_2}{2} + \frac{3}{16}\left[5\overline{\theta} - \sqrt{(5\overline{\theta})^2 - 16(\Delta + c_2)\overline{\theta}}\right].
\end{aligned}$$

Before summarizing the welfare implications of high stigma, we introduce the notion of "green trap".

Definition 2.2. ***(Green trap, over-adoption of clean technology)*** *A firm is said to be in a green trap if (a) absent stigma the firm would not adopt clean production and that would be socially-preferred but, (b) accounting for stigma the firm adopts the clean technology, which reduces welfare.*

We can then establish the following.

Proposition 2.6. ***(High stigma welfare effects)*** *With high stigma $\sigma > \widetilde{\sigma}$ firm 1 may fall into a green trap, firm 2 may fall into a brown trap or a green trap.*

(a) For $\sigma \in (\widetilde{\sigma}, \overline{\sigma}]$ firm 1 adopts clean over $(0, \overline{\gamma}_{1R}]$ and firm 2 falls into a brown trap over $(\overline{\gamma}_{1R}, c_2]$. In those respective intervals, absent stigma, firm 1 would not adopt, while firm 2 would, although it would be socially-preferred that both adopt; accounting for stigma firm 1 adopts, and firm 2 does not.

(b) For $\sigma \in (\overline{\sigma}, \overline{\overline{\sigma}}]$ firm 1 adopts clean over $(0, \overline{\gamma}_{1R}]$ and firm 2 adopts clean over $(c_2, \overline{\gamma}_{1R}]$. In those respective intervals, absent stigma, firms would not adopt clean, although it would be socially-preferred that they do; accounting for stigma both firms choose clean.

(c) For $\sigma \in (\overline{\overline{\sigma}}, \overline{\overline{\overline{\sigma}}}]$ firm 1 falls into a green trap $(\Delta, \overline{\gamma}_{1R}]$ and firm 2 adopts over $(c_2, \overline{\gamma}_{1R}]$. In those respective intervals, absent stigma, firm 1 would not adopt and that would be socially-preferred, while firm 2 would not adopt although it would be sociall-preferred that it does; accounting for stigma both firms choose clean.

(d) For $\sigma > \overline{\overline{\overline{\sigma}}}$ both firms fall into green traps $(\Delta, \overline{\gamma}_{1R}]$ and $(\Delta + c_2, \overline{\gamma}_{1R}]$, respectively. In those intervals absent stigma firms would not adopt clean, and that would be socially-preferred, but accounting for stigma they both choose clean.

The above proposition points out the welfare effects of high stigma and the welfare traps it generates. Figure 2.4 illustrates the welfare implications when $\sigma \in (\overline{\overline{\sigma}}, \overline{\overline{\overline{\sigma}}}]$ (point (c) above), and it is helpful for understanding welfare implications of high stigma overall.

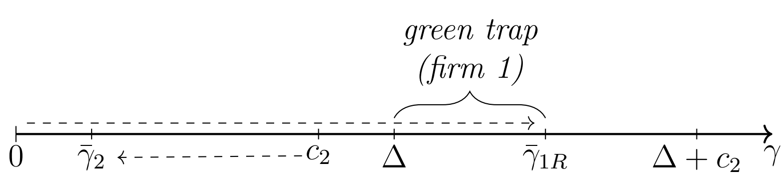

Figure 2.4: High stigma welfare effects ($\bar{\bar{\sigma}} < \sigma < \bar{\bar{\bar{\sigma}}}$, Prop. 2.6 (c))

It is socially-preferred that firm 1 and firm 2 adopt clean for costs that are lower than Δ and $\Delta + c_2$, respectively. In the absence of stigma firm 1 never adopts clean, while firm 2 only adopts for costs lower than c_2. Stigma intensity dictates where firms' adoption threshold $\overline{\gamma}_{1R}$ ends up on the $\gamma-$axis in Figure 2.4 above and the resulting welfare implications.

Below a certain threshold ($\widetilde{\sigma} < \sigma < \overline{\sigma}$) high stigma shifts $\overline{\gamma}_{1R}$ past $\overline{\gamma}_2$, but not past c_2. Welfare effects are mixed and very similar to those generated by low stigma. Firm 1 adopts over $(0, \overline{\gamma}_{1R}]$ when it is socially-preferred that it does, and it would not adopt without stigma. Firm 2 adopts over the same interval, but that means it does not adopt over $(\overline{\gamma}_{1R}, c_2]$. Absent stigma firm 2 would adopt for costs lower than c_2, including over $(\overline{\gamma}_{1R}, c_2]$, and it is socially-preferred that it does adopt over that interval. This leads to a firm 2 brown trap $(\overline{\gamma}_{1R}, c_2]$; it shrinks as stigma approaches $\overline{\sigma}$ ($\overline{\gamma}_{1R}$ approaches c_2).

Stigma levels above $\overline{\sigma}$ and below $\overline{\overline{\sigma}}$ push firms' adoption threshold past c_2 and no higher than Δ. Here stigma is clearly beneficial to welfare. Firm 1 and firm 2 would not adopt over intervals $(0, \overline{\gamma}_{1R}]$ and $(c_2, \overline{\gamma}_{1R}]$ in the absence of stigma, although it would be socially-preferred that they do, but accounting for stigma both firms adopt.

Stigma levels above $\overline{\overline{\sigma}}$ and below $\overline{\overline{\overline{\sigma}}}$ push firms to adopt above firm 1's socially-preferred adoption threshold Δ, but not past firm 2's socially-preferred adoption threshold $\Delta + c_2$. This is the scenario shown in Figure 2.4. Welfare effects are again mixed. Firm 1 over-adopts for costs $(\Delta, \overline{\gamma}_{1R}]$ although in the absence of stigma it would not adopt over that interval. Thus stigma generates a green trap $(\Delta, \overline{\gamma}_{1R}]$ for firm 1. At the same time firm 2 adopts at costs that approach its socially-preferred adoption threshold $\Delta + c_2$ as stigma approaches $\overline{\overline{\overline{\sigma}}}$, which is beneficial to welfare.

Finally, stigma levels above $\overline{\overline{\overline{\sigma}}}$ can push both firms to over-adopt. Firm 1 and firm 2 adopt over $(\Delta, \overline{\gamma}_{1R}]$ and $(\Delta + c_2, \overline{\gamma}_{1R}]$, respectively, intervals over which they would not adopt absent stigma, and over which producing dirty is socially-preferred. Such high levels of stigma are clearly detrimental to welfare as they generate green traps for both firms.

A pattern that emerges under high stigma is that the higher stigma is, the more likely that it generates green traps and incentivizes firms to over-adopt.[18]

Under the alternative set-up with symmetric costs of dirty production ($c_1 = c_2 = 0$) firm 2 behaves similarly to firm 1, and has similar welfare outcomes. Absent stigma firms would

[18] Under the alternative assumption that firms implement $(D, D)^{NE}$ instead of $(C, C)^{NE}$ when both (C, C) and (D, D) are NE ($\sigma > \widetilde{\sigma}$, $\overline{\gamma}_2 < \gamma < \overline{\gamma}_{1R}$, Prop. 2.4), high stigma welfare effects are similar to those of low stigma (Prop. 2.5). Both firms adopt for $\gamma < \overline{\gamma}_2 (< \Delta)$, and none adopts otherwise. Firm 2 falls into a brown trap for $\gamma \in (\overline{\gamma}_2, c_2]$; absent stigma firm 2 would adopt within that interval, and that would be socially-preferred, but accounting for stigma it chooses dirty. Firm 1 adopts for $\gamma \in (0, \overline{\gamma}_2]$; absent stigma firm 1 would not adopt within that interval although it would be socially-preferred, but accounting for stigma it chooses clean.

never adopt clean production. A social planner would prefer both firms to adopt for costs below marginal damage Δ, and none to adopt for costs above it. In the presence of stigma both firms adopt for $\gamma \in (0, \overline{\gamma}_{1R}]$, and none adopts for $\gamma > \overline{\gamma}_{1R}$. If stigma remains below $\overline{\overline{\sigma}}$, both firms adopt for $\gamma < \overline{\gamma}_{1R} (< \Delta)$, and that is socially-preferred. If stigma increases above $\overline{\overline{\sigma}}$ such that it pushes firms' adoption threshold past the socially-preferred threshold Δ, then both firms fall into a green trap for $\gamma \in (\Delta, \overline{\gamma}_{1R}]$.

Overall stigma has mixed effects on welfare. It can motivate firms to adopt the clean technology when that is socially-prefered, but it can also induce them to fall into brown traps or green traps.

It is interesting to think about whether the degree of competition in the market can mitigate or eliminate inefficiency in adoption incentives. In this model $\overline{\theta}$ serves as a measure of competition between the two firms, θ_i being a measure of consumer i's net preference for the product of firm 2 over the product of firm 1 uniformly distributed on the support $(-\overline{\theta}, \overline{\theta})$. Given that the number of consumers is held fixed at unity, a decrease in $\overline{\theta}$ means that, on average, consumers regard the products of the two firms as closer substitutes. So a decrease in $\overline{\theta}$ represents an increase in competition, $\overline{\theta} = 0$ corresponding to the case of identical products.

All cost intervals over which welfare traps occur are bounded by planner's socially-preferred adoption thresholds — Δ for firm 1, $\Delta + c_2$ for firm 2 —, and firms' relevant adoption thresholds — $\overline{\gamma}_{1R}$ for firm 1, $\overline{\gamma}_2$ for firm 2. Green traps occur when stigma pushes firms' thresholds beyond the socially-preferred adoption thresholds, whereas brown traps occur when stigma pulls firms' thresholds below their socially-preferred levels.

Unlike the socially-preferred thresholds, firms' thresholds are sensitive to the degree of market competition. Thus the impact of competition increase on welfare traps is determined by the effect of a $\overline{\theta}$ decrease on $\overline{\gamma}_{1R}$ and $\overline{\gamma}_2$. We show in Appendix A that:

$$\frac{\partial \overline{\gamma}_{1R}}{\partial \overline{\theta}} > 0; \frac{\partial \overline{\gamma}_2}{\partial \overline{\theta}} > 0 \Leftrightarrow \sigma < \frac{24\overline{\theta}^2 c_2}{(3\overline{\theta} + c_2)^2}.$$

An increase in competition (lower $\overline{\theta}$) magnifies firm 1's cost advantage of dirty production, so it is less willing to give it up. It requires a lower cost of clean production to do so ($\frac{\partial \overline{\gamma}_{1R}}{\partial \overline{\theta}} > 0$).

The effect on firm 2's threshold is not as clear-cut. On the one hand increased competition magnifies firm 2's cost disadvantage. On the other hand it increases the share of demand that firm 2 attracts. Up to a certain stigma level ($\sigma = \frac{24\overline{\theta}^2 c_2}{(3\overline{\theta}+c_2)^2}$) the former effect dominates the latter, so firm 2 is more reluctant to engage in a stigma tug-of-war. It too requires a lower cost of clean production to do so ($\frac{\partial \overline{\gamma}_2}{\partial \overline{\theta}} > 0$).

Thus up to a level of stigma increased competition puts downward pressure on both firms' thresholds. We show in Appendix A that this is always the case when stigma is low ($\widetilde{\sigma} < \frac{24\overline{\theta}^2 c_2}{(3\overline{\theta}+c_2)^2}$).

Provided stigma is low then ($\sigma < \widetilde{\sigma}$), increased competition is clearly detrimental to welfare. It widens firm 2's brown trap $(\overline{\gamma}_2, c_2]$ as it puts downward pressure on firm 2's adoption threshold. It also reduces firm 1's interval $(0, \overline{\gamma}_{1R}]$ over which the firm adopts clean when doing so is socially-preferred (Prop. 2.5).

In the case of high stigma ($\sigma > \widetilde{\sigma}$) increased competition effects are more nuanced. High stigma welfare traps are determined by firm 1's adoption threshold on which increased competition always puts downward pressure. Then increased competition always reduces firms' green traps (Prop. 2.6 (c) and (d)), but it likewise reduces firms' interval $(0, \overline{\gamma}_{1R}]$ over which they adopt clean when doing so is socially-preferred (Prop. 2.6 (a), (b) and (c)) and also widens firm 2's brown trap (Prop. 2.6, (a)).

The following proposition summarizes these last findings.

Proposition 2.7. ***(Competition and stigma)*** *Competition reduces green traps, but widens brown traps.*

In the absence of stigma competition does not affect firms' adoption thresholds 0 and c_2, respectively (Prop. 2.1). It is specifically in the presence of stigma that competition induces these mixed welfare effects, and thus increased competition is not necessarily a remedy for inefficiencies. It is beneficial to welfare when firms over-adopt, but it exacerbates rather than reduce inefficiencies when firms under-adopt.[19]

2.3 Conclusions

We have presented the first model on the adoption of clean technologies that incorporates consumer social stigma experienced by consumers of brown products. Although at an individual level social stigma increases the likelihood of purchasing the green good, our model shows that at the market level social stigma can decrease the likelihood of adopting clean production, thus decreasing the likelihood that a green good is available for purchase.

Social stigma of consumers' brown choices intensifies price competition between firms when a green good is available on the market. At low levels of stigma ($\sigma < \widetilde{\sigma}$), over an interval of intermediary clean production costs, the firm with the high cost of dirty production adopts clean, but the low-cost firm does not — intensified price competition induced by stigma does not completely erode its cost advantage of dirty production. At high levels of stigma ($\sigma > \widetilde{\sigma}$) intensified price competition always erodes low-cost firm's advantage, and thus firms' adoption decisions are always symmetric.

In the absence of stigma firms adopt the clean technology motivated by cost consideration only. Stigma disturbs this pattern. The high-cost firm requires a lower cost of clean production to compensate for the intensified price competition induced by stigma in a mixed-adoption scenario. The low-cost firm is willing to pay a higher cost of clean production to avoid the mixed-adoption stigma tug-of-war.

This can generate a brown trap for the high-cost firm — under-adoption of the clean technology, and can generate a green trap for the low-cost firm — over-adoption of clean. Increased competition is effective in reducing the green trap, but not the brown trap. On

[19]Under the alternative set-up with symmetric costs of dirty production ($c_1 = c_2 = 0$) firm 2 behaves similarly to firm 1, high stigma welfare traps apply (see Prop. 2.6), and competition effects are determined by effects on $\overline{\gamma}_{1R}$. Increased competition reduces the green trap $(\Delta, \overline{\gamma}_{1R}]$ for both firms when they over-adopt, but reduces the interval $(0, \overline{\gamma}_{1R}]$ over which they adopt clean when doing so is socially-preferred.

the contrary, in the presence of stigma increased competition exacerbates rather than reduce the brown trap.

This scenario invites questions about the effects of downstream stigma on the upstream clean technologies R&D market. In order to successfully bring a clean technology to market in the presence of some marginal level of stigma, R&D firm has to produce a cheaper technology, which generally requires more research and/or resources. However, if the firm is successful, stigma increases the likelihood of market diffusion — it is more likely that both firms will want to purchase the technology, rather than just the firm with higher cost of dirty production. What are then the effects of downstream stigma on the number and size of upstream R&D firms, and on the pricing of their clean technologies?

The high stigma case presented in the paper suggests a role for the social planner in nudging the market towards the socially preferrable symmetric adoption choice over an interval of intermediary clean production costs, where both symmetric adoption and symmetric non-adoption are Nash equilibria. Stigma gives the planner leverage as both firms are interested in avoiding the intensified price competition induced by stigma in a mixed-adoption scenario. It may be sufficient to incentivize only one firm (or its customers), and its competitor will follow suit.

What is then the most efficient policy to determine both firms to produce with the socially preferable technology in the presence of stigma? Is it possible to design incentives for mixed-adoption — which high stigma precludes from market implementation — when socially-preferred? If downstream stigma does impact the upstream green R&D market, do these additional considerations change the socially-preferred adoption outcome and/or social planner's policy?

These quite general questions coupled with the more surprising results uncovered in this paper, such as the possibility of welfare traps exacerbated rather than corrected by increased competition in the presence of stigma, show that while social stigma of brown choices can have non-trivial market effects, there is very little we know about them. Therefore further research is needed to understand the market effects of social stigma and inform environmental policy, and more so as numerous industries currently transition towards low carbon economies.

2.4 Appendix A

Proposition 2.1 proof: The stages of the game are: Stage 1 — firms 1 and 2 simultaneously choose clean (C) or dirty (D) technology; Stage 2 — firms choose and announce prices, consumers make purchases, firms obtain profits. We solve by backward induction using the same method presented in detail in proof of Proposition 2.2, and by setting stigma $\sigma = 0$, to obtain payoffs for all adoption outcomes.

firm 1→ firm 2 ↓	D	C
D	$\Pi_1(D,D) = \frac{1}{2\overline{\theta}}\left(\overline{\theta} + \frac{c_2}{3}\right)^2$ $\Pi_2(D,D) = \frac{1}{2\overline{\theta}}\left(\overline{\theta} - \frac{c_2}{3}\right)^2$	$\Pi_1(C,D) = \frac{1}{2\overline{\theta}}\left(\overline{\theta} + \frac{c_2-\gamma}{3}\right)^2$ $\Pi_2(C,D) = \frac{1}{2\overline{\theta}}\left(\overline{\theta} + \frac{\gamma-c_2}{3}\right)^2$
C	$\Pi_1(D,C) = \frac{1}{2\overline{\theta}}\left(\overline{\theta} + \frac{\gamma}{3}\right)^2$ $\Pi_2(D,C) = \frac{1}{2\overline{\theta}}\left(\overline{\theta} - \frac{\gamma}{3}\right)^2$	$\Pi_1(C,C) = \frac{\overline{\theta}}{2}$ $\Pi_2(C,C) = \frac{\overline{\theta}}{2}$

Table 2.2: Payoffs in baseline (no stigma)

(D) is a strictly dominant strategy for firm 1, $\forall\gamma > 0$: $\Pi_1(D,D) > \Pi_1(C,D)$ and $\Pi_1(D,C) > \Pi_1(C,C) \Leftrightarrow \gamma > 0$.

(C) is a strictly dominant strategy for firm 2, $\forall\gamma < c_2$: $\Pi_2(C,C) > \Pi_2(C,D)$ and $\Pi_2(D,C) > \Pi_2(D,D) \Leftrightarrow \gamma < c_2$.

By elimination of strictly dominated strategies we obtain: $(D,C)^{NE}$, $\forall\gamma < c_2$; $(D,D)^{NE}$, $\forall\gamma > c_2$.

Conclusion: Absent stigma, firm 1 never adopts clean production, while firm 2 adopts if it is cheaper than its dirty technology, $\gamma \leq c_2$.

Proposition 2.2 proof: Solve by backward induction starting with Stage 2. The indifferent consumer is characterized by the following equations for each possible pair of (firm 1, firm 2) adoption outcomes, where $\widehat{\theta}$ is the location of the consumer indifferent between purchasing from firm 1 or firm 2, p_1 and p_2 are the prices set by firm 1 and firm 2, respectively, σ is level of stigma, Λ_1 and Λ_2 are demands for the good of firm 1 and firm 2, respectively:

$$(D,D): p_1 + \widehat{\theta} = p_2 \Leftrightarrow \widehat{\theta} = p_2 - p_1; \tag{2.14}$$

$$(C,D): p_1 + \widehat{\theta} = p_2 + \sigma\Lambda_1 \Leftrightarrow \widehat{\theta} = p_2 - p_1 + \sigma\Lambda_1; \tag{2.15}$$

$$(D,C): p_1 + \widehat{\theta} + \sigma\Lambda_2 = p_2 \Leftrightarrow \widehat{\theta} = p_2 - p_1 - \sigma\Lambda_2;$$

$$(C,C): p_1 + \widehat{\theta} = p_2 \Leftrightarrow \widehat{\theta} = p_2 - p_1. \tag{2.16}$$

We use (C,D) outcome as example, and payoffs for all other possible adoption outcomes can be derived similarly. By assumption total demand is 1, and using $\widehat{\theta}$ obtained at (2.15) demand functions Λ_1 and Λ_2 for firm 1 and firm 2, respectively, are:

$$\Lambda_1 = \frac{\overline{\theta} + p_2 - p_1 + \sigma\Lambda_1}{2\overline{\theta}} \Leftrightarrow \Lambda_1(p_1,p_2,\sigma) = \frac{\frac{1}{2} + \frac{p_2-p_1}{2\overline{\theta}}}{1 - \frac{\sigma}{2\overline{\theta}}}; \tag{2.17}$$

$$\Lambda_2(p_1,p_2,\sigma) = 1 - \Lambda_1(p_1,p_2,\sigma). \tag{2.18}$$

Firms maximize profit functions:

$$\underset{p_1}{Max}\Pi_1(p_1,p_2,\sigma,\gamma) = (p_1 - \gamma)\left(\frac{\frac{1}{2} + \frac{p_2-p_1}{2\overline{\theta}}}{1 - \frac{\sigma}{2\overline{\theta}}}\right); \tag{2.19}$$

$$\underset{p_2}{Max}\Pi_2(p_1,p_2,\sigma,c_2) = (p_2 - c_2)(1 - \Lambda_1(p_1,p_2,\sigma)). \tag{2.20}$$

$\frac{\partial\Pi_1(p_1,p_2,\sigma,\gamma)}{\partial p_1} = 0$ and $\frac{\partial\Pi_2(p_1,p_2,\sigma,c_2)}{\partial p_2} = 0$ if and only if:

$$p_1^* = \overline{\theta} + \frac{2\gamma + c_2 - \sigma}{3}, p_2^* = \overline{\theta} + \frac{\gamma + 2c_2 - 2\sigma}{3}; \tag{2.21}$$

Plug equilibrium prices from (2.21) into demand functions from (2.17) and (2.18), and profit functions from (2.19) and (2.20) to obtain equilibrium demands and profits, respectively:

$$\Lambda_1^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{c_2 - \gamma - \sigma}{3}\right), \Lambda_2^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{\gamma - c_2 - 2\sigma}{3}\right); \tag{2.22}$$
$$\Pi_1^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{c_2 - \gamma - \sigma}{3}\right)^2, \Pi_2^* = \frac{1}{2\overline{\theta} - \sigma}\left(\overline{\theta} + \frac{\gamma - c_2 - 2\sigma}{3}\right)^2.$$

Calculate Stage 2 payoffs for all possible adoption outcomes using the same method to obtain:

firm 1→ firm 2 ↓	D	C
D	$\Pi_1 = \frac{1}{2\overline{\theta}}\left(\overline{\theta} + \frac{c_2}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}}\left(\overline{\theta} - \frac{c_2}{3}\right)^2$	$\Pi_1 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{c_2-\gamma-\sigma}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma-c_2-2\sigma}{3}\right)^2$
C	$\Pi_1 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma-2\sigma}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} - \frac{\gamma+\sigma}{3}\right)^2$	$\Pi_1 = \frac{\overline{\theta}}{2}$ $\Pi_2 = \frac{\overline{\theta}}{2}$

Table 2.3: Payoffs (with stigma)

In Stage 1 firms choose clean (C) or dirty (D) production given the payoffs from Table 2.3.

Firm 1 unilateral clean adoption threshold: $\Pi_1(C, D) > \Pi_1(D, D) \Leftrightarrow \gamma < \overline{\gamma}_1$, where:

$$\overline{\gamma}_1(\sigma, c_2) \equiv (3\overline{\theta} + c_2)\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) - \sigma. \tag{2.23}$$

Firm 2 unilateral clean adoption threshold: $\Pi_2(D, C) > \Pi_2(D, D) \Leftrightarrow \gamma < \overline{\gamma}_2$, where:

$$\overline{\gamma}_2(\sigma, c_2) \equiv c_2 + (3\overline{\theta} - c_2)\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) - \sigma.$$

Firm 1 clean adoption threshold given firm 2 clean adoption: $\Pi_1(C, C) > \Pi_1(D, C) \Leftrightarrow \gamma < \overline{\gamma}_{1R}$, where:

$$\overline{\gamma}_{1R}(\sigma) \equiv -3\overline{\theta}\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) + 2\sigma.$$

Firm 2 clean adoption threshold given firm 1 clean adoption: $\Pi_2(C, C) > \Pi_2(C, D) \Leftrightarrow$

$\gamma < \overline{\gamma}_{2R}$, where:

$$\overline{\gamma}_{2R}(\sigma, c_2) \equiv c_2 - 3\overline{\theta}\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) + 2\sigma. \tag{2.24}$$

By assumption $\overline{\theta}$ is always large enough to generate an interior solution (fn. 4). Derive the highest admissible value σ can take. The most restrictive condition is for firm 2's demand level to be positive in case of firm 1's unilateral adoption (C, D). Plug $\overline{\gamma}_1$ from (2.23) into Λ_2^* from (2.22): $\Lambda_2^*(C,D)|_{\gamma=\overline{\gamma}_1} > 0 \Leftrightarrow A \equiv 3\overline{\theta}(2 - \sqrt{1-\frac{\sigma}{2\overline{\theta}}}) - c_2\sqrt{1-\frac{\sigma}{2\overline{\theta}}} - 3\sigma > 0$; $A = 0 \Leftrightarrow \sigma \in \{\frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}}, 2\overline{\theta}\}$; $\frac{\partial A}{\partial \sigma} = 0 \Leftrightarrow \sigma = \frac{(15\overline{\theta}+c_2)(9\overline{\theta}-c_2)}{72\overline{\theta}}$; $\frac{\partial^2 A}{\partial \sigma^2} = \frac{3\overline{\theta}+c_2}{8\overline{\theta}(2\overline{\theta}-\sigma)\sqrt{1-\frac{\sigma}{2\overline{\theta}}}} > 0$, $\forall \sigma < 2\overline{\theta}$; thus $A > 0$, $\forall \sigma \in (0, \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}})$, $\forall c_2 \in (0, 3\overline{\theta})$, and therefore $\Lambda_2^*(C,D)|_{\gamma=\overline{\gamma}_1} > 0 \Leftrightarrow \sigma \in (0, \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}})$. Impose the following restriction on σ:

$$\sigma < \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}}. \tag{2.25}$$

Derive relationships between thresholds (2.23)–(2.24) for any admissible σ (per 2.25).

$\overline{\gamma}_1 < \overline{\gamma}_2$: $\overline{\gamma}_2 - \overline{\gamma}_1 = c_2\left(2\sqrt{1-\frac{\sigma}{2\overline{\theta}}} - 1\right) = 0 \Leftrightarrow \sigma = \frac{3\overline{\theta}}{2}$; $\frac{\partial(\overline{\gamma}_2 - \overline{\gamma}_1)}{\partial \sigma} = -\frac{c_2}{2\overline{\theta}\sqrt{1-\frac{\sigma}{2\overline{\theta}}}} < 0$, $\forall \sigma \in (0, 2\overline{\theta})$; thus $\overline{\gamma}_2 > \overline{\gamma}_1$, $\forall \sigma \in (0, \frac{3\overline{\theta}}{2})$, where $\frac{3\overline{\theta}}{2} > \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}}$, $\forall c_2 > 0$.

$\overline{\gamma}_1 < \overline{\gamma}_{1R}$: $\overline{\gamma}_{1R} - \overline{\gamma}_1 = 3\sigma - (6\overline{\theta} + c_2)\left(1 - \sqrt{1-\frac{\sigma}{2\overline{\theta}}}\right) = 0 \Leftrightarrow \sigma \in \{0, 2\overline{\theta} - \frac{c_2^2}{18\overline{\theta}}\}$; $\frac{\partial(\overline{\gamma}_{1R} - \overline{\gamma}_1)}{\partial \sigma} = 0 \Leftrightarrow \sigma = \frac{(6\overline{\theta}-c_2)(18\overline{\theta}+c_2)}{72\overline{\theta}}$; $\frac{\partial^2(\overline{\gamma}_{1R} - \overline{\gamma}_1)}{\partial \sigma^2} = -\frac{6\overline{\theta}+c_2}{8\overline{\theta}(2\overline{\theta}-\sigma)\sqrt{1-\frac{\sigma}{2\overline{\theta}}}} < 0$, $\forall \sigma \in (0, 2\overline{\theta})$; thus $\overline{\gamma}_{1R} > \overline{\gamma}_1$, $\forall \sigma \in (0, 2\overline{\theta} - \frac{c_2^2}{18\overline{\theta}})$, where $2\overline{\theta} - \frac{c_2^2}{18\overline{\theta}} > \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}}$, $\forall c_2 > 0$.

$\overline{\gamma}_{1R} < \overline{\gamma}_{2R}$: $\overline{\gamma}_{2R} - \overline{\gamma}_{1R} = c_2$; thus $\overline{\gamma}_{2R} > \overline{\gamma}_{1R}$, $\forall c_2 > 0$.

$\overline{\gamma}_2 < \overline{\gamma}_{2R}$: $\overline{\gamma}_{2R} - \overline{\gamma}_2 = 3\sigma - (6\overline{\theta} - c_2)\left(1 - \sqrt{1-\frac{\sigma}{2\overline{\theta}}}\right) = 0 \Leftrightarrow \sigma \in \{0, 2\overline{\theta} - \frac{c_2^2}{18\overline{\theta}}\}$; $\frac{\partial(\overline{\gamma}_{2R} - \overline{\gamma}_2)}{\partial \sigma} = 0 \Leftrightarrow \sigma = \frac{(6\overline{\theta}+c_2)(18\overline{\theta}-c_2)}{72\overline{\theta}}$; $\frac{\partial^2(\overline{\gamma}_{2R} - \overline{\gamma}_2)}{\partial \sigma^2} = -\frac{6\overline{\theta}-c_2}{16\overline{\theta}^2\left(1-\frac{\sigma}{2\overline{\theta}}\right)^{\frac{3}{2}}} < 0$, $\forall \sigma \in (0, 2\overline{\theta})$; thus $\overline{\gamma}_{2R} > \overline{\gamma}_2$, $\forall \sigma \in (0, 2\overline{\theta} - \frac{c_2^2}{18\overline{\theta}})$, where $2\overline{\theta} - \frac{c_2^2}{18\overline{\theta}} > \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}}$, $\forall c_2 > 0$.

Therefore the following relationships always hold among firms' γ thresholds for any admissible σ:

$$\overline{\gamma}_1 < \overline{\gamma}_{1R} < \overline{\gamma}_{2R} \text{ and } \overline{\gamma}_1 < \overline{\gamma}_2 < \overline{\gamma}_{2R}. \tag{2.26}$$

The relationship between $\overline{\gamma}_{1R}$ and $\overline{\gamma}_2$ depends on the relationship between σ and c_2.

$\overline{\gamma}_2 > \overline{\gamma}_{1R} : \overline{\gamma}_2 - \overline{\gamma}_{1R} = 6\overline{\theta}\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) + c_2\sqrt{1 - \frac{\sigma}{2\overline{\theta}}} - 3\sigma = 0 \Leftrightarrow \sigma \in \{\frac{c_2(12\overline{\theta}-c_2)}{18\overline{\theta}}, 2\overline{\theta}\}$; $\frac{\partial(\overline{\gamma}_2-\overline{\gamma}_{1R})}{\partial\sigma} = 0 \Leftrightarrow \sigma = \frac{(6\overline{\theta}+c_2)(18\overline{\theta}-c_2)}{72\overline{\theta}}$; $\frac{\partial^2(\overline{\gamma}_2-\overline{\gamma}_{1R})}{\partial\sigma^2} = \frac{6\overline{\theta}-c_2}{8\overline{\theta}(2\overline{\theta}-\sigma)\sqrt{1-\frac{\sigma}{2\overline{\theta}}}} > 0$, $\forall\sigma \in (0, 2\overline{\theta})$; thus $\overline{\gamma}_2 > \overline{\gamma}_{1R} \Leftrightarrow \sigma \in (0, \frac{c_2(12\overline{\theta}-c_2)}{18\overline{\theta}})$, and therefore:

$$\overline{\gamma}_2 > \overline{\gamma}_{1R} \Leftrightarrow \sigma < \widetilde{\sigma}(c_2, \overline{\theta}), \text{ where } \widetilde{\sigma}(c_2, \overline{\theta}) \equiv \frac{(12\overline{\theta} - c_2)}{18\overline{\theta}}c_2. \tag{2.27}$$

To ensure that $\widetilde{\sigma}(c_2, \overline{\theta})$ is always part of the support of σ as per (2.25), impose the following restriction on c_2 going forward:

$$\widetilde{\sigma}(c_2, \overline{\theta}) < \frac{(9\overline{\theta} + c_2)(3\overline{\theta} - c_2)}{18\overline{\theta}} \Leftrightarrow c_2 < \frac{3\overline{\theta}}{2}. \tag{2.28}$$

Derive the relationships between firms' adoption thresholds in the presence of stigma $\overline{\gamma}_{1R|\sigma>0}$ and $\overline{\gamma}_{2|\sigma>0}$, respectively, and firms' adoption thresholds in the absence of stigma $\overline{\gamma}_{1R|\sigma=0} = 0$ and $\overline{\gamma}_{2|\sigma=0} = c_2$, respectively.

$\overline{\gamma}_{2|\sigma>0} < \overline{\gamma}_{2|\sigma=0} : \overline{\gamma}_{2|\sigma=0} - \overline{\gamma}_{2|\sigma>0} = \sigma - (3\overline{\theta} - c_2)\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) = 0 \Leftrightarrow \sigma \in \{0, \frac{(3\overline{\theta}-c_2)(\overline{\theta}+c_2)}{2\overline{\theta}}\}$; $\frac{\partial(\overline{\gamma}_{2|\sigma=0}-\overline{\gamma}_{2|\sigma>0})}{\partial\sigma} = 0 \Leftrightarrow \sigma = \frac{(7\overline{\theta}-c_2)(\overline{\theta}+c_2)}{8\overline{\theta}}$; $\frac{\partial^2(\overline{\gamma}_{2|\sigma=0}-\overline{\gamma}_{2|\sigma>0})}{\partial\sigma^2} = -\frac{3\overline{\theta}-c_2}{16\overline{\theta}^2\left(1-\frac{\sigma}{2\overline{\theta}}\right)^{\frac{3}{2}}} < 0$, $\forall\sigma \in (0, 2\overline{\theta})$, $\forall c_2 \in (0, 3\overline{\theta})$; thus $\overline{\gamma}_{2|\sigma=0} > \overline{\gamma}_{2|\sigma>0} \Leftrightarrow \sigma \in (0, \frac{(3\overline{\theta}-c_2)(\overline{\theta}+c_2)}{2\overline{\theta}})$, where $\frac{(3\overline{\theta}-c_2)(\overline{\theta}+c_2)}{2\overline{\theta}} > \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}}$, $\forall c_2 > 0$.

$\overline{\gamma}_{1R|\sigma>0} > \overline{\gamma}_{1R|\sigma=0} : \overline{\gamma}_{1R|\sigma>0} - \overline{\gamma}_{1R|\sigma=0} = 2\sigma - 3\overline{\theta}\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) = 0 \Leftrightarrow \sigma = 0$; $\frac{\partial(\overline{\gamma}_{1R|\sigma>0}-\overline{\gamma}_{1R|\sigma=0})}{\partial\sigma} = 2 - \frac{3}{4\sqrt{1-\frac{\sigma}{2\overline{\theta}}}} > 0 \Leftrightarrow \sigma < \frac{55\overline{\theta}}{32}$; thus $\overline{\gamma}_{1R|\sigma>0} > \overline{\gamma}_{1R|\sigma=0}$, $\forall\sigma \in (0, \frac{55\overline{\theta}}{32})$, where $\frac{55\overline{\theta}}{32} > \frac{(9\overline{\theta}+c_2)(3\overline{\theta}-c_2)}{18\overline{\theta}}$, $\forall c_2 > 0$.

Conclusion: The introduction of stigma — $\sigma > 0$ instead of $\sigma = 0$ — serves to (a) reduce $\overline{\gamma}_2$, the clean technology cost threshold below which firm 2 would wish to adopt unilaterally clean production and, (b) increase $\overline{\gamma}_{1R}$, the cost threshold below which firm 1 would wish to adopt clean conditional on firm 2 having adopted clean.

Proposition 2.3 proof: For any $\sigma < \widetilde{\sigma}(c_2, \overline{\theta})$ the relationships between thresholds from (2.26) update to:

$$\overline{\gamma}_1 < \overline{\gamma}_{1R} < \overline{\gamma}_2 < \overline{\gamma}_{2R}.$$

Derive the Nash equilibria for any γ, given that $\sigma < \widetilde{\sigma}$.

$\gamma < \overline{\gamma}_{1R}$: $\Pi_2(C,C) > \Pi_2(C,D)$ and $\Pi_2(D,C) > \Pi_2(D,D)$; eliminate firm 2's strictly dominated strategy D; then $\Pi_1(C,C) > \Pi_1(D,C)$; eliminate firm 1's strictly dominated strategy D; thus $(C,C)^{NE}$.

$\overline{\gamma}_{1R} < \gamma < \overline{\gamma}_2$: $\Pi_2(C,C) > \Pi_2(C,D)$ and $\Pi_2(D,C) > \Pi_2(D,D)$; eliminate firm 2's strictly dominated strategy D; then $\Pi_1(D,C) > \Pi_1(C,C)$; eliminate firm 1's strictly dominated strategy C; thus $(D,C)^{NE}$.

$\gamma > \overline{\gamma}_2$: $\Pi_1(D,D) > \Pi_1(C,D)$ and $\Pi_1(D,C) > \Pi_1(C,C)$; eliminate firm 1's strictly dominated strategy C; then $\Pi_2(D,D) > \Pi_2(D,C)$; eliminate firm 2's strictly dominated strategy C; thus $(D,D)^{NE}$.

Conclusion: A stigma critical level $\widetilde{\sigma} = \frac{(12\overline{\theta}-c_2)}{18\overline{\theta}}c_2$ exists such that if $\sigma < \widetilde{\sigma}$ then $\overline{\gamma}_{1R} < \overline{\gamma}_2$, and for $\gamma \in (0, \overline{\gamma}_{1R}]$ both firms adopt the clean technology, for $\gamma \in (\overline{\gamma}_{1R}, \overline{\gamma}_2]$ only firm 2 adopts, while for $\gamma > \overline{\gamma}_2$ no firm adopts.

Proposition 2.4 proof: For any $\sigma > \widetilde{\sigma}(c_2, \overline{\theta})$ the relationships between thresholds from (2.26) update to:

$$\overline{\gamma}_1 < \overline{\gamma}_2 < \overline{\gamma}_{1R} < \overline{\gamma}_{2R}.$$

Derive the Nash equilibria for any γ, given that $\sigma > \widetilde{\sigma}$.

$\gamma < \overline{\gamma}_2$: $\Pi_2(C,C) > \Pi_2(C,D)$ and $\Pi_2(D,C) > \Pi_2(D,D)$; eliminate firm 2's strictly dominated strategy D; then $\Pi_1(C,C) > \Pi_1(D,C)$; eliminate firm 1's strictly dominated strategy D; thus $(C,C)^{NE}$.

$\overline{\gamma}_2 < \gamma < \overline{\gamma}_{1R}$: $\Pi_1(D,D) > \Pi_1(C,D)$ and $\Pi_2(D,D) > \Pi_2(D,C)$, thus $(D,D)^{NE}$; $\Pi_1(C,C) > \Pi_1(D,C)$ and $\Pi_2(C,C) > \Pi_2(C,D)$, thus $(C,C)^{NE}$ as well.

$\gamma > \overline{\gamma}_{1R}$: $\Pi_1(D,D) > \Pi_1(C,D)$ and $\Pi_1(D,C) > \Pi_1(C,C)$; eliminate firm 1's strictly dominated strategy C; then $\Pi_2(D,D) > \Pi_2(D,C)$; eliminate firm 2's strictly dominated strategy C; thus $(D,D)^{NE}$.

Conclusion: If $\sigma > \widetilde{\sigma}$ then $\overline{\gamma}_2 < \overline{\gamma}_{1R}$, and for $\gamma \in (0, \overline{\gamma}_2]$ both firms adopt clean, for $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R}]$ either both firms adopt clean or none of them does, while for $\gamma > \overline{\gamma}_{1R}$ no firm adopts clean.

Proposition 2.5 proof: Calculate total welfare costs Γ: $\Delta \times$ (demand for dirty good(s)) + $\gamma \times$ (demand for clean good(s)) + $c_2 \times$ (demand for firm 2's dirty good) + (loss of consumer surplus relative to max surplus $\frac{1}{2\overline{\theta}} \times 2 \times \int_0^{\overline{\theta}} \theta d\theta = \frac{\overline{\theta}}{2}$). We will express total costs for (C, D) and (D, C) in the most convenient way (a sum of strictly positive terms[20]) for each level of γ. Expressions of total costs for (C, C) and (D, D) remain unchanged at all cost levels..

For any γ:

$\Gamma(C, C) = \gamma$.

$\Gamma(D, D) = \Delta \times 1 + c_2 \left(\frac{1}{2} - \frac{c_2}{6\overline{\theta}}\right) + \frac{1}{2\overline{\theta}} \times 2 \times \int_0^{\frac{c_2}{3}} \theta d\theta = \Delta + c_2 \left(\frac{1}{2} - \frac{c_2}{6\overline{\theta}}\right) + \frac{c_2^2}{18\overline{\theta}} = \Delta + c_2 \left(\frac{1}{2} - \frac{c_2}{9\overline{\theta}}\right)$.

For any $\gamma < \Delta$:

$\Gamma(D, C) = \Delta \times \left(\frac{1}{2} - \frac{\Delta - \gamma}{6\overline{\theta}}\right) + \gamma \times \left(\frac{1}{2} + \frac{\Delta - \gamma}{6\overline{\theta}}\right) + \frac{1}{2\overline{\theta}} \times 2 \times \int_0^{\frac{\Delta - \gamma}{3}} \theta d\theta = \gamma + (\Delta - \gamma) \left(\frac{1}{2} - \frac{\Delta - \gamma}{6\overline{\theta}}\right) + \frac{(\Delta - \gamma)^2}{18\overline{\theta}} = \gamma + (\Delta - \gamma) \left(\frac{1}{2} - \frac{\Delta - \gamma}{9\overline{\theta}}\right)$;

$\Gamma(C, D) = \gamma \left(\frac{1}{2} + \frac{\Delta + c_2 - \gamma}{6\overline{\theta}}\right) + (\Delta + c_2) \left(\frac{1}{2} - \frac{\Delta + c_2 - \gamma}{6\overline{\theta}}\right) + \frac{1}{2\overline{\theta}} \times 2 \times \int_0^{\frac{\Delta + c_2 - \gamma}{3}} \theta d\theta = \gamma + (\Delta + c_2 - \gamma) \left(\frac{1}{2} - \frac{\Delta + c_2 - \gamma}{9\overline{\theta}}\right)$.

It is obvious that $\Gamma(C, C) < \Gamma(D, C)$ and $\Gamma(C, C) < \Gamma(C, D)$, and for any $\gamma < \Delta$ that $\Gamma(C, C) < \Gamma(D, D)$.

Therefore (C, C) is socially-preferred for any $\gamma \in (0, \Delta)$.

For any $\Delta < \gamma < \Delta + c_2$:

$\Gamma(D, C) = \Delta \times \left(\frac{1}{2} + \frac{\gamma - \Delta}{6\overline{\theta}}\right) + \gamma \times \left(\frac{1}{2} - \frac{\gamma - \Delta}{6\overline{\theta}}\right) + \frac{1}{2\overline{\theta}} \times 2 \times \int_0^{\frac{\gamma - \Delta}{3}} \theta d\theta = \Delta + (\gamma - \Delta) \left(\frac{1}{2} - \frac{\gamma - \Delta}{9\overline{\theta}}\right)$;

$\Gamma(C, D) = \gamma \left(\frac{1}{2} + \frac{\Delta + c_2 - \gamma}{6\overline{\theta}}\right) + (\Delta + c_2) \left(\frac{1}{2} - \frac{\Delta + c_2 - \gamma}{6\overline{\theta}}\right) + \frac{1}{2\overline{\theta}} \times 2 \times \int_0^{\frac{\Delta + c_2 - \gamma}{3}} \theta d\theta = \gamma + (\Delta + c_2 - \gamma) \left(\frac{1}{2} - \frac{\Delta + c_2 - \gamma}{9\overline{\theta}}\right)$.

It is obvious that $\Gamma(C, C) < \Gamma(C, D)$, and for any $\gamma > \Delta$ that $\Gamma(C, C) - \Gamma(D, C) = (\gamma - \Delta) \left(\frac{1}{2} + \frac{\gamma - \Delta}{9\overline{\theta}}\right) > 0$; thus $\Gamma(D, C) < \Gamma(C, C) < \Gamma(C, D)$.

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[20] For each adoption scenario we express total costs as a sum of two strictly positive terms. For example, in the case of (D, C) for $\gamma < \Delta$, $\Gamma(D, C) = \gamma + (\Delta - \gamma) \left(\frac{1}{2} - \frac{\Delta - \gamma}{9\overline{\theta}}\right)$, where: $\gamma > 0$; $(\Delta - \gamma) > 0$ because $\gamma < \Delta$; $\left(\frac{1}{2} - \frac{\Delta - \gamma}{9\overline{\theta}}\right) > 0$ because demand for firm 1's dirty good $\left(\frac{1}{2} - \frac{\Delta - \gamma}{6\overline{\theta}}\right) > 0$ (by assumption $\overline{\theta}$ is always large enough to generate an interior solution), and $\left(\frac{1}{2} - \frac{\Delta - \gamma}{9\overline{\theta}}\right) > \left(\frac{1}{2} - \frac{\Delta - \gamma}{6\overline{\theta}}\right) > 0$. In most cases this makes welfare costs inequalities obvious throughout this proof.

$\Gamma(D,D)-\Gamma(D,C)=c_2\left(\frac{1}{2}-\frac{c_2}{6\overline{\theta}}\right)-(\gamma-\Delta)\left(\frac{1}{2}-\frac{\gamma-\Delta}{9\overline{\theta}}\right)=0\Leftrightarrow\gamma\in\{\Delta+c_2,\Delta+\frac{9\overline{\theta}}{2}-c_2\}$, where $\Delta+c_2<\Delta+\frac{9\overline{\theta}}{2}-c_2$, $\forall c_2<\frac{9\overline{\theta}}{4}$; $\frac{\partial[\Gamma(D,D)-\Gamma(D,C)]}{\partial\gamma}=\Delta+\frac{9\overline{\theta}}{4}$; $\frac{\partial^2[\Gamma(D,D)-\Gamma(D,C)]}{\partial\gamma^2}=\frac{2}{9\overline{\theta}}>0$; thus $\Gamma(D,D)-\Gamma(D,C)>0$, $\forall\gamma<\Delta+c_2$, $\forall c_2<\frac{9\overline{\theta}}{4}$, and thus $\Gamma(D,C)<\Gamma(D,D)$, $\forall\gamma\in(\Delta,\Delta+c_2)$, $\forall c_2\in(0,\frac{3\overline{\theta}}{2})$ (2.28).

Therefore (D,C) is socially-preferred for any $\gamma\in(\Delta,\Delta+c_2)$.

For any $\gamma>\Delta+c_2$:

$\Gamma(D,C)=\Delta\times\left(\frac{1}{2}+\frac{\gamma-\Delta}{6\overline{\theta}}\right)+\gamma\times\left(\frac{1}{2}-\frac{\gamma-\Delta}{6\overline{\theta}}\right)+\frac{1}{2\overline{\theta}}\times2\times\int_0^{\frac{\gamma-\Delta}{3}}\theta d\theta=\Delta+(\gamma-\Delta)\left(\frac{1}{2}-\frac{\gamma-\Delta}{9\overline{\theta}}\right)$;

$\Gamma(C,D)=\gamma\left[\frac{1}{2}-\frac{\gamma-(\Delta+c_2)}{6\overline{\theta}}\right]+(\Delta+c_2)\left[\frac{1}{2}+\frac{\gamma-(\Delta+c_2)}{6\overline{\theta}}\right]+\frac{1}{2\overline{\theta}}\times2\times\int_0^{\frac{\gamma-(\Delta+c_2)}{3}}\theta d\theta=(\Delta+c_2)+[\gamma-(\Delta+c_2)]\left[\frac{1}{2}-\frac{\gamma-(\Delta+c_2)}{9\overline{\theta}}\right]$.

It is obvious that $\Gamma(D,D)<\Gamma(C,D)$, and for any $\Delta+c_2<\gamma$ that $\Gamma(D,D)<\Gamma(C,C)$.

Making use of the above characterization for $\Gamma(D,D)-\Gamma(D,C)$, we know that $\Gamma(D,D)-\Gamma(D,C)<0\Leftrightarrow\gamma\in(\Delta+c_2,\Delta+\frac{9\overline{\theta}}{2}-c_2)$, $\forall c_2<\frac{9\overline{\theta}}{4}$, and thus $\Gamma(D,D)<\Gamma(D,C)$, $\forall\gamma\in(\Delta+c_2,3\overline{\theta})$, $\forall c_2\in(0,\frac{3\overline{\theta}}{2})$ (per 2.28).

Therefore (D,D) is socially-preferred for any $\gamma>\Delta+c_2$.

To summarize: $\gamma<\Delta$, (C,C) is socially-preferred; $\Delta<\gamma<\Delta+c_2$, (D,C) is socially-preferred; $\gamma>\Delta+c_2$, (D,D) is socially-preferred.

From Proposition 2.3 we know $\widetilde{\sigma}=\frac{\left(12\overline{\theta}-c_2\right)}{18\overline{\theta}}c_2>0$ exists, such that if $\sigma<\widetilde{\sigma}$ then $\overline{\gamma}_{1R}<\overline{\gamma}_2$, and: for $\gamma<\overline{\gamma}_{1R}$, $(C,C)^{NE}$; for $\overline{\gamma}_{1R}<\gamma<\overline{\gamma}_2$, $(D,C)^{NE}$; for $\gamma>\overline{\gamma}_2$, $(D,D)^{NE}$. Evaluate firms' adoption thresholds in the absence of stigma: $\overline{\gamma}_{1R}|_{\sigma=0}=0$ and $\overline{\gamma}_2|_{\sigma=0}=c_2$.

From Proposition 2.2 we know that the introduction of stigma — $\sigma>0$ instead of $\sigma=0$ — serves to reduce $\overline{\gamma}_2$ below $\overline{\gamma}_2|_{\sigma=0}=c_2$, while at the same time increase $\overline{\gamma}_{1R}$ above $\overline{\gamma}_{1R}|_{\sigma=0}=0$. By assumption $c_2<\Delta$, and therefore stigma decreases firm 2 adoption, but increases firm 1 adoption when the social planner prefers that both firms adopt ($\Gamma(C,C)$ lowest for $\gamma<\Delta$).

Conclusion: Low stigma $\sigma<\widetilde{\sigma}$ generates a brown trap for the high-cost firm, but also generates a clean adoption interval for the low-cost firm. (a) Firm 2 falls into a brown trap for clean technology costs $\gamma\in(\overline{\gamma}_2,c_2]$. In that interval absent stigma firm 2 would adopt clean production and that would be socially-preferred, but accounting for stigma it chooses dirty. (b) Firm 1 adopts for clean technology costs $\gamma \in (0, \overline{\gamma}_{1R}]$. In that interval absent stigma firm 1 would not adopt clean production although it would be socially-preferred, but accounting for stigma it chooses clean.

Proposition 2.6 proof: From (2.27) we know that $\overline{\gamma}_2 < \overline{\gamma}_{1R} \Leftrightarrow \sigma > \widetilde{\sigma}(c_2, \overline{\theta})$. Derive levels of σ such that $\overline{\gamma}_{1R} > c_2$, $\overline{\gamma}_{1R} > \Delta$ and $\overline{\gamma}_{1R} > \Delta + c_2$, respectively.

$\overline{\gamma}_{1R} > \Delta : \overline{\gamma}_{1R} - \Delta = 2\sigma - 3\overline{\theta}\left(1 - \sqrt{1 - \frac{\sigma}{2\overline{\theta}}}\right) - \Delta = 0 \Leftrightarrow \sigma \in \left\{\frac{\Delta}{2} + \frac{3}{16}\left[5\overline{\theta} \pm \sqrt{(5\overline{\theta})^2 - 16\Delta\overline{\theta}}\right]\right\}$; $\frac{\partial(\overline{\gamma}_{1R} - \Delta)}{\partial\sigma} = 0 \Leftrightarrow \sigma = \frac{55\overline{\theta}}{32}$; $\frac{\partial^2(\overline{\gamma}_{1R} - \Delta)}{\partial\sigma^2} = -\frac{3}{16\overline{\theta}\left(1 - \frac{\sigma}{2\overline{\theta}}\right)^{\frac{3}{2}}} < 0$, $\forall\sigma \in (0, 2\overline{\theta})$; thus $\overline{\gamma}_{1R} > \Delta \Leftrightarrow \sigma > \overline{\overline{\sigma}}(\Delta)$, where $\overline{\overline{\sigma}}(\Delta) \equiv \frac{\Delta}{2} + \frac{3}{16}\left[5\overline{\theta} - \sqrt{(5\overline{\theta})^2 - 16\Delta\overline{\theta}}\right]$.

Similarly $\overline{\gamma}_{1R} > c_2 \Leftrightarrow \sigma > \overline{\sigma}(c_2)$, where $\overline{\sigma}(c_2) \equiv \frac{c_2}{2} + \frac{3}{16}\left[5\overline{\theta} - \sqrt{(5\overline{\theta})^2 - 16c_2\overline{\theta}}\right]$.

Similarly $\overline{\gamma}_{1R} > \Delta + c_2 \Leftrightarrow \sigma > \overline{\overline{\overline{\sigma}}}(\Delta)$, where $\overline{\overline{\overline{\sigma}}}(\Delta, c_2) \equiv \frac{\Delta + c_2}{2} + \frac{3}{16}\left[5\overline{\theta} - \sqrt{(5\overline{\theta})^2 - 16(\Delta + c_2)\overline{\theta}}\right]$.

Assuming firms implement $(C, C)^{NE}$ for $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$ (Prop. 2.4), then both firms adopt for $\gamma < \overline{\gamma}_{1R}$.

Social planner prefers that both firms adopt for $\gamma < \Delta$, only firm 2 adopts for $\Delta < \gamma < \Delta + c_2$, and that none adopts for $\gamma > \Delta + c_2$. (Prop. 2.5 proof).

Conclusion: With high stigma $\sigma > \widetilde{\sigma}$ firm 1 may fall into a green trap, firm 2 may fall into a brown trap or a green trap.

(a) For $\sigma \in (\widetilde{\sigma}, \overline{\sigma}]$ firm 1 adopts clean over $(0, \overline{\gamma}_{1R}]$ and firm 2 falls into a brown trap over $(\overline{\gamma}_{1R}, c_2]$. In those respective intervals, absent stigma, firm 1 would not adopt, while firm 2 would, although it would be socially-preferred that both adopt; accounting for stigma firm 1 adopts, and firm 2 does not.

(b) For $\sigma \in (\overline{\sigma}, \overline{\overline{\sigma}}]$ firm 1 adopts clean over $(0, \overline{\gamma}_{1R}]$ and firm 2 adopts clean over $(c_2, \overline{\gamma}_{1R}]$. In those respective intervals, absent stigma, firms would not adopt clean, although it would be socially-preferred that they do; accounting for stigma both firms choose clean.

(c) For $\sigma \in (\overline{\overline{\sigma}}, \overline{\overline{\overline{\sigma}}}]$ firm 1 falls into a green trap $(\Delta, \overline{\gamma}_{1R}]$ and firm 2 adopts over $(c_2, \overline{\gamma}_{1R}]$.

In those respective intervals, absent stigma, firm 1 would not adopt and that would be socially-preferred, while firm 2 would not adopt although it would be sociall-preferred that it does; accounting for stigma both firms choose clean.

(d) For $\sigma > \overline{\overline{\overline{\sigma}}}$ both firms fall into green traps $(\Delta, \overline{\gamma}_{1R}]$ and $(\Delta + c_2, \overline{\gamma}_{1R}]$, respectively. In those intervals absent stigma firms would not adopt clean, and that would be socially-preferred, but accounting for stigma they both choose clean.

Proposition 2.7 proof: From Propositions 2.5 and 2.6 we know that welfare traps intervals are determined by firms' adoption thresholds $\overline{\gamma}_{1R}$ and $\overline{\gamma}_2$ — which are sensitive to competition —, as well as social planner's adoption thresholds Δ and $\Delta + c_2$ — which are not. Derive signs of $\frac{\partial \overline{\gamma}_{1R}}{\partial \overline{\theta}}$ and $\frac{\partial \overline{\gamma}_2}{\partial \overline{\theta}}$.

$\frac{\partial \overline{\gamma}_{1R}}{\partial \overline{\theta}} > 0 : \frac{\partial \overline{\gamma}_{1R}}{\partial \overline{\theta}} = \frac{12\overline{\theta}\left(1-\sqrt{1-\frac{\sigma}{2\overline{\theta}}}\right)-3\sigma}{4\overline{\theta}\sqrt{1-\frac{\sigma}{2\overline{\theta}}}} = 0 \Leftrightarrow \sigma = 0$; $\frac{\partial^2 \overline{\gamma}_{1R}}{\partial \overline{\theta} \partial \sigma} = \frac{3\sigma}{16\overline{\theta}^2\left(1-\frac{\sigma}{2\overline{\theta}}\right)^{\frac{3}{2}}} > 0, \forall \sigma \in (0, 2\overline{\theta})$; thus $\frac{\partial \overline{\gamma}_{1R}}{\partial \overline{\theta}} > 0$ for any admissible σ.

An increase in competition (a decrease in $\overline{\theta}$) narrows firm 1's green trap $(\Delta, \overline{\gamma}_{1R}]$, and firm 2's green trap $(\Delta + c_2, \overline{\gamma}_{1R}]$ in the high stigma case (Prop. 2.6 (c) and (d)), but widens firm 2's brown trap $(\overline{\gamma}_{1R}, c_2]$ (Prop. 2.6 (a)).

$\frac{\partial \overline{\gamma}_2}{\partial \overline{\theta}} > 0 \Leftrightarrow \sigma < \frac{24\overline{\theta}^2 c_2}{(3\overline{\theta}+c_2)^2} : \frac{\partial \overline{\gamma}_2}{\partial \overline{\theta}} = \frac{\sigma(3\overline{\theta}+c_2)-12\overline{\theta}^2\left(1-\sqrt{1-\frac{\sigma}{2\overline{\theta}}}\right)}{4\overline{\theta}^2\sqrt{1-\frac{\sigma}{2\overline{\theta}}}} = 0 \Leftrightarrow \sigma \in \{0, \frac{24\overline{\theta}^2 c_2}{(3\overline{\theta}+c_2)^2}\}$; $\frac{\partial^2 \overline{\gamma}_2}{\partial \overline{\theta} \partial \sigma} = 0 \Leftrightarrow \sigma = \frac{4\overline{\theta} c_2}{3\overline{\theta}+c_2}$; $\frac{\partial^3 \overline{\gamma}_2}{\partial \overline{\theta} \partial \sigma^2} = \frac{(8\overline{\theta}-\sigma)c_2-3\overline{\theta}(4\overline{\theta}+\sigma)}{16\overline{\theta}^2(2\overline{\theta}-\sigma)^2\sqrt{1-\frac{\sigma}{2\overline{\theta}}}}$; $sign\left[\frac{\partial^3 \overline{\gamma}_2}{\partial \overline{\theta} \partial \sigma^2}\right] = sign\left[B \equiv (8\overline{\theta}-\sigma)c_2 - 3\overline{\theta}(4\overline{\theta}+\sigma)\right], \forall \sigma \in (0, 2\overline{\theta})$; $\lim_{\sigma \to 0} B = -4\overline{\theta}(3\overline{\theta} - 2c_2) < 0$, $\forall c_2 < \frac{3\overline{\theta}}{2}$ (per 2.28), and $\frac{\partial B}{\partial \sigma} = -(3\overline{\theta}+c_2) < 0$; thus $\frac{\partial^3 \overline{\gamma}_2}{\partial \overline{\theta} \partial \sigma^2} < 0, \forall \sigma \in (0, 2\overline{\theta}), \forall c_2 \in (0, \frac{3\overline{\theta}}{2})$, and therefore $\frac{\partial \overline{\gamma}_2}{\partial \overline{\theta}} > 0$, $\forall \sigma \in (0, \frac{24\overline{\theta}^2 c_2}{(3\overline{\theta}+c_2)^2})$.

Moreover, $\frac{24\overline{\theta}^2 c_2}{(3\overline{\theta}+c_2)^2} > \widetilde{\sigma}(c_2) \Leftrightarrow \frac{24\overline{\theta}^2}{(3\overline{\theta}+c_2)^2} > \frac{12\overline{\theta}-c_2}{18\overline{\theta}}$, where $\frac{12\overline{\theta}-c_2}{18\overline{\theta}} < 1$ and $\frac{24\overline{\theta}^2}{(3\overline{\theta}+c_2)^2} > 1, \forall c_2 \in (0, \frac{3\overline{\theta}}{2})$, and thus $\frac{24\overline{\theta}^2 c_2}{(3\overline{\theta}+c_2)^2} > \widetilde{\sigma}(c_2)$ holds. Therefore $\frac{\partial \overline{\gamma}_2}{\partial \overline{\theta}} > 0$ under low stigma ($\sigma < \widetilde{\sigma}$), and an increase in competition (a decrease in $\overline{\theta}$) widens firm 2's brown trap $(\overline{\gamma}_2, c_2]$ (Prop. 2.5 (a)).

Conclusion: An increase in competition narrows green traps, but widens brown traps.

2.5 Appendix B

The remarks below summarize the results obtained from an analysis of mixed strategies when multiple equilibria emerge, that is for intermediary costs ($\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$) when stigma is high ($\sigma > \widetilde{\sigma}$). The proofs identify the probabilities with which firms mix the strategies, and characterize them.

The probability with which each firm chooses the dirty technology is increasing in stigma. This result holds in the case of symmetric costs of dirty production ($c_1 = c_2 = 0$) as well. Going back to asymmetric costs of dirty production ($c_1 = 0,\ c_2 > 0$), the analysis shows that low-cost firm's probability of choosing dirty is increasing in c_2, whereas high-cost firm's probability of choosing dirty is decreasing in c_2.

Remark 2.1. *For intermediary costs of clean production ($\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$) under high stigma ($\sigma > \widetilde{\sigma}$), a mixed-strategy Nash equilibrium exists in which firm $i \in \{1, 2\}$ chooses the dirty technology with probability $\alpha_i \in (0, 1)$, and this probability is increasing in the level of stigma.*

Remark 2.2. *An increase in firm 2's cost of dirty production increases the probability of firm 1 choosing dirty, and increases the probability of firm 2 choosing clean, in a mixed-strategy Nash equilibrium ($\sigma > \widetilde{\sigma}$, $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$).*

Remark 2.1 proof: Assume firm i plays D with probability $\alpha_i \in (0, 1)$, and plays C with probability $(1 - \alpha_i)$, $i \in \{1, 2\}$. These are included in firms' payoff matrix reproduced below for convenience.

Firm 1 chooses α_1 such that firm 2 is indifferent between playing C or D: $\frac{\alpha_1}{2\overline{\theta}} \left(\overline{\theta} - \frac{c_2}{3}\right)^2 + \frac{(1-\alpha_1)}{2\overline{\theta}-\sigma} \left(\overline{\theta} + \frac{\gamma - c_2 - 2\sigma}{3}\right)^2 = \frac{\alpha_1}{2\overline{\theta}-\sigma} \left(\overline{\theta} - \frac{\gamma+\sigma}{3}\right)^2 + (1 - \alpha_1)\frac{\overline{\theta}}{2} \Leftrightarrow$

$$\Leftrightarrow \alpha_1 = \frac{\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma - c_2 - 2\sigma}{3}\right)^2}{\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma - c_2 - 2\sigma}{3}\right)^2 + \frac{1}{2\overline{\theta}}\left(\overline{\theta} - \frac{c_2}{3}\right)^2 - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} - \frac{\gamma+\sigma}{3}\right)^2}.$$

firm 1→ firm 2 ↓	$D \quad (\alpha_1)$	$C \quad (1-\alpha_1)$
$D \quad (\alpha_2)$	$\Pi_1 = \frac{1}{2\overline{\theta}}\left(\overline{\theta}+\frac{c_2}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}}\left(\overline{\theta}-\frac{c_2}{3}\right)^2$	$\Pi_1 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{c_2-\gamma-\sigma}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{\gamma-c_2-2\sigma}{3}\right)^2$
$C \quad (1-\alpha_2)$	$\Pi_1 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{\gamma-2\sigma}{3}\right)^2$ $\Pi_2 = \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}-\frac{\gamma+\sigma}{3}\right)^2$	$\Pi_1 = \frac{\overline{\theta}}{2}$ $\Pi_2 = \frac{\overline{\theta}}{2}$

Table 2.4: Payoffs and mixed-strategy probabilities (with stigma)

Let $A \equiv \frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{\gamma-c_2-2\sigma}{3}\right)^2$ and $B \equiv \frac{1}{2\overline{\theta}}\left(\overline{\theta}-\frac{c_2}{3}\right)^2 - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}-\frac{\gamma+\sigma}{3}\right)^2$, where[21] $A > 0$ and $B > 0$, $\forall \sigma > \widetilde{\sigma}$ and $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$, such that $\alpha_1 = \frac{A}{A+B}$.

A is increasing in σ: $\frac{\partial A}{\partial \sigma} = \frac{(3\overline{\theta}+\gamma-c_2-2\sigma)(5\overline{\theta}+c_2-\gamma-2\sigma)}{9(2\overline{\theta}-\sigma)^2} > 0$, $\forall \sigma \in (0, 2\overline{\theta})$ and given that $\overline{\theta}$ is assumed large enough for an interior partition (fn. 5).[22]

B is either decreasing in σ, or increasing at a lower rate than A: $\frac{\partial B}{\partial \sigma} = \frac{(3\overline{\theta}-\gamma-\sigma)(\overline{\theta}+\gamma-\sigma)}{9(2\overline{\theta}-\sigma)^2}$; $\frac{\partial A}{\partial \sigma} - \frac{\partial B}{\partial \sigma} = \frac{1}{3} - \frac{(2\overline{\theta}+c_2-2\gamma)c_2}{9(2\theta-\sigma)^2} > 0 \Leftrightarrow \gamma > \overline{\theta} - \frac{3(2\overline{\theta}-\sigma)^2-c_2^2}{2c_2}$; $Z \equiv \overline{\gamma}_2 - \left[\overline{\theta} - \frac{3(2\overline{\theta}-\sigma)^2-c_2^2}{2c_2}\right]$, $\lim\limits_{\sigma\to 0} Z = \frac{5\overline{\theta}^2+(\overline{\theta}-c_2)^2}{2c_2} > 0$, $\lim\limits_{\sigma\to\frac{3\overline{\theta}}{2}} Z = \frac{\overline{\theta}}{2}+\frac{3\overline{\theta}^2}{8c_2} > 0$, $\frac{\partial Z}{\partial \sigma} = \frac{(3\overline{\theta}-c_2)c_2-12\overline{\theta}(2\overline{\theta}-\sigma)\sqrt{1-\frac{\sigma}{2\overline{\theta}}}}{4\overline{\theta}c_2\sqrt{1-\frac{\sigma}{2\overline{\theta}}}}$; $W \equiv (3\overline{\theta}-c_2)c_2-12\overline{\theta}(2\overline{\theta}-\sigma)\sqrt{1-\frac{\sigma}{2\overline{\theta}}}]$, $\lim\limits_{\sigma\to 0} W = -(2\overline{\theta}-c_2)^2 - \overline{\theta}(20\overline{\theta}-c_2) < 0$, $\lim\limits_{\sigma\to\frac{3\overline{\theta}}{2}} W = -(\sqrt{3}\overline{\theta}-c_2)^2 - (2\sqrt{3}-3)\overline{\theta}c_2$, $\frac{\partial W}{\partial \sigma} = 18\overline{\theta}\sqrt{1-\frac{\sigma}{2\overline{\theta}}} > 0$, thus $W < 0$ $\forall \sigma \in (0, \frac{3\overline{\theta}}{2})$ (2.25); it follows that $Z > 0$, and therefore $\frac{\partial A}{\partial \sigma} > \frac{\partial B}{\partial \sigma}$ $\forall \gamma > \overline{\gamma}_2$.

Thus $\frac{\partial A}{\partial \sigma} > \frac{\partial (A+B)}{\partial \sigma}$ — the numerator increases at a higher rate than the denominator —, and therefore $\alpha_1 = \frac{A}{A+B}$ is increasing in σ: $\frac{\partial \alpha_1}{\partial \sigma} > 0$.

Firm 2 likewise chooses α_2 such that firm 1 is indifferent between playing C or D: $\frac{\alpha_2}{2\overline{\theta}}\left(\overline{\theta}+\frac{c_2}{3}\right)^2 + \frac{1-\alpha_2}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{\gamma-2\sigma}{3}\right)^2 = \frac{\alpha_2}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{c_2-\gamma-\sigma}{3}\right)^2 + (1-\alpha_2)\frac{\overline{\theta}}{2} \Leftrightarrow$

$$\Leftrightarrow \alpha_2 = \frac{\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{\gamma-2\sigma}{3}\right)^2}{\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{\gamma-2\sigma}{3}\right)^2 + \frac{1}{2\overline{\theta}}\left(\overline{\theta}+\frac{c_2}{3}\right)^2 - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{c_2-\gamma-\sigma}{3}\right)^2}.$$

Let $X \equiv \frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{\gamma-2\sigma}{3}\right)^2$ and $Y \equiv \frac{1}{2\overline{\theta}}\left(\overline{\theta}+\frac{c_2}{3}\right)^2 - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta}+\frac{c_2-\gamma-\sigma}{3}\right)^2$, where $X > 0$

[21]These are implied by the fact that symmetric choices of technology are Nash equilibria under the particular levels of stigma and costs that follow.

[22]$(3\overline{\theta}+\gamma-c_2-2\sigma) > 0$ guarantees an interior partition in outcome (C, D). $3\overline{\theta}-\gamma-\sigma > 0$ guarantees an interior partition in outcome (D, C), and $\sigma < \frac{3\overline{\theta}}{2}$ (2.25), thus $(5\overline{\theta}+c_2-\gamma-2\sigma) > 0$.

and $Y > 0$, $\forall \sigma > \widetilde{\sigma}$ and $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$, such that $\alpha_2 = \frac{X}{X+Y}$.

Using the same method as in the case of α_1 it can be shown that $\frac{\partial X}{\partial \sigma} > 0$, and that $\frac{\partial X}{\partial \sigma} > \frac{\partial Y}{\partial \sigma}$, and therefore $\alpha_2 = \frac{X}{X+Y}$ is increasing in σ: $\frac{\partial \alpha_2}{\partial \sigma} > 0$.

Conclusion: With high stigma ($\sigma > \widetilde{\sigma}$) and $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$, a mixed strategy Nash equilibrium exists in which firm $i \in \{1, 2\}$ chooses the dirty technology with probability $\alpha_i \in (0, 1)$, and this probability is increasing in the level of stigma.

The result also holds in the case of symmetric dirty production costs ($c_1 = c_2 = 0$): firms employ symmetric mixed strategies such that $\alpha_{1|c_2=0} = \alpha_{2|c_2=0} = \alpha$, where $\alpha = \frac{\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma - 2\sigma}{3}\right)^2}{\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma - 2\sigma}{3}\right)^2 + \frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} - \frac{\gamma + \sigma}{3}\right)^2}$; $\frac{\partial\left[\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma - 2\sigma}{3}\right)^2\right]}{\partial \sigma} = \frac{(5\overline{\theta} - \gamma - 2\sigma)(3\overline{\theta} + \gamma - 2\sigma)}{9(2\theta - \sigma)^2} > 0$, $\forall \sigma \in (0, 2\overline{\theta})$ and given that $\overline{\theta}$ is assumed large enough for an interior partition (fn. 5); $\frac{\partial\left[\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} - \frac{\gamma + \sigma}{3}\right)^2\right]}{\partial \sigma} = \frac{(3\overline{\theta} - \gamma - \sigma)(\overline{\theta} + \gamma - \sigma)}{9(2\theta - \sigma)^2} = \frac{\partial\left[\frac{\overline{\theta}}{2} - \frac{1}{2\overline{\theta}-\sigma}\left(\overline{\theta} + \frac{\gamma - 2\sigma}{3}\right)^2\right]}{\partial \sigma} - \frac{1}{3}$; thus again the numerator is increasing in σ at a higher rate than the denominator, and therefore $\frac{\partial \alpha}{\partial \sigma} > 0$.

Remark 2.2 proof: Using A and B defined in proof of Remark 2.1 such that $\alpha_1 = \frac{A}{A+B}$, $\frac{\partial A}{\partial c_2} = \frac{2(3\overline{\theta} + \gamma - c_2 - 2\sigma)}{9(2\theta - \sigma)^2} > 0$ and $\frac{\partial B}{\partial c_2} = -\frac{(3\overline{\theta} - c_2)}{9\overline{\theta}} < 0$ given that $\overline{\theta}$ is assumed large enough for an interior partition (fn. 5), and therefore $\frac{\partial \alpha_1}{\partial c_2} > 0$.

Making use of X and Y defined in proof of Remark 2.1 such that $\alpha_2 = \frac{X}{X+Y}$, it is obvious that $\frac{\partial X}{\partial c_2} = 0$, and using the same method employed in the proof of Remark 2.1 it can be shown that $\frac{\partial X}{\partial c_2} > 0$, therefore $\frac{\partial \alpha_2}{\partial c_2} < 0$.

Conclusion: An increase in firm 2's cost of dirty production increases the probability of firm 1 choosing dirty, and increases the probability of firm 2 choosing clean, in a mixed strategy Nash equilibrium ($\sigma > \widetilde{\sigma}$, $\gamma \in (\overline{\gamma}_2, \overline{\gamma}_{1R})$).

Chapter 3

Warm-glow and the Optimal Number of Ideologically Differentiated NGOs

3.1 Introduction

Although not known to have a particularly welcoming stance towards NGOs, China had about 500,000 registered and an estimated 1.5 million unregistered NGOs in 2014, or one NGO for less than 700 Chinese (The Economist, 2014). Estimates for India placed their number at around 3.3 million for 2009, meaning there was one NGO for less than 400 Indians (Yadav, 2015). In the United States there were 1.4 million NGOs registered with the Internal Revenue Service in 2005; the actual number was larger since only about half of the 350,000 religious congregations exempt from registering did nonetheless register. Of the 1.4 million, around 900,000 collected less than $25,000 in gross receipts (Blackwood et al., 2008).

This leads to an estimate of around 1 million very small NGOs by the amount of collected funds if we take into account the unregistered ones, or about one very small NGO for every 300 Americans. Figures like these invite questions. Are there too many NGOs? Are they doing too little through their projects?

Answers gain added importance when we consider that NGOs are overwhelmingly funded by individuals, who forgo some personal consumption in order to donate a portion of their incomes. In 2019 American individuals donated an estimated \$309.66 billion, more than twice the amount donated by foundations, bequests and corporations put together (Giving USA, 2020). While true that not everybody gives, most people do: 89% of U.S. households donated and the average donation was around \$1620 in 2003 (Mayr et al., 2009).

It may be tempting to think that only well-off citizens donate, especially when the difference of 11% above is close to the U.S. poverty rate of 12.5% for 2003 (DeNavas-Walt et al., 2004). However, as an example, in 1995 almost half of U.S. households with an income lower than \$10,000 donated more than \$300 on average (Andreoni, 2006). These figures invite more questions. Should not more households — and especially the poor ones — free-ride on the contributions of others? Are people over-donating? If so, why?

In search for answers we begin with two helping questions. Why do people donate? How do they choose the donee?

Attempts to explain donation behavior have been at the core of many theoretical and empirical papers. Within the economic theory of pure altruism, individuals derive utility from private goods and public goods, but they only care about the levels of the public goods for their own consumption. They do not care how that level is reached, if the opportunity to free-ride on the contributions of others arises, it is only rational to do so. In light of this, government contributions to a public good should crowd out dollar for dollar individuals' contributions (Warr, 1982; Bergstrom et al., 1986).

However, numerous experiments and statistics show that this is not the case (Abrams & Schmitz, 1978; Andreoni, 1993). The pure altruism model fails three times because: there is less free-riding than predicted, government contributions do not reduce individual contributions dollar for dollar, and people with low incomes, who might not be expected to donate, actually do (Mayr et al., 2009, p. 307).

To address these three issues, Andreoni (1990) proposed a model of impure altruism where, in addition to deriving utility from private goods and public goods, individuals also derive utility from their own contributions to the public goods: "When people make donations to privately provided public goods, they may not only gain utility from increasing its total supply, but they may also gain utility from the act of giving" (p. 473). This utility has been coined "warm-glow". Experiments show support for impure altruism as a model that can better explain observed donation behavior (Palfrey and Prisbrey, 1997; Goeree et al., 2002).

Interestingly, evidence from the field of neuroeconomics is emerging in support of the impure altruism model. Moll et al. (2006) used functional magnetic resonance imaging to show that donating to NGOs activated two highly localized reward systems in the brain: one associated with pure monetary rewards to the subject and the second associated with social attachment and affiliative reward mechanisms. By contrasting costly and non-costly decisions times and analyzing the correlation with brain activity they were able to rule out that activation reflected decision difficulty.

Harbaugh et al. (2007) built on the experiments of Moll et al. (2006) and showed that there was increased activity in the same localized areas that respond to individualistic rewards when subjects observed mandatory donations similar to taxation. However, they showed relatively higher activity and reported higher satisfaction when subjects made voluntary contributions rather than mandatory contributions even after controlling for their own monetary payoffs. This points out that individuals derive more pleasure when they are personally responsible for contributing to the public good. While this is not conclusive evidence of warm-glow, it is certainly consistent with it and it represents further support for the impure altruism model.

Therefore people are likely motivated to donate for their own consumption of the public good to which they contribute, and by the warm-glow satisfaction from personally contributing to the public good — a rather selfish reward for a pro-social act. How do people choose the NGO to which they donate?

NGOs provide public goods — non-rival and non-excludable — when there is a public demand for them. Therefore public demand, which is the expression of individuals' preferences and ideologies, shapes up the NGO network and has a primary role in determining what, where, how and how much of a public good is provided. For example, in a study on the allocation of benefits to endangered species, Czech et al. (1998) found that plants, birds, mammals and fish have a significantly more positive social construction than reptiles, amphibians, invertebrates and microorganisms, based on public perception. Consequently, there was a larger number of NGOs representing the former and they had a higher allocation of the benefits of the U.S. Endangered Species Act.

NGOs differ not only by the public goods they are providing, but also in the way they are providing the same public good.[1] For example, World Vision, Christian Children's Fund of Canada (CCFC) and Plan Canada all have the same mission of supporting children in developing countries, but their missions differ across a religiosity dimension.

For World Vision religion occupies a central role: "Our faith in Jesus is central to who we are, and we follow His example in working alongside the poor and oppressed. We serve every child in need that we possibly can, of any faith, or none. We partner with churches throughout the world, equipping them to meet the needs of their communities" (World Vision, 2015). Plan Canada makes it clear that religion is not at all central to their mission: "Not for profit, independent and inclusive of all faiths and cultures, we have only one agenda: to improve the lives of children" (Plan Canada, 2015). Between the two is CCFC, which implies a religious motivation by its name, but does not explicitly include it in its mission: "Throughout all of our program sectors we emphasize Child Protection, Gender, and Environment — giving children the additional support they need to live in peace and safety. Together, these are the essentials of life" (CCFC, 2015).

[1] NGOs have a history of project differentiation as Landim (1987) indicates in a study of NGOs' role to achieve and guarantee democracy in Latin America: "NGOs first appeared in Latin America in the 1950s, imbued with developmentalist ideology.[...] In general, they have a common outlook, one which involves popular education activities carried out at the grassroots level.[...] NGOs can be differentiated based on the types of projects they prioritize as well as by the groups benefiting from their actions" (p. 29).

Therefore people are likely motivated to donate to an NGO based on the public good it provides, but also based on how the NGO provides that public good. An individual who cares about children in developing countries and wants to support them can donate to any of the above charities. However, World Vision appeals more to a deeply religious donor, whereas Plan Canada appeals more to a non-religious donor.[2]

Procedural utility, introduced to economics by Frey et al. (2004), captures this insight: "Procedural utility means that people not only value actual outcomes, i.e., the what, but also the conditions and processes that lead to these outcomes, i.e., the how" (p. 377); "Empirical evidence supports the existence and relevance of procedural utility in many areas of the economy and society. Integrating procedural utility into economics both enriches it and allows it to account for phenomena that are otherwise difficult or impossible to explain" (p. 396).

The answer to our two helping questions — why do people donate and how do they choose the donee? — is then, in short: they donate for their own consumption of the public good they care about, as well as for the contribution warm-glow, and they donate to the NGO that provides that public good in a way that is ideologically closest to how people think it should be provided.

To answer the initial questions about NGOs — are there too many NGOs, are they doing too little? —, and about donors — are people over-donating, and if so, why? — we build a model of charitable contributions that incorporates warm-glow and procedural utilities in its framework. Individuals who care about a public good are uniformly distributed on an ideological circle in the manner of Salop (1979) according to how they think the public

[2] This is further articulated by Thornton (2006): "Ideology, methodology, or targeted beneficiaries can differentiate an organization's product or service. In practical terms, this implies that a donor may prefer Baptist churches to Pentecostal, or domestic antipoverty initiatives to foreign. Donors will choose the nonprofit that most closely matches their own preferences" (as cited in Aldashev & Verdier, 2010, p. 51). Pestieau and Sato (2006) make a similar point within the context of the 2004 Indian Ocean earthquake and tsunami relief efforts: "Individuals contributed to this cause through a number of charities. In Belgium, e.g., they did that through charities associated with political or religious movements (Catholics, liberals, socialists, ...), and it has been shown that people were more willing to donate through charities close to their religious, political or other leanings" (p. 2).

good should be provided. NGO entrepreneurs enter on the ideological circle and set up NGOs, individuals choose donations and donees, and NGOs provide the public good through differentiated projects funded by donors.

In this setting the initial questions reduce to one: what is the optimal number of NGOs in the presence of warm-glow and ideology? Our model distinguishes two set-ups: first-best, in which a central planner chooses the number of NGOs, and free-entry, in which NGO entrepreneurs enter freely as long as the satisfaction from their project's output at least equals their outside option.

The first-best set-up yields an optimal number of NGOs that can be higher than 1 because donors value ideological proximity to NGOs. As the number of NGOs increases beyond optimum, we identify a warm-glow threshold above (below) which welfare approaches a strictly negative (positive) limit. Thus while too many NGOs always decrease welfare, it is specifically too high warm-glow that can lead to full dissipation of NGOs' total output, outweighed by donors' forgone consumption to fund that output.

The free-entry set-up reveals how warm-glow increases donations through two channels in the presence of ideology. First is a direct channel, as individuals make more generous donations to maximize own utility, including warm-glow utility. Thus fewer donors are needed to fund an NGO, and consequently more NGOs enter. This in turn gives rise to the second, indirect channel: ideological distance between donors and NGOs decreases as a result of additional NGOs' entry, which further increases donations because donors value ideological proximity.

Therefore ideology acts as a warm-glow multiplier on donations, and hence on NGO entry, which can induce NGO entrepreneurs to enter beyond the welfare maximizing number.

While the central planner cannot choose the number of NGOs under free-entry, they can assess the level of warm-glow that would optimize welfare — would induce the welfare-maximizing number of NGOs to enter. The planner can implement one of two equivalent revenue-neutral fiscal policies that optimize free-entry welfare by determining donors to behave *as if* they were experiencing the welfare-maximizing level of warm-glow. If NGO entrepreneurs' outside option is very low, the welfare-optimizing level of warm-glow can even be negative — in fact cold-prickle.[3]

The central planner recognizes here a generosity-induced tragedy of the commons when donors' warm-glow is higher than the welfare-maximizing level. Individuals maximize own utility by forgoing consumption and making generous donations to ideologically close NGOs — the higher the warm-glow and the closer the NGO, the more generous the donation. By doing so they can impose a negative externality on each other as more NGOs enter and donor-NGO ideological proximity increases, leading to even more generous donations that translate into even more forgone consumption. A planner would want donors to internalize the negative externality they impose on each other and experience a lower warm-glow or even cold-prickle as a result. Since that is not possible, the planner can impose a revenue-neutral tax on donations either at the source (donors), or at destination (NGOs), that determines donors to behave overall *as if* they are experiencing the welfare-maximizing level of warm-glow/cold-prickle, and thus limit the number of NGOs.

In most economies donations are subsidized, often indiscriminately. Our model shows that ideology acts as a warm-glow multiplier on donations, and this can determine individuals to over-donate and support too many NGOs. Without recognizing this, a subsidy can push donations and number of NGOs beyond efficient levels in some charity markets, and thus lower welfare or even push it into negative territory. Therefore warm-glow coupled with ideological considerations provides an explanation on how individuals may indeed over-donate and end up supporting too many NGOs doing too little through their projects.

The paper proceeds as follows: Section 3.2 presents the existing literature; Section 3.3 presents the model and optimal policies; Section 3.4 concludes with a summary of our findings, policy implications and avenues for future research.

[3] "While there is no theory for the dis-utility individuals may get from the act of doing bad, an analog to the warm-glow is, naturally enough, the 'cold-prickle'." (Andreoni, 1995, p. 11)

3.2 Literature

The question on the optimal number of NGOs is not new in the economic literature. Rose-Ackerman (1982) built several models in which NGOs design strategies to maximize net expected receipts. She concludes that the absence of entry barriers leads to too many NGOs and excessive fundraising.

Pestieau and Sato (2006) model ideologically differentiated NGOs that raise money for one common project, such as emergency relief. They conclude that without set-up costs there would be as many NGOs as individuals. However, with a strictly positive set-up cost, without inequality aversion and without tax distortion, one NGO would suffice in a first-best scenario. An increase in the optimal number of NGOs is driven by an increase in inequality aversion, an increase in tax distortion or a decrease in the set-up cost. In an earlier attempt to determine the optimal number of NGOs, Barla and Pestieau (2005) do not include ideological preferences in their framework. When the central planner ignores the joy of giving (warm-glow), the optimal number of NGOs is zero because they are costly. The free-entry number of NGOs is sub-optimal except if the joy of giving is sufficiently high.

Models of ideologically differentiated NGOs have been useful for analysis of their strategic interactions, particularly fundraising (e.g., Aldashev & Verdier, 2009, 2010; Mungan & Yörük, 2012), labeling and mission design (e.g., Heyes & Martin, 2015, 2017, 2018), in settings where warm-glow occupies a secondary role, or none. Pestieau and Sato (2006) focus on optimal number of NGOs and optimal subsidy in order to reach a fixed amount of total donations, and ideology is relevant only during fundraising for a common project.

We make abstraction of fundraising costs, focus on how warm-glow affects the number of NGOs and welfare in the presence of ideology, and we do not impose limits on individual, nor on total donations. We allow for multiple ideologically differentiated projects addressing the same cause, a setting applicable to public goods that are provided on an on-going basis, such as supporting children in developing countries, or the protection of an endangered animal species.

The fiscal policies we propose are likewise driven by warm-glow, specifically by the difference between donors' warm-glow and the level of warm-glow/cold-prickle that would induce the welfare-maximizing number of NGOs under free-entry. Thus our results are also relevant for the literature on optimal tax treatment of donations (e.g., Warr, 1982; Saez, 2004; Diamond, 2006; Aronsson et al., 2016). These policies constitute an argument for differential tax treatment of different charity markets, and thus support an emerging literature that questions the often indiscriminate charitable subsidies, particularly in the legal field (e.g., Fleischer, 2009; McCormack, 2010; Galle, 2011, 2012), and to a lesser extent in economics (Carmichael, 2010, 2012a, 2012b).

3.3 Model

The model comprises citizens, NGO entrepreneurs and NGOs in a one-shot charity market game. Each NGO entrepreneur decides whether to enter the market, set up an NGO, and collect donations. Citizens decide whether to donate, and which NGO to donate to.[4] NGOs use funds to realize projects that produce a public good.

Citizens care about a specific issue and they differ in their opinions about how this issue should be approached. They are uniformly distributed with unit density on an ideological circle of unit length such that the population is of size unity.[5] They derive satisfaction from projects meant to address the issue regardless of the approach, but they derive more satisfaction from projects that address the issue in ways that are ideologically closer to their own subjective preference. In other words there is some ideological discounting that is part of a citizen's satisfaction.

Each NGO on the ideological circle initiates only one project to address the issue. For simplicity we assume these projects have a linear effect on the total output from all NGOs.

[4]Thus each citizen donates to at most one NGO, consistent with similar models where each consumer purchases at most one good (e.g., Hotelling, 1929; Salop, 1979).

[5]This modeling approach introduced by Salop (1979) avoids dealing with any corner complications when solving the model. Qualitatively similar conclusions apply if the ideological space was represented by a finite line in the tradition of Hotelling (1929).

In addition to the satisfaction from the output of NGOs, a citizen may also derive warm-glow satisfaction as per Andreoni (1990) from the act of donating to help fund one of these projects. The resulting utility function for citizen i from the output of projects $j = 1, ..., N$ is:

$$U_i = \sum_{j=1}^{N} \frac{X_j}{1 + d_{ij}} + \frac{\gamma}{1 + d_{ik}} x_{ik} - \frac{x_{ik}^2}{2}, \tag{3.1}$$

where U_i is the utility of concerned citizen i, X_j is the output of NGO j, d_{ij} is the ideological distance between citizen i and NGO j, $\gamma > 0$ is the constant marginal warm-glow satisfaction from the donation made to an NGO, and x_{ik} is the potential donation of citizen i to NGO $k \epsilon \{1, ..., N\}$, making the last term the cost of forgone consumption utility due to the potential donation.

A donor derives more warm-glow if they are able to support an ideologically closer NGO, so warm-glow is also ideologically discounted. Assuming otherwise would not impact the qualitative conclusions of this paper. Nonetheless, we would find it hard to assume otherwise. If warm-glow is the subjective satisfaction derived from the donation to a cause that the individual cares about, and by following Frey et al. (2004) individuals care about both the cause and the way it is approached, then it is natural to assume that an individual derives more warm-glow both because the NGO does what the individual wants and also because it does it in a way that the individual prefers.

There is an unlimited number of identical NGO entrepreneurs who decide at the same time whether to set up an NGO and start a project to address the issue or not. NGO entrepreneurs set up an NGO on the ideological circle as long as they can make enough of a difference on the issue or derive a high enough psychic payoff.[6] For simplicity an

[6] "The truth is that entrepreneurs are rarely motivated by the prospect of financial gain [...] Instead both the entrepreneur and the social entrepreneur are strongly motivated by the opportunity they identify, pursuing that vision relentlessly, and deriving considerable psychic reward from the process of realizing their ideas." (Martin & Osberg, 2007, p. 34). Hamilton (2000) provides empirical support based on data drawn from the 1984 Survey of Income and Program Participation focused on small business owners: "Most entrepreneurs enter and persist in business despite the fact that they have both lower initial earnings and lower earnings growth than in paid employment, implying a median earnings differential of 35 percent for individuals in business for 10 years. The differential cannot be explained by the selection of low-ability employees into self-employment and is similar for three alternative measures of self-employment earnings

entrepreneur's monetary payoff from the NGO is normalized to zero and the non-monetary payoff is linear in the output of the NGO. Entrepreneurs do not have a preferred position on the ideological circle dictated by subjective procedural preferences; they decide to set up an NGO if and where they can raise enough donations to derive at least the minimum desired non-monetary payoff from the NGO's output.[7]

Each NGO uses a similar constant returns to scale technology to address the issue, transforming each donated monetary unit into one unit of output. Let $F > 0$ be the outside monetary payoff that entrepreneurs can obtain if they do not set up an NGO, making it the minimum output level required by the NGO entrepreneurs in order to set up an NGO on the circle and start a project. NGOs locate themselves equidistantly from one another in accordance with the symmetric Nash equilibrium (Salop, 1979). Then entrepreneurs' problem becomes one of coordination in numbers so each obtains the minimum required payoff, given they will set up equidistant NGOs.[8]

3.3.1 First Best

In the first-best setting, a central planner who cares about the total welfare of all citizens concerned about the issue chooses the socially optimal number of NGOs to maximize total welfare. In order to achieve that, the central planner has to understand the decisions of concerned citizens.

Each citizen acts independently to maximize their own utility as described in equation 3.1:

$$\frac{\partial U_i}{\partial x_{ij}} = \frac{1}{1+d_{ij}} + \frac{\gamma}{1+d_{ij}} - x_{ij} = 0 \Leftrightarrow x_{ij} = \frac{1+\gamma}{1+d_{ij}} > 0. \tag{3.2}$$

The optimal donation to any given NGO is increasing in the level of warm-glow γ and

and across industries." (p. 604)

[7]Alternatively we can assume that there is an unlimited number of entrepreneurs with a preferred ideological position who are uniformly distributed according to the ideological dimension.

[8]If entrepreneurs have ideological preferences then the problem would become one of coordination in both numbers and ideologies such that only one set of the right number of entrepreneurs and with equidistant ideological positions enter. Under both assumptions about entrepreneurs' ideological preferences the equilibrium outcome is the same.

decreasing in the ideological distance d_{ij} between the NGO and the donor. Since there is an optimal donation for any given NGO and it is greater than zero, all concerned citizens find it optimal to donate. Besides the optimal donation to any NGO, donors also decide which NGO to donate to. They donate to the NGO which is located at the utility maximizing distance:

$$\frac{dU_i}{dd_{ik}} = \frac{\partial U_i}{\partial d_{ik}} + \frac{\partial U_i}{\partial x_{ik}}\frac{\partial x_{ik}}{\partial d_{ik}} = -\frac{X_k + \gamma}{(1 + d_{ik})^2} < 0. \tag{3.3}$$

Even though donating to a closer NGO implies a higher optimal donation, from (3.3) it follows that each donor finds it utility increasing to donate to closer NGOs, which makes it optimal to donate to the ideologically closest NGO.

This result is in line with the findings of Hare et al. (2010) from an experiment using functional magnetic resonance imaging while subjects decided whether to donate and how much to a selection of charities; some of these charities addressed similar issues in different ways. Volunteers in the experiment were first asked to rate the selected NGOs on deservingness. Given that we follow Frey et al. (2004) in that both "what" and "how" matter, the more deserving charities in this model are the ones which address the issue of concern in a way that is ideologically closest to how donors think the issue should be approached. Unsurprisingly, the volunteers in Hare et al.'s experiment donated on average more to the charities they subjectively rated as more deserving to receive. The results from (3.2) and (3.3) are summarized as follows.

Proposition 3.1. *Each concerned citizen finds it optimal to donate to the NGO which is ideologically closest. The optimal donation $\frac{1+\gamma}{1+d_{ij}}$ is positively related to level of warm-glow γ and negatively related to ideological distance d_{ij}.*

Given the optimal donation, if an NGO entrepreneur sets up an NGO on the ideological circle, then they are able to raise the following amount for their project:

$$X_j = 2\int_0^{\frac{1}{2N}} x_{ij}\, dd_{ij} = 2\int_0^{\frac{1}{2N}} \frac{1+\gamma}{1+d_{ij}} dd_{ij} = 2(1+\gamma)\ln\left(1 + \frac{1}{2N}\right). \tag{3.4}$$

This amount is increasing in the level of warm-glow ($\frac{\partial X_j}{\partial \gamma} > 0$) and decreasing in the number of NGOs ($\frac{\partial X_j}{\partial N} < 0$). It is used in a project which produces linear output X_j and which generates satisfaction not only for donors to that respective NGO, but for all donors on the ideological circle, as per individual utility function (3.1). Thus total satisfaction generated by an NGO j through a project is:

$$S_j = 2\int_0^{\frac{1}{2}} \frac{X_j}{1+d_{ij}} dd_{ij} = 2\ln\left(\frac{3}{2}\right) X_j.$$

Each NGO generates this satisfaction with donations from its own donors and the total cost to them in terms of forgone consumption utility is:

$$C_j = 2\int_0^{\frac{1}{2N}} \frac{x_{ij}^2}{2} dd_{ij} = \frac{(1+\gamma)^2}{2N+1}. \tag{3.5}$$

Therefore a social planner maximizes the following total welfare function:

$$TW = N(S_j - C_j) = N\left[4\ln\left(\frac{3}{2}\right)(1+\gamma)\ln\left(1+\frac{1}{2N}\right) - \frac{(1+\gamma)^2}{2N+1}\right]. \tag{3.6}$$

An immediately obvious feature is the exclusion of warm-glow satisfaction from the central planner's objective function. In that respect we follow Diamond and Hausman (1994), Andreoni (2006), Diamond (2006), Heyes and Kapur (2011), to name just a few. Andreoni (2006) provides a thorough discussion and highlights four non-exhaustive reasons why warm-glow should not be included in welfare:

1. real world choices are distorted by the institutions within which they are made, however optimal social policy should aim towards decisions that would be made in an idealized world;

2. different institutions lead to different decision utilities which do not represent in themselves any new consumption and therefore social welfare calculations should be

independent of them;

3. if warm-glow is included, it is uncertain whether it should increase or decrease welfare;

4. warm-glow giving may purchase a good, such as maintaining a self-image, for which there may be no compelling social interest.

He concludes that "it is most prudent and most informative to first recognize that behavior is chosen by people seeking warm-glows, but then to set the social welfare-maximizing goals that makes no adjustment for warm-glow in aggregating welfare. That is, all social welfare prescriptions should be made without counting warm-glow, but should be constrained by behavior that is dictated by seeking warm-glow." (Andreoni, 2006, p. 1227).

The socially optimal number of NGOs $N^*(\gamma)$ on the ideological circle is implicitly determined by $\frac{\partial TW}{\partial N} = 0$, where:

$$\frac{\partial TW}{\partial N} = \left[2\ln\left(\frac{3}{2}\right)X_j - \frac{(1+\gamma)^2}{2N+1}\right] + \left[2N\ln\left(\frac{3}{2}\right)\frac{\partial X_j}{\partial N} + 2N\frac{(1+\gamma)^2}{(2N+1)^2}\right]. \tag{3.7}$$

The first term in the first-order condition from (3.7) is the benefit of adding another NGO. It is composed of the satisfaction generated around the ideological circle and the forgone consumption cost to donors who fund this additional NGO.

The second term is the impact this additional NGO has on the net benefit from already existing NGOs. It is composed of the reduction in satisfaction generated by all existing NGOs ($\frac{\partial X_j}{\partial N} < 0$) and the corresponding reduction in forgone consumption utility costs for all existing NGOs' own donors.

The optimal number of NGOs is implicitly determined by equating (3.7) with 0, and for an additional NGO beyond this level total welfare starts to decrease. However, even as the number of NGOs continues to increase beyond the optimal number, we find that total welfare does not move into negative territory if warm-glow is low enough[9], $\gamma \leq 4\ln\left(\frac{3}{2}\right) - 1$.

[9] $4\ln\left(\frac{3}{2}\right) - 1 \simeq 0.62$

It decreases towards a strictly positive limit even as the number of NGOs approaches infinity. Total welfare crosses into negative territory only if warm-glow is higher than $4\ln\left(\frac{3}{2}\right) - 1$ and the number of NGOs is higher than the one implicitly defined by $TW = 0$; beyond this point it would be socially-preferred for donors not to make any donations such that entrepreneurs do not set up any NGOs and do not realize any projects. Proposition 3.2 summarizes these results.

Proposition 3.2. *A socially optimal number of NGOs $N^*(\gamma)$ exists in the first-best scenario, and is implicitly determined by $\frac{\partial TW}{\partial N} = 0$. As the number of NGOs increases beyond $N^*(\gamma)$, total welfare decreases towards a positive limit if warm-glow γ is lower than $4\ln\left(\frac{3}{2}\right) - 1$, or towards a strictly negative limit if warm-glow is higher.*

Pestieau and Sato (2006) concluded that in the absence of any NGO costs there would be no reason not to have an NGO for each individual. Our model shows that when donors have ideological preferences and NGOs offer ideologically differentiated public goods, a socially optimal number of NGOs exists even though NGOs do not have any fundraising costs or fixed costs, and we make abstraction of entrepreneurs' opportunity cost for the time being. An explanation follows.

We have already established that the equilibrium donation of each donor is made to the ideologically closest NGO and takes the form $\frac{1+\gamma}{1+d_{ij}}$; it is increasing in the level of warm-glow and decreasing in ideological distance. As more NGOs enter, d_{ij} decreases and equilibrium donations increase.

This creates two competing effects: it increases the level of the public good for everyone to enjoy which is a positive effect, but it also increases the total cost of forgone consumption utility which is a negative effect. As the process continues, ideological distance d_{ij} approaches its limit of 0, the equivalent of each individual having and funding their own NGO. For this reason total welfare ultimately approaches a limit as the number of NGOs continues to increase.

What happens with the two competing effects as the number of NGOs increases beyond the optimal $N^*(\gamma)$ — where they exactly offset each other at the margin — depends on warm-glow γ. For lower levels of warm-glow ($\gamma \leq 4 \ln\left(\frac{3}{2}\right) - 1$) the negative effect overcomes the positive effect at the margin, but not overall. For higher levels of warm-glow ($\gamma > 4 \ln\left(\frac{3}{2}\right) - 1$) the negative effect overcomes the positive effect at the margin, and ultimately overall.

3.3.2 Free Entry

As previously assumed, NGO entrepreneurs enter on the ideological circle and start a project as long as the non-monetary payoff they derive is at least equal to their outside option $F > 0$. The non-monetary payoff is linear in the output of own NGO, and each NGO can transform one monetary unit into an output unit through a project. Therefore NGO entrepreneurs enter as long as $X_j \geq F$, and the free-entry equilibrium number of NGOs N^{FE} is explicitly given by the free-entry equilibrium condition $X_j = F$:

$$X_j = F \Leftrightarrow 2(1+\gamma) \ln\left(1 + \frac{1}{2N^{FE}}\right) = F \Leftrightarrow N^{FE} = \frac{1}{2\left[e^{\frac{F}{2(1+\gamma)}} - 1\right]}. \tag{3.8}$$

The equilibrium number of NGOs under free-entry is increasing in the level of warm-glow ($\frac{\partial N^{FE}}{\partial \gamma} > 0$), and it is decreasing in the outside option ($\frac{\partial N^{FE}}{\partial F} < 0$). Since warm-glow increases the number of NGOs, and the length of the ideological circle is fixed at unity, it follows that ideological distances between donors and their respective closest NGOs decrease as a result. Thus warm-glow increases the optimal donation to the closest NGO — derived at (3.2) as $x_{ij} = \frac{1+\gamma}{1+d_{ij}}$ — through two channels: a direct channel, through the increase in γ, and an indirect channel through the decrease in d_{ij}.

In the free-entry scenario a social planner obviously cannot choose the number of NGOs. Given that warm-glow is the main determinant of donations, and ultimately of the number of NGOs that enter, a social planner can nonetheless assess the hypothetical level of warm-glow that would maximize welfare under free-entry.

To be clear, the planner cannot choose the level of warm-glow donors experience either.

However, the hypothetical level that would optimize welfare can be a useful tool for government policy, as we show in the next section. To avoid any confusion with the actual level of warm-glow γ, we define this government policy tool as:

$$g \in \mathbb{R}.$$

It incorporates an important consideration. Unlike γ which is always positive, g can take negative values. If NGO entrepreneurs' outside option F is very low, from a social perspective over-entry may occur even with zero warm-glow $\gamma = 0$. In a scenario like this a social planner may conclude that donors would be better off overall if they did not experience warm-glow, but rather its negative counterpart: cold-prickle. We will return to this point shortly with an example.

Under free-entry, the main modifications relative to central planner's first-best objective function from (3.6) are that the amount each NGO raises is constrained to equate the NGO entrepreneur's outside option ($X_j = F$), the number of NGOs is replaced by the free-entry number of NGOs derived above ($N = N^{FE}$), and of course warm-glow γ is replaced by social planner's optimization tool g. The resulting objective function under free-entry is:

$$TW^{FE} = N^{FE}(S_j^{FE} - C_j^{FE}) = \frac{1}{2\left[e^{\frac{F}{2(1+g)}} - 1\right]} \left[2\ln\left(\frac{3}{2}\right)F - \frac{(1+g)^2}{\frac{1}{e^{\frac{F}{2(1+g)}}-1} + 1}\right]. \tag{3.9}$$

The mechanics are similar to the ones from first-best total welfare. The first term is the number of NGOs that enter N^{FE}, which is increasing in g. The second term is the net satisfaction that each NGO generates. The gross satisfaction that each NGO generates around the ideological circle S_j^{FE} is constant because the output of each NGO is fixed at entrepreneurs' outside option F. As g increases, donors' utility cost C_j^{FE} of funding each NGO increases not only as a direct effect of donors' willingness to make more generous donations, but also due to the increased ideological proximity between donors and the NGO they support, which means that fewer and fewer donors are needed to support an NGO with the fixed amount F. Consequently the net satisfaction ($S_j^{FE} - C_j^{FE}$) that each NGO generates is decreasing in g.

Thus an increase in g increases the number of NGOs while decreasing the net benefit from each NGO. The optimal level $g^*(F)$ is implicitly determined by $\frac{\partial TW^{FE}}{\partial g} = 0$, and we find that $g^*(F) > -1$. Therefore the central planner always finds it optimal for individuals to donate under free-entry[10]: optimal individual donation is $x_{ij} = \frac{1+\gamma}{1+d_{ij}}$ (3.2), and thus $\frac{1+g^*(F)}{1+d_{ij}} > 0$, $\forall g^*(F) > -1$.

Proposition 3.3. *Under a free-entry regime a socially optimal level of warm-glow or cold-prickle $g^*(F) > -1$ always exists, and it is implicitly determined by $\frac{\partial TW^{FE}}{\partial g} = 0$.*

As warm-glow γ increases individuals are willing to make increasingly generous donations $x_{ij} = \frac{1+\gamma}{1+d_{ij}}$. NGO entrepreneurs increasingly enter the ideological space as more of them are able to raise the minimum required F and set up NGOs. This increases proximity between donors and NGOs, which further increases donations, and further increases the number of entrants. As per Proposition 3.2, for high enough levels of warm-glow and a large enough number of entrants, total welfare can even cross into negative territory, as the total cost to donors in terms of forgone consumption utility outweighs the total benefits generated by all NGOs.

For example, let us assume a relatively low outside option $F = \frac{1}{2}$, and a relatively high warm-glow $\gamma = 0.77$. The free-entry number of NGOs is $N^{FE}|_{\gamma=0.77,F=0.5} \simeq 3.29$ and the corresponding total welfare is $TW^{FE}|_{\gamma=0.77,F=0.5} \simeq -0.02$ (rounded down $N^{FE} = 3$, and $TW|_{\gamma=0.77,N=3} \simeq -0.01$). Total welfare is strictly negative.

This is in essence a generosity-induced tragedy of the commons. Motivated by high warm-glow, individuals give generously and end up imposing a negative externality on one

[10]This implies that for any level of $F > 0$ the optimal number of NGOs is always strictly positive under free-entry — in theory. In practice, one cannot have only a half-NGO for example, so when designing a policy a planner would compare total welfare for the rounded down number with the one for the rounded up number of NGOs.

another in the form of increased donor-NGO ideological proximity, which further increases donations and leads to NGO over-entry. Total output of entrant NGOs is outweighed by donors' total consumption utility that they forgo in order to fund too many NGOs in too close ideological proximity.

Donors maximize own utilities in the process, but a social planner recognizes the negative externality that donors impose on each other as a result, and can assess the level of warm-glow/cold-prickle that would optimize welfare under free-entry. Given $F = \frac{1}{2}$, the level of g that would maximize TW^{FE} is $g = -0.07$, such that the number of NGOs is $N^{FE}|_{g=-0.07,F=0.5} \simeq 1.62 < 3.29$, and the corresponding total welfare is $TW^{FE}|_{g=-0.07,F=0.5} \simeq 0.32 > -0.02$ (rounded down $N^{FE} = 1$, and $TW|_{g=-0.07,N=1} \simeq 0.32$).

Given the low outside option $F = \frac{1}{2}$ we chose for illustrative purposes, even zero warm-glow ($\gamma = 0$) leads to over-entry from planner's perspective. Strictly positive warm-glow only increases the negative externality that individuals impose on each other through their generous donations. However, we show in the Appendix that even as F approaches zero — the equivalent of each donor having their own NGO under free-entry — total welfare with zero warm-glow is always strictly positive ($TW^{FE}|_{\gamma=0} > 0, \forall F > 0$). Thus it is specifically high enough warm-glow that can, not only lead to a decrease in total welfare, but actually push it into negative territory.

A social planner would prefer that donors recognize the negative externality associated with strictly positive warm-glow in the above example, and experience cold-prickle when donating instead. That is likely not possible, however we explore in the next section policies that determine donors to behave *as if* they are experiencing the welfare-maximizing level of warm-glow/cold-prickle under free-entry.

3.3.3 Free Entry Optimization Policies

What can a central planner do to increase total welfare under free-entry if they cannot choose the number of NGOs, nor can they impose an optimal level of warm-glow/cold-prickle that citizens experience when donating?

A quick fix would be a process of NGO licensing, however this would only work when under free-entry there would be more NGOs N^{FE} than the optimal number N^*. NGO entrepreneurs who would obtain a license would get higher non-monetary satisfaction from their project's output than the minimum required F. Besides the fact that limiting the number of NGOs through licensing means that entry is not free any longer, licensing has no effect when $N^{FE} < N^*$ because NGO entrepreneurs would not accept a lower non-monetary payoff than the minimum required F.

When donors' warm-glow γ is higher than $g^*(F)$, it leads to over-entry of NGOs, whereas when γ is lower than $g^*(F)$, it leads to under-entry of NGOs. To correct these situations a taxation/subsidy system may be a good option. We assume a revenue-neutral fiscal system under which all taxes collected are entirely returned to the population as a lump sum. The total collected taxes are divided equally among donors and we assume that the central planner has zero inequality aversion.

If the planner taxes the donor, then the individual utility function from (3.1) becomes:

$$U_i = \sum_{j=1}^{N} \frac{X_j}{1+d_{ij}} + \frac{\gamma}{1+d_{ij}} x_{ij} - \frac{[x_{ij}(1+t_r) - B]^2}{2}, \tag{3.10}$$

where B is the lump-sum refund and t_r is the donor tax rate. The optimal donation becomes:

$$\frac{\partial U_i}{\partial x_{ij}} = \frac{1}{1+d_{ij}} + \frac{\gamma}{1+d_{ij}} - x_{ij}(1+t_r)^2 - B(1+t_r) = 0 \Leftrightarrow x_{ij} = \frac{1+\gamma}{(1+d_{ij})(1+t_r)^2} + \frac{B}{1+t_r}. \tag{3.11}$$

The total amount each NGO is able to raise becomes:

$$X_j = 2\int_0^{\frac{1}{2N}} x_{ij} dd_{ij} = \frac{2(1+\gamma)}{(1+t_r)^2} \ln\left(1 + \frac{1}{2N}\right) + \frac{1}{N}\frac{B}{1+t_r}. \tag{3.12}$$

Since all taxes collected are refunded to donors as equal lump sum payments, the following revenue neutrality relationship has to hold:

$$t_r X_j = \frac{B}{N}. \tag{3.13}$$

From 3.12 and 3.13 results the amount each NGO is able to raise under donor taxation:

$$X_j = \frac{2(1+\gamma)}{1+t_r} \ln\left(1 + \frac{1}{2N}\right). \tag{3.14}$$

The total cost of donations in terms of forgone consumption utility for an NGO's donors becomes:

$$C_j = 2\int_0^{\frac{1}{2N}} \frac{[x_{ij}(1+t_r) - B]^2}{2} dd_{ij} = \frac{(1+\gamma)^2}{(1+t_r)^2} \frac{1}{2N+1}. \tag{3.15}$$

This taxation policy would be applicable in the free-entry case where $X_j = F$. From this and (3.14) results the number of free-entry NGOs that set up projects in the case of donor taxation as:

$$N_r^{FE} = \frac{1}{2\left[e^{\frac{F(1+t_r)}{2(1+\gamma)}} - 1\right]}. \tag{3.16}$$

The resulting objective function for a donor taxation system under free-entry is:

$$TW_r^{FE} = \frac{1}{2\left[e^{\frac{F(1+t_r)}{2(1+\gamma)}} - 1\right]} \left[2\ln\left(\frac{3}{2}\right) F - \frac{(1+\gamma)^2}{(1+t_r)^2} \frac{1}{\frac{1}{e^{\frac{F(1+t_r)}{2(1+\gamma)}} - 1} + 1}\right]. \tag{3.17}$$

The central planner's objective function for an NGO taxation system under free-entry can be derived in a similar fashion, where t_G is the NGO taxation rate. The individual utility function becomes:

$$U_i = \sum_{j=1}^{N} \frac{X_j(1-t_G)}{1+d_{ij}} + \frac{\gamma}{1+d_{ij}}(1-t_G)x_{ij} - \frac{(x_{ij}-B)^2}{2}. \tag{3.18}$$

We assume that donors do not derive warm-glow satisfaction from the part of the donation that they know it goes towards taxes because it does not help with anything in addressing the issue that donors are concerned about. The optimal donation becomes:

$$\frac{\partial U_i}{\partial x_{ij}} = \frac{1-t_G}{1+d_{ij}} + \frac{\gamma(1-t_G)}{1+d_{ij}} - x_{ij} + B = 0 \Leftrightarrow x_{ij} = \frac{(1+\gamma)(1-t_G)}{(1+d_{ij})} + B. \tag{3.19}$$

The revenue neutrality relationship from (3.13) holds for t_G as well, and thus the total amount of donations each NGO raises is[11]:

$$X_j = 2(1+\gamma)\ln\left(1+\frac{1}{2N}\right). \tag{3.20}$$

The total forgone consumption utility cost of donations for an NGO's donors becomes:

$$C_j = 2\int_0^{\frac{1}{2N}} \frac{(x_{ij}-B)^2}{2} dd_{ij} = \frac{(1+\gamma)^2(1-t_G)^2}{2N+1}. \tag{3.21}$$

In this case the free-entry number of NGOs is given by $X_j(1-t_G) = F$ because the NGO entrepreneur derives non-monetary satisfaction from the output of the project and not from the amount raised. It follows that the equilibrium number of NGOs is:

$$N_G^{FE} = \frac{1}{2\left[e^{\frac{F}{2(1+\gamma)(1-t_G)}} - 1\right]}. \tag{3.22}$$

Planner's free-entry objective function under an NGO taxation system takes the following form:

$$TW_G^{FE} = \frac{1}{2\left[e^{\frac{F}{2(1+\gamma)(1-t_G)}} - 1\right]}\left[2\ln\left(\frac{3}{2}\right)F - \frac{(1+\gamma)^2(1-t_G)^2}{\frac{1}{e^{\frac{F}{2(1+\gamma)(1-t_G)}}-1}+1}\right]. \tag{3.23}$$

The total welfare functions from 3.17 and 3.23 can be optimized with respect to their respective tax rates in the usual way, by taking the first-order conditions. However, it is much

[11] Using x_{ij} obtained at (3.19): $X_j = 2\int_0^{\frac{1}{2N}} x_{ij} dd_{ij} = 2(1-t_G)(1+\gamma)\ln\left(1+\frac{1}{2N}\right) + \frac{B}{N}$. Plugging in B from revenue neutrality condition $t_G X_j = \frac{B}{N}$ yields (3.20).

easier to view them as functions of $\frac{1+\gamma}{1+t_r}$ and of $(1+\gamma)(1-t_G)$, respectively, and planner's initial initial free-entry objective function TW^{FE} from (3.9) as a function of $(1+g)$.

The central planner is trying to determine donors to behave overall *as if* they were experiencing the optimal level of warm-glow/cold-prickle $g^*(F)$. Warm-glow cannot be taxed or subsidized directly, so the central planner is taxing it indirectly by taxing the donation either at the source, when the donor makes it, or at the destination, when the NGO receives it. Since we have already established that an optimal level of warm-glow $g^*(F)$ exists for the initial total welfare function under free-entry from (3.9), it follows that an optimal level of taxation also exists under both taxation regimes.

The optimal donor tax under free-entry is given by:

$$1+g^* = \frac{1+\gamma}{1+t_r^*} \Leftrightarrow t_r^* = \frac{1+\gamma}{1+g^*} - 1 = \frac{\gamma - g^*}{1+g^*}. \tag{3.24}$$

The optimal NGO tax under free-entry is given by:

$$1+g^* = (1+\gamma)(1-t_G^*) \Leftrightarrow t_G^* = 1 - \frac{1+g^*}{1+\gamma} = \frac{\gamma - g^*}{1+\gamma}. \tag{3.25}$$

When the level of warm-glow in the concerned population is higher than g^* and donors over-donate, the optimal tax is strictly positive. When the level of warm-glow in the concerned population is lower than g^* and donors under-donate, the optimal tax is strictly negative, in effect a subsidy.

Although the optimal taxes from (3.24) and (3.25) are quantitatively different, they are in effect equivalent to one another because they both achieve the maximization of total welfare as if the actual level of warm-glow/cold-prickle was the optimal g^* under free-entry. In fact, one can easily be deduced from the other:

$$\frac{1}{1+t_r^*} = 1 - t_G^* \Leftrightarrow t_G^* = \frac{t_r^*}{1+t_r^*} \Leftrightarrow t_r^* = \frac{t_G^*}{1-t_G^*}. \tag{3.26}$$

We have to emphasize that these tax rates are optimal assuming the social planner has no aversion to inequality. Incorporating inequality aversion in social planner's objective function would change these rates as there would be a trade-off between increasing total net satisfaction from the public good and increasing inequality.

Proposition 3.4. *Free-entry welfare can be optimized by using one of two available taxation systems:*

1. *by taxing donors' donations at the rate of* $t_r^* = \frac{\gamma - g^*}{1+g^*}$*;*

2. *by taxing NGOs' raised donations at the rate of* $t_G^* = \frac{\gamma - g^*}{1+\gamma}$*.*

3.4 Concluding Remarks and Policy Implications

Within a one-shot charity market game that incorporates warm-glow utility and procedural utility (ideology), we find that in the first-best scenario an optimal number of NGOs exists even in the absence of any NGO costs or entry barriers. In the case of free-entry we likewise show the existence of a warm-glow or cold-prickle level that would optimize welfare. A social planner can maximize free-entry welfare by taxing donations at the source or at the destination when donors' warm-glow is too high, or similarly through subsidies when donors' warm-glow is too low.

Warm-glow increases donations through two channels in the presence of ideology. The first is a direct channel: an increase in warm-glow leads to more generous donations as donors maximize own utilities. This in turn leads to more NGO entry and the second, indirect channel: ideological distances between donors and NGOs decrease, leading to even more generous donations and to even more NGO entry because donors value ideological proximity. This mechanism fueled by warm-glow provides one explanation why on some charity markets donors may end up over-donating and supporting too many NGOs doing too little through their projects.

In today's highly interconnected world there are many issues citizens become aware of and concerned about. Therefore charity markets on which there is not enough warm-glow and markets on which there is too much warm-glow likely exist at the same time in the same economy. In light of this and based on the results from this paper, the optimal fiscal policy would perfectly discriminate between different issues that citizens care about by applying different levels of subsidization or taxation to donors or NGOs on each charity market. A policy of often indiscriminate subsidization[12] applied across all issues may make donors better off on some markets, while making donors worse off on other markets — potentially to the point where their net welfare becomes negative.

Applying and maintaining different policies for each issue though, may not be feasible and costly to the point where the added costs would outweigh the added benefits to society. Given the still limited knowledge of warm-glow and the current limits of technological capabilities, a uniform policy likely remains the best compromise.

Nonetheless, the findings in this paper constitute a motivation for continued research into the process of warm-glow giving and how it translates into donations. Some questions can likely be addressed and inform policy in the short-run. How much of a donation is motivated by warm-glow? Is warm-glow pro-cyclical or counter-cyclical, and how does the business cycle affect the composition of donor population? Does this warrant differential tax treatment of charitable contributions based on the business cycle? Even with a uniform policy, the fine act of choosing the right taxation figures that strike a balance between donors who are made better off and those who are made worse off has the potential to increase welfare.

3.5 Appendix

This is a one-shot game in which:

[12]In Canada a policy of subsidization is used in the form of charitable donation tax credits. The current rates are 15% for eligible amount up to \$200 and 29% for eligible amount over \$200 at a federal level; provinces have their additional rates, which bring the previous rates up to totals of around 20% and 40% respectively, for the province of Ontario, as an example (Canada Revenue Agency, 2014).

– a finite number of NGO entrepreneurs from an unlimited outside pool simultaneously decide whether to enter on an ideological circle with unit length and set up equidistant NGOs; entrepreneurs' outside monetary option is $F > 0$;

– NGOs use a linear technology to transform donations into environmental output; entrepreneurs obtain psychic payoffs that are linear in the output of their own NGOs, and monetary payoff is normalized to zero;

– citizens are uniformly distributed with unit density on the ideological circle and decide whether or not to donate, how much, and to which NGO; they derive ideologically discounted satisfaction from the output of all NGOs, and ideologically discounted warm-glow satisfaction $\gamma > 0$ from their own donation.

Proposition 3.1 proof: The utility function of each citizen is:

$$U_i = \sum_{j=1}^{N} \frac{X_j}{1 + d_{ij}} + \frac{\gamma}{1 + d_{ik}} x_{ik} - \frac{x_{ik}^2}{2},$$

where U_i is the utility of citizen i, X_j is the output of NGO j, d_{ij} is the ideological distance between citizen i and NGO $j \epsilon \{1, ..., N\}$, $\gamma > 0$ is the constant marginal warm-glow satisfaction from the donation made to an NGO, x_{ik} is the potential donation of citizen i to NGO k, and the last term is the cost of forgone consumption utility due to the potential donation.

Equilibrium donation from donor i to any given NGO j is:

$$\frac{\partial U_i}{\partial x_{ij}} = \frac{1}{1 + d_{ij}} + \frac{\gamma}{1 + d_{ij}} - x_{ij} = 0 \Leftrightarrow x_{ij} = \frac{1 + \gamma}{1 + d_{ij}} > 0; \frac{\partial^2 U_i}{\partial x_{ij}^2} = -1 < 0. \tag{3.27}$$

Each donor finds it optimal to donate to the ideologically closest NGO k: $\frac{dU_i}{dd_{ik}} = \frac{\partial U_i}{\partial d_{ik}} + \frac{\partial U_i}{\partial x_{ik}} \frac{\partial x_{ik}}{\partial d_{ik}} = -\frac{X_k + \gamma}{(1 + d_{ik})^2} < 0$.

Conclusion: Each citizen finds it optimal to donate $\frac{1+\gamma}{1+d_{ij}}$ to the ideologically closest NGO. The optimal donation is positively related to the level of warm-glow γ and negatively related to the ideological distance d_{ij}.

Proposition 3.2 proof: In the first-best scenario a social planner chooses the number of NGOs N, and we make abstraction of entrepreneurs' outside option F for the time being. Given a number of NGOs $N > 0$, each NGO is able to raise:

$$X_j = 2\int_0^{\frac{1}{2N}} x_{ij}\ dd_{ij} = 2\int_0^{\frac{1}{2N}} \frac{1+\gamma}{1+d_{ij}} dd_{ij} = 2(1+\gamma)\ln\left(1+\frac{1}{2N}\right). \tag{3.28}$$

X_j is increasing in γ and decreasing in N: $\frac{\partial X_j}{\partial \gamma} = 2\ln\left(1+\frac{1}{2N}\right) > 0$; $\frac{\partial X_j}{\partial N} = -\frac{2(1+\gamma)}{N(2N+1)} < 0$.

The satisfaction S generated around the ideological circle by an NGO j through a project is:

$$S_j = 2\int_0^{\frac{1}{2}} \frac{X_j}{1+d_{ij}} dd_{ij} = 2\ln\left(\frac{3}{2}\right) X_j.$$

The cost C for an NGO's donors in terms of forgone consumption utility is:

$$C_j = 2\int_0^{\frac{1}{2N}} \frac{x_{ij}^2}{2} dd_{ij} = \frac{(1+\gamma)^2}{2N+1}.$$

Resulting total welfare function $TW(\gamma, N)$ is:

$$TW(\gamma,N) = N(S_j - C_j) = N\left[4\ln\left(\frac{3}{2}\right)(1+\gamma)\ln\left(1+\frac{1}{2N}\right) - \frac{(1+\gamma)^2}{2N+1}\right]; \tag{3.29}$$

$$\lim_{N\to 0} TW(\gamma,N) = 0; \tag{3.30}$$

$$\lim_{N\to\infty} TW(\gamma,N) = \frac{(1+\gamma)}{2}\left[4\ln\left(\frac{3}{2}\right) - (1+\gamma)\right] \gtrless 0 \Leftrightarrow \gamma \lessgtr 4\ln\left(\frac{3}{2}\right) - 1. \tag{3.31}$$

Central planner optimizes $TW(\gamma, N)$: $\frac{\partial TW(\gamma,N)}{\partial N} = 0 \Leftrightarrow N = N^*(\gamma)$. We cannot solve explicitly for $N^*(\gamma)$, but we show it exists.

$$\frac{\partial TW}{\partial N} = \frac{(1+\gamma)}{(2N+1)^2}\left\{4\ln\left(\frac{3}{2}\right)(2N+1)\left[\ln\left(1+\frac{1}{2N}\right)(2N+1)-1\right]-(1+\gamma)\right\}; \quad (3.32)$$

$$\lim_{N\to 0}\frac{\partial TW(\gamma,N)}{\partial N} = \infty; \quad (3.33)$$

$$\lim_{N\to\infty}\frac{\partial TW(\gamma,N)}{\partial N} = 0. \quad (3.34)$$

Second derivative:

$$\frac{\partial^2 TW}{\partial N^2} = \frac{4(1+\gamma)}{N(2N+1)^3}\left[(1+\gamma)N-\ln\left(\frac{3}{2}\right)(2N+1)\right] \lesseqgtr 0 \Leftrightarrow N \lesseqgtr \frac{\ln\left(\frac{3}{2}\right)}{(1+\gamma)-2\ln\left(\frac{3}{2}\right)}; \quad (3.35)$$

$$\lim_{N\to 0}\frac{\partial^2 TW(\gamma,N)}{\partial N^2} = -\infty; \quad (3.36)$$

$$\lim_{N\to\infty}\frac{\partial^2 TW(\gamma,N)}{\partial N^2} = 0. \quad (3.37)$$

Third derivative:

$$\frac{\partial^3 TW(\gamma,N)}{\partial N^3} = \frac{4(1+\gamma)}{N^2(2N+1)^4}\left[\ln\left(\frac{3}{2}\right)(12N^2+8N+1)-6(1+\gamma)N^2\right]; \quad (3.38)$$

$$\frac{\partial^3 TW(\gamma,N)}{\partial N^3} = \frac{4\left[(1+\gamma)-2\ln\left(\frac{3}{2}\right)\right]^5}{\ln\left(\frac{3}{2}\right)(1+\gamma)^2} > 0 \text{ for } N = \frac{\ln\left(\frac{3}{2}\right)}{(1+\gamma)-2\ln\left(\frac{3}{2}\right)}. \quad (3.39)$$

Second derivative $\frac{\partial^2 TW(\gamma,N)}{\partial N^2}$ is differentiable (3.38) and therefore continuous, equals 0 for $N = \frac{\ln\left(\frac{3}{2}\right)}{(1+\gamma)-2\ln\left(\frac{3}{2}\right)}$, is negative for lower N, and positive for higher N (3.35). First derivative $\frac{\partial TW(\gamma,N)}{\partial N}$ is differentiable (3.35) and therefore continuous, decreases from ∞ (3.33 and 3.35), crosses the x–axis from above at $N^*(\gamma)$, reaches its minimum at $N = \frac{\ln\left(\frac{3}{2}\right)}{(1+\gamma)-2\ln\left(\frac{3}{2}\right)}$ (3.35 and 3.39), then increases and approaches 0 from below (3.35 and 3.34). Thus:

$$\frac{\partial TW(\gamma,N)}{\partial N} \gtreqless 0 \Leftrightarrow N \lesseqgtr N^*(\gamma). \quad (3.40)$$

Total welfare TW increases from 0 (3.30), reaches its maximum at $N^*(\gamma)$ (3.40), decreases faster at first (3.40, 3.35 and 3.36) towards inflection point $N = \frac{\ln\left(\frac{3}{2}\right)}{(1+\gamma)-2\ln\left(\frac{3}{2}\right)}$, and then decreases slower (3.40, 3.35 and 3.37) towards limit $\frac{(1+\gamma)}{2}\left[4\ln\left(\frac{3}{2}\right)-(1+\gamma)\right]$, which is positive for $\gamma \leq 4\ln\left(\frac{3}{2}\right)-1$, and negative for $\gamma > 4\ln\left(\frac{3}{2}\right)-1$ (3.31).

Conclusion: A socially optimal number of NGOs $N^*(\gamma)$ exists in the first-best scenario, and is implicitly determined by $\frac{\partial TW}{\partial N}=0$. As the number of NGOs increases beyond $N^*(\gamma)$, total welfare decreases towards a positive limit if warm-glow γ is lower than $4\ln\left(\frac{3}{2}\right)-1$, or towards a strictly negative limit if warm-glow is higher.

Proposition 3.3 proof: In the free-entry scenario a social planner cannot choose the number of NGOs directly, and we now take into account NGO entrepreneurs' outside option $F>0$. Entrepreneurs enter as long as $X_j \geq F$. Equating X_j (3.28) with F yields equilibrium number of NGOs under free-entry $N^{FE}(\gamma, F)$:

$$X_j = F \Leftrightarrow 2(1+\gamma)\ln\left(1+\frac{1}{2N^{FE}}\right) = F \Leftrightarrow N^{FE}(\gamma,F) = \frac{1}{2\left[e^{\frac{F}{2(1+\gamma)}}-1\right]}. \tag{3.41}$$

$N^{FE}(\gamma,F)$ is increasing in γ and decreasing in F: $\frac{\partial N^{FE}(\gamma,F)}{\partial \gamma} = \frac{e^{\frac{F}{2(1+\gamma)}}F}{4(1+\gamma)^2\left[e^{\frac{F}{2(1+\gamma)}}-1\right]^2} > 0$; $\frac{\partial N^{FE}(\gamma,F)}{\partial F} = -\frac{e^{\frac{F}{2(1+\gamma)}}}{4(1+\gamma)\left[e^{\frac{F}{2(1+\gamma)}}-1\right]^2} < 0$.

The free-entry satisfaction S^{FE} generated around the ideological circle by an NGO j is:

$$S_j^{FE} = 2\int_0^{\frac{1}{2}} \frac{F}{1+d_{ij}}dd_{ij} = 2\ln\left(\frac{3}{2}\right)F.$$

The free-entry cost C^{FE} for an NGO's donors in terms of forgone consumption utility, making use of x_{ij} (3.27) and N^{FE} (3.41), is:

$$C_j^{FE} = 2\int_0^{\frac{1}{2N^{FE}}} \frac{x_{ij}^2}{2}dd_{ij} = \frac{(1+\gamma)^2}{2N^{FE}+1} = \frac{(1+\gamma)^2}{\frac{1}{e^{\frac{F}{2(1+\gamma)}}-1}+1}.$$

A social planner cannot choose a level of warm-glow γ, but can assess the level of warm-glow/cold-prickle — which we define as $g \in \mathbb{R}$, and set $\gamma = g$ — that would maximize total welfare under free-entry $TW^{FE}(g, F)$:

$$TW^{FE}(g,F) = N^{FE}(S_j^{FE} - C_j^{FE}) = \frac{1}{2\left[e^{\frac{F}{2(1+g)}} - 1\right]}\left[2\ln\left(\frac{3}{2}\right)F - \frac{(1+g)^2}{\frac{1}{e^{\frac{F}{2(1+g)}}-1} + 1}\right].$$

For ease of analysis we split total welfare into total satisfaction $TS^{FE} = N^{FE}S_j^{FE}$ and total cost $TC^{FE} = N^{FE}C_j^{FE}$.

Given that optimal donation (3.27) $x_{ij}|_{\gamma=g} = \frac{1+g}{1+d_{ij}} > 0 \Leftrightarrow g > -1$, a social planner would find $g \leq -1$ optimal iff they would find optimal for consumers not to make donations. In that case no NGO entrepreneurs would enter since $F > 0$, and total welfare would be $TW^{FE} = 0$. Thus we first analyze TS^{FE} and TC^{FE} assuming $g > -1$.

$\frac{\partial TS^{FE}(g,F)}{\partial g}$ increases from 0 to $2\ln\left(\frac{3}{2}\right)$ as g increases from -1 to ∞: $TS^{FE}(g,F) = \frac{\ln\left(\frac{3}{2}\right)F}{e^{\frac{F}{2(1+g)}}-1}$; $\frac{\partial TS^{FE}(g,F)}{\partial g} = \frac{\ln\left(\frac{3}{2}\right)e^{\frac{F}{2(1+g)}}F^2}{2(1+g)^2\left[e^{\frac{F}{2(1+g)}}-1\right]^2}$; $\lim_{g\to-1}\frac{\partial TS^{FE}(g,F)}{\partial g} = 0$; $\lim_{g\to\infty}\frac{\partial TS^{FE}(g,F)}{\partial g} = 2\ln\left(\frac{3}{2}\right)$; $\frac{\partial^2 TS^{FE}(g,F)}{\partial g^2} = \frac{\ln\left(\frac{3}{2}\right)e^{\frac{F}{2(1+g)}}F^2}{4(1+g)^4\left[e^{\frac{F}{2(1+g)}}-1\right]^3}A$, where $A \equiv F\left[e^{\frac{F}{2(1+g)}} + 1\right] - 4(1+g)\left[e^{\frac{F}{2(1+g)}} - 1\right]$, and $sign\left[\frac{\partial^2 TS^{FE}(g,F)}{\partial g^2}\right] = sign[A]$; $\lim_{F\to0} A = 0$, $\frac{\partial A}{\partial F} = \frac{e^{\frac{F}{2(1+g)}}F}{2(1+g)} - \left[e^{\frac{F}{2(1+g)}} - 1\right]$, $\lim_{F\to0}\frac{\partial A}{\partial F} = 0$, $\frac{\partial^2 A}{\partial F^2} = \frac{e^{\frac{F}{2(1+g)}}F}{4(1+g)^2} > 0$, $\forall F > 0$, $\forall g > -1$; thus $\frac{\partial A}{\partial F} > 0$, then $A > 0$, and therefore $\frac{\partial^2 TS^{FE}(g,F)}{\partial g^2} > 0$, $\forall F > 0$, $\forall g > -1$.

$\frac{\partial TC^{FE}(g,F)}{\partial g}$ increases from 0 to ∞ as g increases from -1 to ∞: $TC^{FE}(g,F) = \frac{(1+g)^2}{2e^{\frac{F}{2(1+g)}}}$; $\frac{\partial TC^{FE}(g,F)}{\partial g} = \frac{4(1+g)+F}{4e^{\frac{F}{2(1+g)}}}$; $\lim_{g\to-1}\frac{\partial TC^{FE}(g,F)}{\partial g} = 0$; $\lim_{g\to\infty}\frac{\partial TC^{FE}(g,F)}{\partial g} = \infty$; $\frac{\partial^2 TC^{FE}(g,F)}{\partial g^2} = \frac{8(1+g)^2+4F(1+g)+F^2}{8(1+g)^2 e^{\frac{F}{2(1+g)}}} > 0$, $\forall g > -1$, $\forall F > 0$.

$TW^{FE}(g,F)$ is always positive for $g = 0$: $TW^{FE}|_{g=0} = \frac{2\ln\left(\frac{3}{2}\right)F + \frac{1}{e^{\frac{F}{2}}} - 1}{2\left(e^{\frac{F}{2}} - 1\right)}$, $sign\left[TW^{FE}|_{g=0}\right] = sign[Z]$, where $Z \equiv 2\ln\left(\frac{3}{2}\right)F + \frac{1}{e^{\frac{F}{2}}} - 1$; $\lim_{F\to0} Z = 0$, $\frac{\partial Z}{\partial F} = 2\ln\left(\frac{3}{2}\right) - \frac{1}{2e^{\frac{F}{2}}}$, $\lim_{F\to0}\frac{\partial Z}{\partial F} = 2\ln\left(\frac{3}{2}\right) - \frac{1}{2} > 0$, $\frac{\partial^2 Z}{\partial F^2} = \frac{1}{4e^{\frac{F}{2}}} > 0$, $\forall F > 0$; thus $Z > 0$, $\forall F > 0$, and therefore $TW^{FE}|_{g=0} > 0$, $\forall F > 0$.

Since both $\frac{\partial TS^{FE}(g,F)}{\partial g}$ and $\frac{\partial TC^{FE}(g,F)}{\partial g}$ increase from 0 to $2\ln\left(\frac{3}{2}\right)$ and ∞, respectively, as g increases from -1 to ∞, and $\exists g = 0$ such that $TS^{FE}(g,F) - TC^{FE}(g,F) > 0$, it follows that:

$$\exists! g^*(F) > -1 \text{ s.t. } \frac{TS^{FE}(g,F)}{\partial g} = \frac{\partial TC^{FE}(g,F)}{\partial g} \Longrightarrow \frac{\partial TW^{FE}(g,F)}{\partial g} = 0.$$

Conclusion: Under a free-entry regime a socially optimal level of warm-glow or cold-prickle $g^*(F) > -1$ always exists, and it is implicitly determined by $\frac{\partial TW^{FE}}{\partial g} = 0$.

Proposition 3.4 proof: Step-by-step derivation provided in Section 3.3.3 Free Entry Optimization Policies.

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