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Prasenjit Banerjee

Jason F. Shogren

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School of Social Sciences
The University of Manchester
Manchester M13 9PL

Climate Change: Risk, Reputation, and Mechanism Design*

Prasenjit Banerjee[a] and Jason F. Shogren[b]

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Abstract

This paper investigates the interaction between consumers and producers in designing incentive mechanism for climate protection. Firms have material interests in building a moral reputation for those consumers who prefer buying from socially responsible firms. We examine optimal monetary transfer by addressing a *crowding out effect* due to reputation. We find that a green reputation leads to *over-adaptation by the firm* if the consumers are *green* buyers and a *brown* firm prefers to buy a reputation. A firm tends to exploit its private information on the consumers' green preference to extract information rents.

Key Words: Asymmetric Information, Climate change, Crowding out, Mechanism Design, Reputation.

JEL Classification: D02, D03, D82, D86, Q54.

[a] (Corresponding Author) University of Manchester, Economics, Oxford Road, Manchester, M13 9PL, UK. Ph: +44(0)1613066916. Fax: +44(0)1612754812. Email: prasenjit.banerjee@manchester.ac.uk.
[b] University of Wyoming, Economics, Laramie, Wyoming, 82072, USA

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1. Introduction

Climate change policy requires behavioral change, both in production and consumption. Firms see this change as "going green"—they are viewed as socially responsible by stakeholders and consumers by reducing CO_2 emissions and investing in energy efficient technology (see for example Arora and Gangopadhyay 1995). Producers must either believe this behavior will pay off monetarily by attracting *green consumers* and stakeholders, or they might capture intrinsic, non-monetary benefits because they are truly concerned about climate change (Friedman 1970; Besley and Ghatak 2007). If firms undertake costly investments towards climate protection to buy a good reputation, a policy maker can exploit this behavior by designing incentive mechanism that explicitly addresses the desire to buy a "green reputation" (see Banerjee and Shogren, 2012).

Herein we explore whether the decision maker can design a mechanism to help reduce climate change risk at less cost given she allows firms to purchase a socially responsible "reputation". We investigate the interaction between consumers and firms when designing an incentive mechanism for climate protection when firms have material interests in building a moral reputation for consumers who prefer buying from socially responsible firms. Following Bénabou and Tirole (2003) and Frey (1994), we examine mechanism design by focusing on both firms' extrinsic material interests (e.g., Baliga and Maskin 2003; Smith and Shogren 2002) and its' intrinsic motives (e.g., warm glow). For an intrinsically-motivated person or firm, monetary rewards can create doubt about one's true motives for doing a good deed, i.e., the classic *crowding out effect* (see Bowles, 2008).

But intrinsic motives are not the end of the story—the moral reputation of people and firms also matters (Bénabou and Tirole, 2006; Andreoni and Bernheim, 2010; Milgrom and

Roberts, 1986). For example, since the mid-1990s, firms started adopting new technology to comply with climate protection either for social reasons to capture a good reputation or to prepare for expected regulation (Kolk and Pinkse 2004; Levy and Egan 2003). If we witness a firm engaging in a pro-climate action with little or no compensation it might be because it is "buying" a good reputation, not because of intrinsic motivation. The open question then is: can the regulator redesign an incentive mechanism to save public funds by exploiting the firm's concern about its reputation.

Our model examines how private information about reputation affects the performance of a Laffont-style (1995) mechanism designed for an optimal regulation to reduce the risk of a climate catastrophe (see Weitzman 2010, 2009 on fat-tailed risks; Pindyck 2010). A firm cares about its reputation of being socially responsible because consumers get utility when they buy from a socially responsible firm. Consumers gain intrinsic satisfaction if they buy from a climate-friendly firm (Klein 1990; Cairncross 1992; Arora and Gangopadhaya 1995). We define reputation based on the firm's intrinsic motivation toward climate protection – a high intrinsic motivation for climate protection implies a green reputation, and vice-versa. Climate protection without compensation increases a firm's reputation, whereas climate protection for the monetary reward only decreases reputation. This is the crowding out effect—the firm loses reputation if it is perceived within society as "money hungry" (Bénabou and Tirole, 2006).

A firm can have social preference for climate protection even though it is privately costly. The firm is said to have social preference for reduce climate risk if it does not receive compensation from those who benefit. Actually paying the firm to protect nature might be counter-productive to its reputation as "green". Other firms, however, do not have strong social preferences for investing in climate mitigation and adaptation. They are uninterested in paying a private cost to protect a public good—unless they get something out of it themselves. These firms might invest in climate protection to "buy" a green reputation. As consumers care about green reputation, firms can increase their profit by gaining green reputation.

In our model, the regulator does not have complete information about consumers' green preference and firms' reputation. Some consumers want to purchase from a green firm; others do not. The regulator does not know consumers' preferences with certainty. A firm cares about its reputation because future profit depends on a good reputation. But if consumers do not care, a firm cannot extract surplus from gaining a green reputation. The regulator faces a challenge—she lacks information on which firms are socially responsible and which firms are reputation buyers. She does not want to chase away the firm with social preferences by crowding out their incentives to do the "right thing"; but she does not want to reward the reputation seeker by paying out extra money that could be spent elsewhere. The challenge for mechanism design is to use a firm's observed behavior to identify why it contributes to a social project: does the firm contribute due to intrinsic motivation or social preferences (Dana et al. 2003)—as firms care about reputation too. The regulator's challenge is to design a mechanism that specifies a menu of monetary transfer-to-effort that maximizes efficiency and minimizes information rents given two types of firms—green and brown, and two types of consumers—low and high preferences for purchasing from a green firm.

This paper extends Banerjee and Shogren (2010) by introducing the interaction between consumer and producer behavior. In our previous works, we designed incentive mechanism to correct market failure by considering behavioral failure when producers (e.g., firms, landowners) care about their reputation in society (Banerjee and Shogren, 2010, 2012). We argued, but we did not explicitly examine until now, one of the main reasons behind the reputation-concerned behavior of a firm—the motive to build a reputation to increase future profits. Now we address this selfish motive of a firm trying to buy a moral reputation – it can secure higher revenue when a consumer prefers to buy from a green firm. The key insight is that now when designing the mechanism the regulator must consider a feedback effect on a firm's behavior through a consumer's choice on purchasing decisions.

Our results suggest that a green firm over-adapts to climate risk than optimal given a consumer is a green buyer. While this result supports our previous general findings, it is conditional on a consumer's preference on the origin-of-purchase. In contrast, a reputation-buying brown firm adapts to climate risk optimally. In addition, a firm can exploit private information about a consumer's green preference to capture information rents. If a consumer is green, a brown firm can secure a positive information rent by exploiting the consumer's preference. This possibility did not emerge in Banerjee and Shogren's model (2010) because we did not address how a consumer's preference for the origin-of-purchase explicitly affected a firm's reputation seeking behavior.

2. Consumers' preference, firm's reputation, and mechanism

Over the last three decades, behavioral economists have focused on adding three behavioral realities to rational choice theory– bounded rationality, bounded will-power, and bounded self-interest (see Thaler and Sunstein, 2008; Mullainathan and Thaler, 2000). The open challenge is finding an elegant approach to incorporate these realities into formal mechanism design (e.g., tax, subsidies) (see Bowles and Hwang, 2008; Bénabou and Tirole, 2006). Mechanism design models assume people and firms have a non-monetary motivation to take part in social project. This work, however, has treated bounded self-interest, also called social preferences, as exogenous. In reality, preferences are not necessarily always exogenous, and they can depend on institutional factors (see Bowles, 1998). For example, a firm's behavior is affected by consumers' behavior, stakeholders' preference, market structure, and so on.

In this paper, we assume the owner of a firm has endogenous social preference which depends on consumers' preference for a green product. We focus on mechanism design to induce a firm to participate in climate protection. We assume the firm already has a non-monetary reason to do the job either because the firm's owners have social preferences or the firm wants to attract green customers by creating a "green reputation".

In general, a reputation is created by how others perceive a firm's type, nature, or value (Weigelt and Camerer, 1988). People and firms are concerned about their reputation either because they feel good when others appreciate their work (Batson, 1998) or for another selfish motive. For example, a firm desires a good reputation to make more profits by attracting those consumers who care social responsibility and environmentally-friendly manufacturing practices (Klein, 1990; Drumwright, 1994).[1] Over the years rather than resisting policies that restrict carbon emission, firms have changed their policies more toward a more pro-climate activity. Business groups once within the Global Climate Coalition (GCC), a group of multinationals resisting efforts to reduce GHG emissions, have moved in to a different tent – Center for Climate and Energy Solution (CCES) (previously known as Pew Center for Global Climate Change), the largest U.S.-based association of companies committed to climate protection. Perhaps they are attempting to reap economic and strategic benefit to align with the growing concerns on climate change among consumers and other players. Forty two companies, including BP, IBM, Intel, Shell, United Technologies and Whirlpool, have joined the Business Environmental Leadership

[1] Firms try to build a good reputation by signaling about product quality to (i) charge a premium (e.g., Klein and Leffler, 1981; Milgrom and Roberts, 1986b; Shapiro, 1983), (ii) attract better applicants and investors (Stigler, 1962; Milgrom and Roberts, 1986a), (iii) increase their access to the capital markets (Beatty and Ritter, 1986), and (iv) sometimes just signal their key characteristics to maximize their social status (Spence, 1974).

Council of the CCES, which supports the Kyoto Protocol and have agreed to take concrete steps for emission reduction.[2]

Evidence from the social psychology and marketing literature reveals many consumers prefer to buy from socially responsible firms (see e.g., Guagnano et al., 1995; Drumwright, 1994). Studies have shown that consumers have strong preference for green products, 'fair trade' products, and 'ethically superior' products, and they are willing to pay more (see the MORI's studies in Besley and Ghatak (2007) and Arora and Gangopadhaay (1995)). A profit seeking firm values its consumers' preference and will adapt its behavior to match the consumer accordingly (e.g., product variation, packaging, social responsibility).

Consider now our case of climate protection to help understand better how social preferences are relevant to mechanism design. Suppose a firm has social preferences to reduce GHG emissions although it is privately costly. If a regulator paid this firm for climate protection, the end result could backfire. If the compensation "crowded out" the firm's willingness to do the "right thing", the compensation would be counter-prodcutive (see Bowles, 2008; Titmuss, 1970). In contrast, another firm might not have social preferences to reduce carbon emissions. It will avoid paying a private cost to protect a public good—unless it gets

[2] This reputation-seeking behavior would increase contributions to a public good relatively more in a public setting than in a private setting, i.e., an "audience effect" (Dana et al, 2006; Andreoni and Bernheim, 2010). This helps explain why firms like to broadcast their contributions to the general public. For example, C2ES (Centre for Climate and Energy Solutions) lists names of corporations in its website who have taken adaptation and mitigation effort to climate change (http://www.c2es.org/business/belc/members). Nationalgrid, one prominent gas and energy company in the UK, has publicized its contribution to climate protection in the C2ES website – what they have done and what they plan to do in future as they believe: "Climate change is the biggest challenge ……. and energy companies have a central role … to support the move to a low carbon economy." Voluntary reductions of GHG emission could bring an opportunity for corporations to gain corporate reputation. Hoffman noted Cinergy's plan to achieve its CO_2 reduction goal to gain 'valuable customer good will' (Hoffman 2004). Also, companies' efforts are awarded and publicized, e.g., IBM and San Diego Gas and Electric received Organizational Leadership Award for their exemplary organizational leadership in their response to climate change (http://www.c2es.org/business/climate-leadership-awards). A survey by McKinsey reveals nearly 70 percent of global executives believe climate change is an important consideration in their strategy for their corporate reputation and brand (http://www.mckinseyquarterly.com/How_companies_think_about_climate_change_A_McKinsey_Global_Survey_2099).

something out of the investment. This firm might want to protect to "buy" a *good reputation*. A good reputation can be helpful in attracting new customers, gaining better access to capital or credit markets, and enticing new property buyers. Offering monetary rewards to this firm could also be counterproductive as it may wish to avoid being *viewed* as "greedy", and irresponsible (Bènabou and Tirole 2006). As consumers are willing to buy from a socially responsible firm, losing reputation leads to lower profit. Recent empirical trend indicates many firms today tend to over-shoot environmental compliance to gain a green image given that consumers care about green goods (see Arora and Gangopadhyay 1995; Basely and Ghatak 2007).

The traditional literature on mechanism design, however, has focused primarily on material interests and has prescribed monetary incentive is *the* tool to change behavior. This narrow focus has started to broaden out, however, as scholars have attempted to develop mechanism exploiting psychological factors such as altruism. In our case, we focus on reputation that can increases a firm's motives towards making investments in social projects at less cost (e,g., Bénabou and Tirole, 2006; Bowles and Hwang, 2008). In our previous work, Banerjee and Shogren (2010, 2012) developed an incentive mechanism that exploits firms' reputational concern behavior and found that green firms have incentive to take less money to protect the environment and brown firms actually buy reputation. We considered an interaction between consumers' and producers' behavior focus on point-source monopoly pollution and on non-point source threats to endangered species protection. We now extend this model to focus on climate change in which firms might have true social preference to protect the nature or they want to increase their profit by gaining green reputation as consumers care about green reputation.

By one estimate, climate change is helping to cause species extinction at a rate 10,000 times faster than in the period before the emergence of humans (Wilson 1988); damaging the ozone layer that shields living things from harmful ultraviolet radiation (Stern 2007; IPCC 2001); and making other alterations in the earth's life support systems, some known, some suspected, and probably others yet unrecognized, e.g., fat-tail risk of climate catastrophe (Weitzman, 2009). Scientists have emphasized that the global climate change is anthropogenic in origin—they point to human actions (such as burning fossil fuels, clearing great forests, manufacturing and consuming chemical products, and farming marginal lands, all at unparalleled rates) as the main driver of this change. Many people now realize their consumption patterns and purchasing decisions directly influence the environment. These consumers are becoming increasingly concerned about climate change and environmental issues.[3] Firms are trying to accommodate this consumer concern into production practice. For example, one study shows people want to stay in a hotel that cares about the environment and management has contributed to gain green image as a strategic and competitive tool (Mensah, 2004; Butler, 2008).

The regulator's dilemma is to determine why a firm contributes to climate protection by observing its behavior. She knows a climate-friendly firm can be one of two types—social preference-motivated or a reputation buyer—but she cannot distinguish between them. The regulator also faces another challenge since she does not know the consumer's true preference about the origin-of-purchase—he can be one of two types, i.e., a person with a high or low intrinsic satisfaction from buying from a green firm. The challenge for mechanism design is to create an incentive structure which encourages a firm to reveal its true type through its observed behavior.

3. Analytical Model

[3] According to a study by MORI the majority of people in the UK think the climate is changing and they are preparing to act on this (http://www.ipsos-mori.com/researchpublications/researcharchive/2620/Climate-Change-Still-High-on-Publics-Agenda.aspx).

Following Banerjee and Shogren (2010), we begin by defining our analytical model of mechanism design. We introduce the idea of social preferences and reputation under asymmetric information, assuming homogenous technology.

3.1. Basic model

Despite of complexity of global climate and lack of empirical data supporting climate catastrophe, many scientists fear climate change could potentially cause several disastrous events such as sea level rises, increased tropical storms, and reduced biodiversity. Emissions of CO_2 and other GHGs cause climate change as these gases trap intra-red radiation in the atmosphere. CO_2 concentration in the upper atmosphere has increased from 28- ppm in 1880 to 355 ppm in 1992 (IPCC, 2001). Major contribution of CO_2 is from energy and transport sector (e.g., coal mining, oil discovery, production of fertilizer) in the form of fossil fuel.

A regulator would like a firm to invest in *mitigation*—actions to abate CO_2 emissions to lessen the probability of loss due to climate catastrophe, and to invest in *adaptation*—efforts to reduce the severity of any realized damage (see for example Kane and Shogren, 2000). Regardless of mitigation efforts, adaptation at local level is important to reduce the unfavorable incidents due to climate change. Policy makers try to reduce the risk of climate change through mitigation and adaptation. Mitigation is restricting CO_2 or other GHG emissions to reduce the probability of climate catastrophe. Adaptation is reducing the severity of a climate catastrophe if it occurs by changing our production and consumption practices. Policy makers and scholars differ in opinion regarding the importance of these tools – mitigation and adaptation. Mitigation efforts have been dominant policy choice to lessen future climate change at the national and international level. But even drastic reduction in carbon emission would not reduce atmospheric carbon concentration to the pre-industrial level. As a result, global temperatures are likely to increase which increases the risk of more events such as sea level rise, biodiversity loss, severe weather events, and so on. It is necessary then to take "measures to facilitate adequate adaptation to climate change" (Article 4.1, UNFCCC) as adaptation is important response strategy along with mitigation to reduce climate risk (Kane and Shogren, 2000; Pielke, 1998). Policy maker have to examine the viability of a portfolio of adaptive tools and mitigation.

Following Laffont (1995), consider a model on mechanism design to induce a firm in energy sector to take adaptation actions against a climate catastrophe, e.g., a fat-tailed risk. Examples of adaptation in this sector include underground cabling for utilities, use of renewable resources (IPCC, 2007). A firm's adaptation to climate change has social value S and cost $C = \beta - \theta e_1$, where β is the efficiency parameter of the firm and e_1 is adaptation. The efficiency parameter is the firm's technical efficiency characteristic, e.g., emission control technology. The regulator observes the cost ex-ante. The market is a competitive market and in mechanism design the regulator considers one firm which can be of two types depending on β, holding the other firms' behavior constant. Let $(1-\pi)$ be the probability that a climate catastrophe occurs $(0 \leq \pi \leq 1)$ and E is the realized damage. The firm mitigates, e_2, to reduce the probability of a catastrophe. Examples of mitigation are early applications of CO_2 and storage, renewable resources etc. As mitigation is public good, the probability of a catastrophe depends on collective mitigation action by all n firms in the energy sector, $1 - \pi(e_2 + (n-1)z)$, where $\pi'(.) > 0$ and z is all other identical (n – 1) firms' efforts at mitigation. We assume other firms' mitigation exercises are fixed – holding free riding constant.[4] We presume all other firms have two types as well, and we aggregate their total mitigation into π. Assume $e_2 \in \{0,1\}$, with

[4] Since mitigation is a public good, firms have incentive to free ride. But, in this paper, we are not modeling a game of strategic interaction between firms per se. We are considering a game between the regulator, consumers, and one firm (holding all other firms' behavior constant, which we recognize as a strict restriction—one that future research can relax to examine the thorny issue of mechanism design, reputation, and free riding) (e.g., see Shogren 1987).

$\pi(e_2 = 1|\text{ fixed } z) > \pi(e_2 = 0|\text{ fixed } z)$. Assume also E is so large that the firm always finds it optimal to invest $e_2 = 1$.

The regulator is going to offer up a monetary net transfer, t, to a firm in exchange for adaptation effort by the firm. This is a standard mechanism design, in which the regulator offers the firm a "menu" of transfers and adaptation. The greater the transfer, the greater the adaptation expected—this is the transfer-menu mechanism. The firm chooses from this transfer- adaptation combination that maximizes its private payoffs.

A firm's ex-post utility is

$$U = t - \psi(e_1 + e_2) \tag{1}$$

where $\psi(e_1 + e_2)$ is the cost function of taking mitigation and adaptation actions with $\psi'(.) > 0$ and $\psi''(.) > 0$. A consumer's expected utility, if the firm mitigates and adapts, is,

$$V = S - \big(1 - \pi(1 + b)\big)E - (1 + \lambda)(C + t) \tag{2}$$

where λ is the social value of public funds used by the regulator to compensate the firm and $b = (n - 1)z$.

The regulator's goal is to prevent the climate change catastrophe. To protect the climate, the regulator wants the firm to adapt (e_1), and mitigate (e_2), and we assume $e_2 = 1$[5]. Adaptation effort by the firm, e_1, is a continuous variable. A firm suffers a monetary loss when it takes actions to protect the climate. It would voluntarily participate in the program of climate protection if it gets a monetary transfer from the regulator to compensate its loss. The regulator designs a contract to maximize social welfare from climate protection subject to the firm's

[5] As mitigation is not playing any role in the subsequent analysis, we will ignore this in section 3.2 and 4.

participation constraint. Social welfare is the utility of a private firm and a consumer, including benefit from climate protection, cost of climate catastrophe, and cost of monetary compensation scaled by social value of public funds. The objective function of the regulator is,

$$W = V + U = S - \left(1 - \pi(1 + b)\right)E - (1 + \lambda)\left(\beta - e_1 + \psi(e_1 + 1)\right) - \lambda U \quad (3)$$

Under complete information about the technical efficiency (i.e., β) and e_1, the regulator offers a contract specifying a monetary compensation. The optimal compensation ensures the firm is exactly compensated for its loss in rents and the firm takes optimal adaptation measure toward climate protection. No firm captures information rent (see Appendix 1 or Laffont 1995).

Under asymmetric information, however, the regulator only knows that a firm can be one of two types, but does not know who is who. The regulator cannot observe β, e_1 ex-ante but can observe the cost and if a catastrophe takes place ex-post. Assume one of two types of firm exist depending on their technical efficiency, $\beta \in \left\{\underline{\beta}, \overline{\beta}\right\}$, and $\underline{\beta} < \overline{\beta}$. According to Revelation Principle, the regulator offers a contract to the firm $(t^c(\beta), t^{nc}(\beta), C(\beta))$ which offers a monetary compensation $t^c(\beta)$ if a catastrophe happens and $t^{nc}(\beta)$ if a catastrophe does not happen for a realization cost $C(\beta)$. If the firm accepts it, it adapts and receives compensation as specified in the contract. The mechanism should be incentive compatible so each type of firm reveals its private information. The regulator considers incentive compatibility constraints and participation constraints of each type (see, Appendix 1). The incentive compatibility constraints say each type should not deviate in truthful announcements of its technical characteristic. The inefficient firm (high β) has no incentive to mimic efficient firm as it would incur a loss. It will participate if the utility from participation is at least as good as not taking part in the project. The efficient firm, however, has the incentive to hide its private information as it could capture some positive rents.

The regulator's challenge is to choose a contract to maximize social welfare given the firm's voluntary participation. Social welfare is the weighted average of the consumer's and the firm's utility, including the benefit from climate protection, realized costs of catastrophe, and cost to fund the compensation paid out. The regulator maximizes social welfare subject to the binding participation and incentive compatibility constraints. The binding constraints are: (i) participation or individual rationality constraint of the inefficient firm, and (ii) incentive compatible constraint of the efficient firm.

Compared to the full information case, the efficient firm invests the optimal level of effort and captures some information rents. The inefficient firm under-invests and captures no information rent. The efficient firm earns information rents because it can mimic the inefficient firm. It forces the regulator to give up a positive rent to the efficient firm, as she wants the inefficient firm to be active. Also, the regulator accepts high-cost firm's contribution less than the optimal level to minimize the information rents paid out.

3.2. Consumers' green preference

We add now consumers' preference of buying from green firms in our baseline model.[6] Suppose there are alternative energy suppliers and a consumer wants to choose a firm that has intrinsic motivation towards climate protection. The origin-of-purchase matters to this consumer—he wants to buy from a green firm. A consumer buys an energy good *x* from a firm that takes *t* transfer from the regulator and puts e_1 effort to adapt a fat-tail risk of climate catastrophe. A consumer gets intrinsic satisfaction, ϑ^C, when she buys from a *green* firm – a firm

[6] We do not have different types of firm based on β – we are now assuming β is same across firm.

that is environmentally responsible. A firm's green reputation is its intrinsic motivation toward climate protection – high intrinsic motivation implies green reputation and vice-versa. Define a firm's intrinsic motivation toward climate protection as θ. This θ is a firm's private information. The consumers cannot observe θ; rather he forms expectation about θ given the firm's adaptation toward climate protection, e_1, and monetary compensation received from the regulator, *t*. The regulator cannot observe θ. She knows the firm is one of two types depending on two levels of θ. Under asymmetric information, the regulator's challenge is to design a mechanism that should be able to extract private information efficiently. (We assume under the full information benchmark, the regulator knows the firm's true θ.)

A consumer forms expectation over θ given a firm's adaptation toward climate protection, e_1, and the monetary compensation it receives from the regulator, *t*. Assume $\hat{\theta}$ is a consumer's posterior expectation of a firm's intrinsic motivation for climate protection given e_1 and *t*,

$$\hat{\theta} = E(\theta | e_1, t) \qquad (4)$$

Consider a consumer's utility as,

$$V = S - (1 + \lambda)(C + t) + \vartheta^C \hat{\theta}(e_1, t) \qquad (5)$$

Consumers have identical preferences but different levels of ϑ^C. Consumers get same marginal utility and disutility from a firm's effort and the compensation paid out through taxation, but each consumer's marginal benefit from buying from a green firm differs. Given same e_1, *t*, and θ, each consumer enjoys different level of benefit depending on ϑ^C.

Now consider utility of a firm. A firm receives monetary transfer from the regulator and incurs a cost from its adaptation effort. A firm gets intrinsic satisfaction from being *green*.

Defining $\theta_{e_1}$is a firm's intrinsic valuation of adaptation. The firm gets $\theta_{e_1} e_1$ benefit from putting $e_1$adaptation effort. We capture this intrinsic valuation in the payoff function, $\psi(\theta_{e_1} e_1 + 1)$, such that adaptation cost is now weighted by the firm's intrinsic valuation from adaptation. One unit of adaptation effort is less costly to a green firm compared to a firm who does not have intrinsic motivation toward climate protection. We write project costs as $C = \beta - \theta_{e_1} e_1$, with fixed β . The firm also values money and its intrinsic valuation of money is θ_t. Depending upon its intrinsic valuation of adaptation and money, the firm is perceived as green or brown by the consumer. Investing in climate adaptation is seen as socially responsible behavior, whereas taking money to protect the climate is considered as socially irresponsible behavior. A firm's green reputation is its' intrinsic motivation toward climate protection and intrinsic valuation for money – high intrinsic motivation implies green reputation and vice-versa. Following Bénabou and Tirole, (2006), we can express a firm's reputation as the consumer's posterior expectation about the firm's characteristic,

$$\theta = E(\theta_{e_1} | e_1, t) - E(\theta_t \; | e_1, t)$$

Assume θ_{e_1} and θ_t are normally distributed with mean $\overline{\theta}_{e_1}$ and $\overline{\theta}_t$ and variance σ_{e_1} and σ_t. Since each consumer cares about a firm's *green* reputation, the firm obtains material benefit through higher revenue. The market share or the revenue of the firm can be obtained from the consumer's surplus. The revenue, *R*, of the firm is now governed by (i) the firm's green reputation perceived by the consumer and (ii) the consumer's intrinsic satisfaction of buying from the green firm, ϑ^C. Given same θ, each firm observes different revenue depending on ϑ^C (Arora and Gangopadhyay, 1995).

We derive demand from a consumer's utility following to Itoh (1983) and Arora and Gangopadhyay (1995) (also see, Mussa and Rosen, 1978). Itoh (1983) considers a monopoly market with a differentiated product with quality. Given constant marginal utility of money, consumers are differentiated based on their marginal utility from quality. This gives net surplus of each consumer depending on the consumer's valuation of the product. In Arora and Gangopadhyay (1995), a consumer gets utility from a firm's green effort and disutility from paying a price. Consumers are different because their marginal utility of money is different. A consumer's surplus is the green effort of the firm from which he buys net the price he pays weighted by his marginal utility of money. Consumers' surplus determines market share of a particular type of firm. A firm's green effort defines its type.

In our paper, a consumer gets utility from a firm's adaptation to climate change and disutility from paying a tax to fund the firm's effort. In addition, a consumer enjoys intrinsic satisfaction buying from a firm that has *green* reputation. Each consumer's marginal utility from the firm's adaptation and marginal disutility from paying tax are same. However, each consumer enjoys a different level of intrinsic satisfaction from a firm's green characteristic – the marginal utility from buying from a green firm differs across consumers. Taking *S*, *E*, and λ as given, a consumer's surplus is his intrinsic satisfaction of buying from a green firm and the firm's reputation minus the net amount he pays to fund the compensation paid out: $(e_1 - t) + \vartheta^C \theta$. Similar to Itoh (1983) and Arora and Gangopadhyay (1995), we derive the market share of a firm as an upper envelope of the consumer's surplus. In our case, there is one consumer who can be two types – high and low – based on his intrinsic satisfaction and one firm which can be two types – green and brown – based on its intrinsic valuation of climate adaptation and money. Then a firm's revenue depends on a consumer's characteristic and the firm's own characteristic. Unlike Itoh (1983) and Arora and Gangopadhyay (1995), we do not derive a firm's profit or revenue explicitly because our goal here is not to derive optimal price-quantity of a firm explicitly. The goal is to construct an optimal contract to induce a firm to adapt to climate change by satisfying its' participation and incentive compatible constraints. To achieve this, we need to understand how different factors, such as adaptation, compensation, and intrinsic valuation, affect agents' (consumer and producer) utility and their interaction. An implicit relationship between a firm's revenue and a consumer's and a firm's green attributes serve our purpose. As we know there is a link between a firm's revenue and ϑ^C, θ, we assume a simplified version of the link to gain insight,

$R = R\left(\vartheta^C \hat{\theta}\right) = R(\vartheta^C \hat{\theta}(e_1, t))$

The utility function of a reputation-concerned firm is

$$U = t - \psi\left(\theta_{e_1} e_1 + 1\right) + R(\vartheta^C \hat{\theta}) \quad (6)$$

with $\frac{\partial R}{\partial e_1} = \frac{\partial R}{\partial \hat{\theta}} \frac{\partial \hat{\theta}}{\partial e_1} > 0$ and $\frac{\partial R}{\partial t} = \frac{\partial R}{\partial \hat{\theta}} \frac{\partial \hat{\theta}}{\partial t} < 0$; $\frac{\partial^2 R}{\partial {e_1}^2} < 0$ and $\frac{\partial^2 R}{\partial t^2} < 0$.

As we claimed earlier, our incentive mechanism addresses a different behavior than the traditional mechanism does, i.e., a self-interested agent increases supply given only monetary incentives—money is *the* tool to construct optimal contract. We address the behavioral failure when a firm has non-monetary incentive to adapt climate change anyway. Monetary gains increase a firm's utility; but the money could also reduce contributions toward the climate protection project, i.e., the *crowding out effect*, in which extrinsic incentives reduce the incentives of a reputation-driven firm. We explore now whether monetary incentive could be counterproductive. The regulator needs to understand this behavior of the firm otherwise the contract would fail to induce the firm to cooperate. The possibility of a crowding-out effect in our model arises because (i) a firm has social preference and (ii) a firm's profit is driven by the consumer's willingness to buy from an environmentally-responsible firm. Taking money for climate protection by a firm is viewed as irresponsible behavior by consumers and they lose intrinsic satisfaction of buying from a green firm. A firm does not want to lose its revenue by losing its green reputation; the firm instead reduces supply. The regulator tries to solve the firm's utility optimization by changing adaptation and then examines how extra monetary compensation could affect the firm's optimal response in choosing adaptation. We show this by maximizing firm's utility described in (6) by varying adaptation given monetary transfer. The first order condition of the firm's utility maximization problem (described in (6)),

$$\frac{\partial R}{\partial e_1} - \frac{\partial \psi(\theta_{e_1} e_1 + 1)}{\partial e_1} = 0 \quad . \qquad (7)$$

The second order condition requires $\frac{\partial^2 R}{\partial {e_1}^2} - \frac{\partial^2 \psi(.)}{\partial {e_1}^2} < 0$. Expression (7) implies the marginal cost of adaptation effort to climate protection equates to the marginal benefits from monetary compensation and revenue from having *green* reputation. The firm gains good reputation as the consumer sees its contribution as 'noble' work. This behavior helps a firm increase its revenue as the consumer prefers to buy from a firm who cares about the climate.

Using the FOC in (7), comparative static result gives

$$\frac{\partial e_1}{\partial t} = \frac{R_{e_1 t}}{\psi'' - R_{e_1 e_1}} \qquad (8)$$

where, $R_{e_1 t} \equiv \frac{\partial^2 R}{\partial e_1 \partial t}$. Since monetary rewards for adaptation to climate suggest the firm is socially irresponsible, the cross partial derivative of reward for revenue gain due to green green reputation, $R_{e_1 t}$, is negative[7]. By the second order condition of utility maximization ($R_{e_1 e_1} - \psi'' < 0$), the denominator is positive. Increase in monetary reward reduces effort on climate protection project for reputation-concerned firm ($\frac{\partial e_1}{\partial t} < 0$). Since monetary rewards adversely

[7] We can show this crowing out effect following Proposition 2 in Benabou and Tirole (2006) – see Appendix 2.

affect the firm's reputation – the firm loses profit as reputation of being socially irresponsible reduces the consumer's satisfaction of buying from the firm – the firm reduces its effort.

The regulator designs the incentive mechanism to address the crowding out effect. We consider the case in which a consumer's intrinsic satisfaction derived from buying from a green firm is same for all consumers (assume ϑ^C is normalized) and allow the reputation of the firm perceived by the consumer (θ) to vary. To design the mechanism we assume the intrinsic valuation of money is same for each type of firm and intrinsic valuation of climate adaptation, θ_{e_1}, is different for different types of firm – a high intrinsic valuation of climate adaptation implies green firm and vise versa. We have one firm which can be of two types – green and brown corresponding to high and low θ. A firm's revenue depends positively on θ. A consumer's perception about θ is related to e_1, and *t* – the likelihood of high θ increases with an increase in e_1 and decrease in *t*. We derive an optimal monetary contract $({e_1}^i, t^i)$ for *i*th firm to induce the firm to adapt. This contract is obtained by optimizing the firm's utility in that the firm is no worse off by voluntarily selecting the contract. Under full information, the regulator knows the firm's intrinsic feeling toward climate protection. The regulator maximizes welfare (expression (9)) by choosing e_1 and U subject to $U \geq 0$.

The objective function of the regulator is[8]

$$W = V + U$$

$$= S - (1+\lambda)(\beta - \theta_{e_1} e_1) - (1+\lambda)t + t - \psi(\theta_{e_1} e_1 + 1) + R(\vartheta^C \hat{\theta})$$

$$= S - (1+\lambda)(\beta - \theta_{e_1} e_1) - \lambda U - (1+\lambda)(\psi(\theta_{e_1} e_1 + 1) - R(\vartheta^C \hat{\theta})) \quad (9)$$

[8] As mitigation is not playing any role in this analysis, we drop $(1 - \pi(1+b))E$ from the regulator's objective function.

Assuming interior solution, optimal regulation implies: (i) information rents are zero, $U = 0$; and (ii) marginal cost of effort equates marginal benefit from monetary reward, intrinsic satisfaction, and revenue through green reputation as the consumer values it

$$\frac{\partial \psi(\theta_{e_1} e_1 + 1)}{\partial e_1} = \theta_{e_1} + \frac{\partial R(\vartheta^C \hat{\theta}(e_1, t))}{\partial e_1} \qquad (10)$$

where, $\frac{\partial R(e_1,t)}{\partial e_1} = \frac{\partial R}{\partial \theta} \frac{\partial \hat{\theta}(e_1,t)}{\partial e_1}$. We can obtain optimal adaptation $e_1{}^*$ from expression (10) and substituting $e_1{}^*$ into the firm's utility function we can get optimal monetary transfer t^*,

$$t^* = U + \psi\left(\theta_{e_1} e_1{}^* + 1\right) - R \qquad (11)$$

Expression (10) shows the firm's marginal costs and benefits of contribution: benefits from monetary reward, direct material costs of adaptation effort weighted by intrinsic value, gain in revenue via higher reputational value due to adaptation effort toward climate protection (as the consumer values a firm's intrinsic motivation of protecting the climate). Compared to the benchmark case, optimal monetary transfer to the firm is less as (i) the firm derives intrinsic value from adaptation, and (ii) the consumer enjoys buying from a green firm. The expression (11) is the optimal monetary transfer to the firm that captures: (i) direct material cost of adaptation weighted by intrinsic value; (ii) higher revenue due to green reputation. Intrinsic valuation from adaptation and revenue gain from green reputation partially offset the material costs of adaptation.

Now consider *incomplete information*. Assuming two types of reputation, we have one of two types of firm: firm with low or high intrinsic valuation toward climate protection: "brown" or "green" firm $\left(i.e., \theta \in \{\underline{\theta}, \overline{\theta}\}\right)$. Let *q* be the probability of a green firm. The green firm participates in climate protection project by exerting high adaptation effort; and has no incentive to hide its private information. The brown firm, however, loses reputation and thereby revenue if the consumer identify its true intrinsic motivation toward climate protection. Under asymmetric information, the brown firm gains a green reputation by pretending it has a high intrinsic valuation (high θ). The mechanism is incentive compatible if reporting the true information is the dominant strategy of each firm. The incentive compatibility constraints for the green and the brown firms are

$$U(\overline{\theta},\overline{\theta}) \geq U(\overline{\theta},\underline{\theta}) \qquad \text{(G1a)}$$

$$U(\underline{\theta},\underline{\theta}) \geq U(\underline{\theta},\overline{\theta}) \qquad \text{(B1a)}$$

and participation constraints are

$$U(\overline{\theta}) \equiv U(\overline{\theta},\overline{\theta}) \geq 0 \qquad \text{(G2a)}$$

$$U(\underline{\theta}) \equiv U(\underline{\theta},\underline{\theta}) \geq 0 \qquad . \qquad \text{(B2a)}$$

where, $U\left(\overline{\theta},\underline{\theta}\right)$ means utility of a green firm (i.e., $\overline{\theta}$) when it reports that it is a brown firm (i.e., $\underline{\theta}$). As the green firm has no incentive to hide its private information, rather it participates if it gains positive utility, the participation constraint (G2a) is binding. A brown firm can raise benefit by pretending to be a green firm, the incentive compatibility constraint (B1a) is binding. From the binding incentive compatibility and participation constraints, we have

$$U(\underline{\theta}) = \Upsilon = \left[\psi\left(\overline{\theta}_{e_1}\overline{e}_1 + 1\right) - \psi\left(\left(\underline{\theta}_{e_1}\underline{e}_1; \overline{\theta}_{e_1}\overline{e}_1\right) + 1\right)\right] + \left[R\left(\underline{\theta};\overline{\theta}\right) - R(\overline{\theta})\right] \qquad \text{(B1a)}$$

$$U\left(\overline{\theta}\right) = 0 \qquad \text{(G2a)}$$

where, $R(\underline{\theta};\overline{\theta})$ represents revenue of a brown firm pretends to be green and $\psi\left(\left(\underline{\theta}_{e_1}\underline{e_1};\overline{\theta}_{e_1}\bar{e}_1\right)+\right.$ $\left.1\right)$ is the cost of adaptation of a brown firm pretends to be a green firm. Revenue of a green firm is greater than a brown firm as the intrinsic satisfaction of the green firm exceeds the brown firm, i.e., $R(\underline{\theta};\overline{\theta}) < R(\overline{\theta})$ as $\underline{\theta} < \overline{\theta}$. A green firm perceives it less costly than does a brown firm for same adaptation effort due to its intrinsic satisfaction, i.e., $\psi\left(\overline{\theta}_{e_1}\bar{e}_1+1\right) < \psi\left(\left(\underline{\theta}_{e_1}\underline{e_1};\overline{\theta}_{e_1}\bar{e}_1\right)+\right.$ $\left.1\right)$. This implies Υ is negative, as *Rθ;θ<R(θ)* and *ψθe1e1+1<ψθe1 e1;θe1e1+1*.

To derive optimal contract under asymmetric information[9], the regulator optimizes welfare with respect to $\left(\underline{e}_1,\ \bar{e}_1, U(\underline{\theta}), U(\overline{\theta})\right)$ subject to the binding constraints

$$W = q\left[S-(1+\lambda)\left(\beta-\overline{\theta}_{e_1}\bar{e}_1\right)-\lambda U(\overline{\theta})-(1+\lambda)(\psi\left(\overline{\theta}_{e_1}\bar{e}_1+1\right)-R\left(\vartheta^C\overline{\theta}\right))\ \right]+$$
$$(1-q)\left[S-(1+\lambda)\left(\beta-\underline{\theta}_{e_1}\underline{e}_1\right)-\lambda U(\underline{\theta})-(1+\lambda)(\psi\left(\underline{\theta}_{e_1}\ \underline{e}_1+1\right)-R\left(\vartheta^C\underline{\theta}\right))\right] \qquad (12)$$

Solving regulator's problem we have

$$\frac{\partial\psi\left(\overline{\theta}_{e_1}\bar{e}_1+1\right)}{\partial\bar{e}_1} = \overline{\theta}_{e_1} + \frac{\partial R\left(\vartheta^C\overline{\theta}(\bar{e}_1,t)\right)}{\partial\bar{e}_1} - \frac{(1-q)}{q}\frac{\lambda}{(1+\lambda)}\frac{\partial\Upsilon}{\partial\bar{e}_1} \qquad (13)$$

$$\frac{\partial\psi\left(\underline{\theta}_{e_1}\underline{e}_1+1\right)}{\partial\underline{e}_1} = \underline{\theta}_{e_1} + \frac{\partial R\left(\vartheta^C\underline{\theta}(\underline{e}_1,t)\right)}{\partial\underline{e}_1} \qquad (14)$$

Equations (13) and (14) state the marginal cost of adaptation equates marginal benefit of adaptation when the firm is intrinsically motivated and cares about its green reputation as the consumer prefers to be a green-buyer. Strong intrinsic motivation to protect the climate

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[9] We have one-sided uncertainty and the regulator deals with two types firm. The contract induces a firm to reveal its private information and we get a separating equilibrium (under some conditions, see Gale (1992, 1999)).

motivates the green firm to adapt more than the brown firm. The green firm perceives adaptation as less costly given its higher intrinsic value from contributing to climate protection than the brown firm. Also, it gets greater revenue as a consumer prefers to buy from a green firm. The marginal increase in adaptation effort toward climate protection increases the firm's revenue because the consumer perceives this behavior as "green", i.e., $\frac{\partial R}{\partial \bar{e}_1} > 0$. A firm's own intrinsic motivation plays a role here – a green firm undermines the cost of adaptation compared to a brown firm. This green firm over-adapts (i.e., $\frac{\partial \Upsilon}{\partial \bar{e}_1} < 0$) because (i) marginal disutility of extra money spent on adaptation is less for a green firm[10]; and (ii) marginal gain through higher revenue is greater (since $R(\underline{\theta};\overline{\theta}) < R(\overline{\theta})$ and $R'(\underline{\theta};\overline{\theta}) < R'(\overline{\theta})$). Compared to the full information case, the green firm adapts more than optimal because this behavior pays off at the margin through higher intrinsic value and greater revenue. This over-compliance emerges in other models as well for different reasons. A firm can over-adapt relative to optimal regulation because it anticipates stricter regulation (Segerson and Micelli, 1998) or it engages in strategic competition to attract green consumers (Arora and Gangopadhaya, 1995) or both (Gunningham et al., 2004).

From binding incentive compatible and individual rationality constraints, we find information rents are negative for the brown firm and zero for the green firm:

$$U(\underline{\theta}) = \Upsilon \text{ and } U(\overline{\theta}) = 0 \quad . \tag{15}$$

The brown firm pays the regulator to increase its reputation ($\Upsilon < 0$). The green firm does not—it has no incentive to increase reputation via the regulator's advertisement of its responsibility to

[10] Given the green firm's adaptation cost is weighted by its' intrinsic satisfaction, single crossing property holds – $\psi\left(\overline{\theta}_{e_1}\bar{e}_1 + 1\right) < \psi\left(\left(\underline{\theta}_{e_1}\underline{e}_1;\overline{\theta}_{e_1}\bar{e}_1\right) + 1\right)$ and $\psi'\left(\overline{\theta}_{e_1}\bar{e}_1 + 1\right) < \psi'\left(\left(\underline{\theta}_{e_1}\underline{e}_1;\overline{\theta}_{e_1}\bar{e}_1\right) + 1\right)$.

the environment. These findings are similar to our previous work (see, Banerjee and Shogren 2010) in which we observe a green firm exerting more effort than optimal and a brown firm buying reputation.

Addressing moral hazard problem in designing policy to reduce environmental risks, the Laffont (1995) mechanism reports the following outcomes, similar to what we see in traditional mechanism design literature given economic agents are rational and self-interested: (i) an efficient monopolist invests optimally in environmental protection and captures a positive information rent; and (ii) an inefficient monopolist under-invests in environmental protection. We see that this benchmark result changes once we incorporate the realities of other psychological motives in mechanism design. Banerjee and Shogren (2010), for instance, considered bounded self-interest as one of the departures from the rational choice theory and designed mechanism by adding social preference of firms in the form of moral reputation. They find a green firm exerts more than optimal effort toward environmental protection and a brown firm buys reputation. In this paper, we again find that over-adaptation by a green firm depends on the firm's material gain. This holds because we treat a firm's social preference as endogenous. We also find that a brown firm adapts optimally to capture the benefits from the green consumer. We find again the possibility of negative information rent – just opposite to what we see in Laffont (1995), but similar to Banerjee and Shogren (2010). Compared to Banerjee and Shogren (2010), the volume of negative information rent is greater as a firm can gain more through greater profit by exploiting a consumer's green preference. Considering this possibility of endogenous preferences could be useful in future work exploring the limits of cost-effective climate protection. Although a firm might know more about a consumer's preference than a regulator, this asymmetric information might lead to different outcomes. We now discuss this possibility in the next section.

4. Asymmetric Information about Consumers' preference

We now explore how to design the mechanism when the regulator does not have complete information about consumers' preference – whether they prefer to buy from a green firm or not – but the firm knows this information. A firm can get information about consumers' preference from their sales, conducting surveys. A firm sometime keeps this information private; it would be difficult for the regulator to know who green consumer is. We still have one of two types of firms – low and high reputation (brown and green firm), corresponding to low- and high-intrinsic motivation for climate protection (i.e., $\theta \in (\underline{\theta}, \overline{\theta})$). We now assume two levels of a consumer's preference on green products: low and high (i.e., $\vartheta^C \in (\underline{\vartheta}^C, \overline{\vartheta}^C)$), where $\overline{\vartheta}^C > \underline{\vartheta}^C$. We have now one consumer who can be two types – high and low. We have four possible cases to consider, given two levels of asymmetric information, they are described by ω, where $\omega \in (GH, GL, BH, BL)$ and, for example, *GH* implies a green (i.e., high θ) firm and a consumer with 'high' (high ϑ^C) preference to buy from a green firm (see Table 1). Assume f is the probability a firm's type is ω, where, $f \in (p, q, r, s)$ (e.g., the probability a firm is *green* with *high preference on green product* is *p*). Combining these two types of firms and consumers, we have now one firm which can now be one of four types: (i) the *green firm and 'high' preference on green product* (*type-GH*) who has no intention to hide private information about its own type, however, it has incentive to report to the regulator that the consumer's true preference is *low*; (ii) the *green firm and 'low' preference on green product* (*type-GL*) who has no incentive to hide private information about its own type and the consumer's type; (iii) the *brown firm and 'high' preference on green product* (*type-BH*) who pretends it is a green type and has incentive to hide the consumer's true preference from the regulator; and (iv) the *brown firm and 'low' preference on green product* (*type-BL*) who wants to be viewed as *green* but has no incentive to hide the consumers' true type.

The regulator faces a trade-off in designing an efficient mechanism: a firm could reduce supply due to the crowding out effect of monetary incentive if the consumer cares about the firm's intrinsic motivation for climate protection. In contrast, a firm could refuse to participate with less monetary reward, if a consumer has low preference on green products. The regulator does not know who is a green firm and who is a green consumer. Here we define an efficient mechanism to induce the firm which can be one of four types. In the full information benchmark case, the regulator faces the same problem as in (9). The optimal conditions also are similar to (10). Under asymmetric information, efficient mechanism should satisfy the following incentive compatibility constraints and individual rationality constraints.

A green firm with a high consumer (*type-GH*):

$$U\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right) \geq U\left(\overline{\theta},\overline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right) \qquad (GH1)$$

$$U\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right) \geq U\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right) \qquad (GH2)$$

$$U\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right) \geq U\left(\overline{\theta},\overline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right) \qquad (GH3)$$

A green firm with a low consumer (*type-GL*):

$$U\left(\overline{\theta},\underline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right) \geq U\left(\overline{\theta},\underline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right) \qquad (GL1)$$

$$U\left(\overline{\theta},\underline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right) \geq U\left(\overline{\theta},\underline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right) \qquad (GL2)$$

$$U\left(\overline{\theta},\underline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right) \geq U\left(\overline{\theta},\underline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right) \qquad (GL3)$$

A brown firm with a high consumer (*type-BH*):

$$U\left(\underline{\theta},\overline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right) \geq U\left(\underline{\theta},\overline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right) \qquad (BH1)$$

$$U\left(\underline{\theta},\overline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right) \geq U\left(\underline{\theta},\overline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right) \qquad (BH2)$$

$$U\left(\underline{\theta},\overline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right) \geq U\left(\underline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right) \qquad (BH3)$$

A brown firm with a low consumer (*type-BL*):

$$U\left(\underline{\theta},\underline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right) \geq U\left(\underline{\theta},\underline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right) \qquad (BL1)$$

$$U\left(\underline{\theta},\underline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right) \geq U\left(\underline{\theta},\underline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right) \qquad (BL2)$$

$$U\left(\underline{\theta},\underline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right) \geq U\left(\underline{\theta},\underline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right) \qquad (BL3)$$

and individual rationality constraints,

$$U\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right) \geq 0 \qquad (GH4)$$

$$U\left(\overline{\theta},\underline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right) \geq 0 \qquad (GL4)$$

$$U\left(\underline{\theta},\overline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right) \geq 0 \qquad (BH4)$$

$$U\left(\underline{\theta},\underline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right) \geq 0 \qquad (BL4)$$

Only (GH2), (GL4), (BH3), and (BL1) are binding. A green firm has no incentive to pretend it is a brown firm – incentive compatibility constraints (GH1) and (GH3) for *type-GH* firm are not binding as its dominant strategy is to tell the truth about its own type; otherwise it would lose reputation and receive less profits because the consumer has high preference on green product. This firm can hide the consumer's high preference on the firm's green attitude, however, which will allow it to capture positive information rents. Now the incentive compatibility constraint (GH2) is binding. In *type-GL* case, only the participation constraint is binding (i.e., constraint (GL4)). This firm's green reputation would be unhelpful to raise profit as the consumer is uninterested about the firm's green attitude.

A brown firm wants to gain a green reputation by pretending it has high intrinsic motivation for climate protection. This could help increase its revenue when it knows a consumer prefers to buy from a green firm. However, a brown firm can hide its private information about the consumer's preference from the regulator and can ask for higher monetary transfer. Here a brown firm wants to report it has high intrinsic motivation for climate protection given the consumer has low preferences on the firm's green behavior (i.e., (BH3) is binding). In contrast, a brown firm would reveal the consumer's true type, but it wants to gain a green reputation by reporting it is a green firm (i.e., (BL1) is binding).

The binding constraints are

$$U\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\overline{\vartheta}^{C}\right)=U\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)=R\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)-R\left(\overline{\theta},\underline{\vartheta}^{C}\right)=\Omega \qquad \text{(GH2)}$$

$$U\left(\overline{\theta},\underline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)=0 \qquad \text{(GL4)}$$

$$U\left(\underline{\theta},\overline{\vartheta}^{C};\underline{\theta},\overline{\vartheta}^{C}\right)=U\left(\underline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)=\Lambda+\Phi \qquad \text{(BH3)}$$

$$U\left(\underline{\theta},\underline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\right)=U\left(\underline{\theta},\underline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)=\Lambda \qquad \text{(BL1)}$$

where, $\Lambda=\left[\psi\left(\overline{\theta}_{e_1}e^{Gi}{}_1+1\right)-\psi\left(\left(\underline{\theta}_{e_1}e^{Bi}{}_1;\overline{\theta}_{e_1}e^{Gi}{}_1\right)+1\right)\right]$and $\Phi=\left[R\left(\underline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)-R(\overline{\theta},\underline{\vartheta}^{C})\right]$, $i=H,L$. The expression $R\left(\overline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)$ represents a green firm's revenue when it reports a consumer's type is low (low preference towards a firm's green attitude). Since the consumer is actually a *high* type (i.e., a consumer has strong preference buying from a green firm), $\Omega>0$ (as $\overline{\vartheta}^{C}>\underline{\vartheta}^{C}$). The cost function of a brown firm which pretends to be a green firm is $\psi\left(\left(\underline{\theta}_{e_1}e_1;\overline{\theta}_{e_1}e_1\right)+1\right)$. Since $\underline{\theta}<\overline{\theta}$, the disutility of money spent on adaptation is lower for a green firm than a brown firm, i.e., $\Lambda<0$ as $\psi\left(\left(\underline{\theta}_{e_1}e_1;\overline{\theta}_{e_1}e_1\right)+1\right)>\psi\left(\overline{\theta}_{e_1}e_1+1\right)$. The expression $R\left(\underline{\theta},\overline{\vartheta}^{C};\overline{\theta},\underline{\vartheta}^{C}\right)$ shows revenue of a *BL-type* firm (a brown firm with high type consumer) when it pretends to be a *GL-type* firm (a green firm and a consumer has low preference).

The sign of the potential information rent for a *BH-type* firm (captured by the term $(\Lambda + \Phi)$ in (BH3)) is ambiguous. The first term on the RHS (i.e., $\Lambda \equiv \Big[\psi\big(\overline{\theta}_{e_1} e_1 + 1\big) -$ $\psi\theta e1e1;\theta e1e1+1$) is negative. The sign of the second term of the RHS (i.e., $\Phi \equiv \Big[R\left(\underline{\theta}, \overline{\vartheta}^{C}; \overline{\theta}, \underline{\vartheta}^{C}\right) - R(\overline{\theta}, \underline{\vartheta}^{C})\Big]$) is ambiguous. The firm would lose revenue if its true type is revealed. This type of firm would try to be viewed as a green type. This raises the possibility of negative information rent – the firm might want to buy reputation from the regulator. At the same time, this firm might capture some positive rent from the regulator by hiding the consumer's true type. The relative magnitude of these countervailing effects determines the sign of Φ.

The regulator designs the mechanism to maximize social welfare[11]: the sum of the utilities of different types of firm with their probability of occurrence. She optimizes social welfare by selecting $({e_1}^{GH}, {e_1}^{GL}, {e_1}^{BH}, {e_1}^{BL})$ subject to (GH1) to (GH4), (GL1) to (GL4), (BH1) to (BH4), and (BL1) to (BL4),

$$W = p\Bigg[S - (1+\lambda)\big(\beta - \overline{\theta}_{e_1} {e_1}^{GH}\big) - \lambda U\left(\overline{\theta}, \overline{\vartheta}^{C}; \overline{\theta}, \overline{\vartheta}^{C}\right) - (1+\lambda)\Bigg(\psi\big(\overline{\theta}_{e_1} {e_1}^{GH} + 1\big) -$$

$$R\left(\overline{\vartheta}^{C} \overline{\theta}\right)\Bigg)\Bigg] + q\Bigg[S - (1+\lambda)\big(\beta - \overline{\theta}_{e_1} {e_1}^{GL}\big) - \lambda U\big(\overline{\theta}, \underline{\vartheta}^{C}; \overline{\theta}, \underline{\vartheta}^{C}\big) - (1+\lambda)\Bigg(\psi\left(\overline{\theta}_{e_1} {e_1}^{GL} + 1\right) -$$

$$R\big(\underline{\vartheta}^{C} \overline{\theta}\big)\Bigg)\Bigg] + r\Bigg[S - (1+\lambda)\big(\beta - \underline{\theta}_{e_1} {e_1}^{BH}\big) - \lambda U\left(\underline{\theta}, \overline{\vartheta}^{C}; \underline{\theta}, \overline{\vartheta}^{C}\right) - (1+\lambda)\Bigg(\psi\big(\underline{\theta}_{e_1} {e_1}^{BH} + 1\big) -$$

[11] Assuming firm can observe a consumer's type, we have one-sided uncertainty but the regulator now confronts 4 types - GH, GL, BH, and BL. The menu offers four items and we have a new separating equilibrium (under stricter conditions, see Section 4 in Gale, 1999). Our model is similar to 'non-responsive' story of adverse selection described in Guesnerie and Laffont (1984). Instead of single adverse selection, we have "quasi"-double adverse selection - hidden types of firm and consumer from the regulator's perspective. We recognize that assuming the firm knows the consumer's preferences but the regulator does not is a strict assumption. Future research can explore a true double adverse selection problem in this context, and examine what happens given the potential for a no-trade equilibrium (e.g., Milgrom and Stokey, 1982).

$R\left(\overline{\vartheta}^{C}\underline{\theta}\right)\Big)\Big] + s\Big[S-(1+\lambda)\big(\beta-\underline{\theta}_{e_1}e_1{}^{BL}\big)-\lambda U\big(\underline{\theta},\underline{\vartheta}^{C};\underline{\theta},\underline{\vartheta}^{C}\big)-(1+\lambda)\Big(\psi\big(\underline{\theta}_{e_1}e_1{}^{BL}+1\big)-$

$$R\big(\underline{\vartheta}^{C}\underline{\theta}\big)\Big)\Big] \qquad (16)$$

Substituting the binding constraint for ωth case into the utility of firm under ωth case, where $\omega \in (GH, GL, BH, BL)$, the regulator's problem is,

$$W = p\left[S-(1+\lambda)\big(\beta-\overline{\theta}_{e_1}e_1{}^{GH}\big)-\lambda\Omega-(1+\lambda)\left(\psi\big(\overline{\theta}_{e_1}e_1{}^{GH}+1\big)-R\left(\overline{\vartheta}^{C}\overline{\theta}\right)\right)\right]+ q\left[S-(1+\lambda)\left(\beta-\overline{\theta}_{e_1}e_1{}^{GL}\right)-(1+\lambda)\left(\psi\left(\overline{\theta}_{e_1}e_1{}^{GL}+1\right)-R\big(\underline{\vartheta}^{C}\overline{\theta}\big)\right)\right]+r\Big[S-(1+\lambda)\big(\beta- \underline{\theta}_{e_1}e_1{}^{BH}\big)-\lambda(\Lambda+\Phi)-(1+\lambda)\left(\psi\big(\underline{\theta}_{e_1}e_1{}^{BH}+1\big)-R\left(\overline{\vartheta}^{C}\underline{\theta}\right)\right)\Big]+s\Big[S-(1+\lambda)\big(\beta- \underline{\theta}_{e_1}e_1{}^{BL}\big)-\lambda\Lambda-(1+\lambda)\Big(\psi\big(\underline{\theta}_{e_1}e_1{}^{BL}+1\big)-R\big(\underline{\vartheta}^{C}\underline{\theta}\big)\Big)\Big]$$

The necessary conditions imply

$$e_1{}^{GH}: \frac{\partial\psi(\overline{\theta}_{e_1}e_1{}^{GH}+1)}{\partial e_1{}^{GH}} = \overline{\theta}_{e_1} + \frac{\partial R\left(\overline{\vartheta}^{C}\overline{\theta}(e_1{}^{GH},t)\right)}{\partial e_1{}^{GH}} - \frac{r+s}{p}\frac{\lambda}{(1+\lambda)}\frac{\partial\Lambda}{\partial e_1{}^{GH}} \qquad (17)$$

$$e_1{}^{GL}: \frac{\partial\psi(\overline{\theta}_{e_1}e_1{}^{GL}+1)}{\partial e_1{}^{GL}} = \overline{\theta}_{e_1} + \frac{\partial R\left(\underline{\vartheta}^{C}\overline{\theta}(e_1{}^{GL},t)\right)}{\partial e_1{}^{GL}} - \frac{p}{q}\frac{\lambda}{(1+\lambda)}\frac{\partial\Omega}{\partial e_1{}^{GL}} - \frac{r}{q}\frac{\lambda}{(1+\lambda)}\left(\frac{\partial\Phi}{\partial e_1{}^{GL}}+\frac{\partial\Lambda}{\partial e_1{}^{GL}}\right) \qquad (18)$$

$$e_1{}^{BH}: \frac{\partial\psi(\underline{\theta}_{e_1}e_1{}^{BH}+1)}{\partial e_1{}^{BH}} = \underline{\theta}_{e_1} + \frac{\partial R\left(\overline{\vartheta}^{C}\underline{\theta}(e_1{}^{BH},t)\right)}{\partial e_1{}^{BH}} \qquad (19)$$

$$e_1{}^{BL}: \frac{\partial\psi(\underline{\theta}_{e_1}e_1{}^{BL}+1)}{\partial e_1{}^{BL}} = \underline{\theta}_{e_1} + \frac{\partial R\left(\underline{\vartheta}^{C}\underline{\theta}(e_1{}^{BL},t)\right)}{\partial e_1{}^{BL}} - \frac{r}{q}\frac{\lambda}{(1+\lambda)}\left(\frac{\partial\Omega}{\partial e_1{}^{BL}}+\frac{\partial\Phi}{\partial e_1{}^{BL}}\right) \qquad (20)$$

A *GH-type* firm gets higher intrinsic value from adaptation relative to a brown firm. A *GH-type* firm's marginal disutility from adaptation is less than a brown firm. Also, a *GH-type* gets greater marginal revenue increase given a consumer is *high* type. This firm over-invests in adaptation effort as $\frac{\partial\Lambda}{\partial e_1{}^{GH}} < 0$ (since $\psi\left(\overline{\theta}_{e_1} e_1^{Gi} + 1\right) < \psi\left(\left(\underline{\theta}_{e_1} e_1^{Bi}; \overline{\theta}_{e_1} e_1^{Gi}\right) + 1\right)$ and $\psi'\left(\overline{\theta}_{e_1} e_1^{Gi} + 1\right) < \psi'\left(\left(\underline{\theta}_{e_1} e_1^{Bi}; \overline{\theta}_{e_1} e_1^{Gi}\right) + 1\right)$) . In contrast, a *GL-type—a* green firm with low type consumer—is unable to reap the same higher revenue as the *GH-type* does because the consumer is less interested to buy from a green firm (expression (18)). A green firm's high intrinsic motivation for climate protection leads it to adapt more to protect the environment (i.e., $\theta \equiv \overline{\theta}$ and $\psi'\left(\overline{\theta}_{e_1} e_1^{Gi} + 1\right)$ is lower than a brown firm and $\frac{\partial\Lambda}{\partial e_1{}^{GL}} < 0$). But this action does not help the *GL* firm increase its benefit because the consumer does not care about the firm's intrinsic motivation for climate protection (i.e., $R\left(\overline{\theta}, \overline{\vartheta}^C; \overline{\theta}, \underline{\vartheta}^C\right) > R\left(\overline{\theta}, \underline{\vartheta}^C\right)$ and $R'\left(\overline{\theta}, \overline{\vartheta}^C; \overline{\theta}, \underline{\vartheta}^C\right) > R'\left(\overline{\theta}, \underline{\vartheta}^C\right)$ and hence $\Omega' > 0$). Moreover, it is not obvious that this *GL-type* firm enjoys higher revenue at the margin compared to a *BH-type* firm (i.e., $\left[R\left(\underline{\theta}, \overline{\vartheta}^C; \overline{\theta}, \underline{\vartheta}^C\right) \lesseqgtr R\left(\overline{\theta}, \underline{\vartheta}^C\right)\right]$ and hence $\Phi' \lesseqgtr 0$). This implies a *GL* firm's adaptation level is ambiguous.

A brown firm has no motivation to invest more than optimal adaptation since it has low intrinsic motivation for climate. Consumer preference again matter. With high green consumer preference, a *BH* firm, does not want to be viewed as irresponsible. The *BH* firm exerts optimal adaptation effort given the consumer has strong preference on buying from a socially responsible firm (expression (19)). But a *BL* firm adapts less than optimal given a consumer cares less about a firms' reputation ($\frac{\partial\Omega}{\partial e_1{}^{BL}} > 0$ and $\frac{\partial\Phi}{\partial e_1{}^{BL}} > 0$ in expression (20)).

Our results show that the green firm adapts *more* than the optimal and the brown firm adapts optimally to climate change provided the consumer is a green buyer. This over-adaptation to the climate protection standard by a green firm has similar findings in alternative modeling contests in which a firm does not want to gain a bad or brown reputation (see Smart 1992 in Arora and Gangopadhyay 1995). This result is similar to Banerjee and Shogren (2012)—a green firm overprotect the environment to maintain its' good reputation (also, see Milinski et al. 2002). Our new work observes, however, *overprotection* by a green firm is possible only if consumers care this green attribute. Banerjee and Shogren (2012) found that a green landowner would retire more than the optimal acres of land if the reputational gained from land retirement is higher than the material costs of land retirement. In this paper, we do not consider asymmetric information of a firm's cost structure—rather we focus on asymmetric information about a firm's reputation and a consumer's green preference. A green firm adapts more than optimal if the consumer is green. A brown firm's endogenous preference motivates the firm to adapt optimally given green buyer. The self-interested motive of gaining greater profit by attracting a green consumer induces a *BH* firm to adapt optimally; without the green consumer, it has no incentive to adapt optimally otherwise. In contrast, a *BL* firm cannot capitalize on the consumer's preference because he is less interested in the firm's green attitude – the firm responses by under-investing in adaptation effort. In contrast, Laffont (1995) found that a firm with low costs exerts *at least* the optimal level, but a firm with high costs retires *less than* the optimal.

The binding incentive compatibility constraint of the green firm when a consumer has strong preference to buy from a green firm (expression (GH2)) shows that the firm can earn positive information rents. Although the firm has no incentive to hide its private information, it can hide the consumer's true type to capture information rents from the regulator. In contrast, a

GL firm has no incentive to hide its private information and the consumer's preference – it earns zero information rent. A brown firm wants to be viewed as green and will buy reputation – it earns a *negative* information rent. Also, if a consumer is green, a brown firm has the incentive to capture some positive information rents by hiding the consumer's true preference. Therefore, a *BH* firm can capture positive (negative) information rents if its revenues gained by hiding the consumer's true type is greater (less) than the volume of negative rent to buy green reputation (i.e., if $\Phi > 0$ and $|\Lambda| < |\Phi|$, then positive rent for *BH* firm, as shown in expression (BH3)). When a consumer does not have strong preference for green products, a brown firm does not hide the consumer's preference. Rather it wants to buy reputation, i.e., it can earn *negative* information rent.

Our results differ from the traditional mechanism design literature on the nature of information rents, which predicts a firm with an information advantage will exploit it (e.g., Laffont, 1995). Here we observe the possibility of *negative* information rent due to a firm's social preference and its relation with a consumer's green preference – a brown firm might buy reputation. This result also supports our previous work in which an agent with low reputation would buy reputation (Banerjee and Shogren 2010, 2012). Our new finding, however, is conditional on a consumer's preference for the origin-of-purchase—it matters whether he buys from a green or brown firm. Once we add a firm's endogenous social preference, we find a green firm can capture information rents by exploiting its private information about a consumer's green preference. A brown firm might also end up with positive information rent when the consumer is green. This possibility did not emerge in Banerjee and Shogren's model (2010) because we did not consider how a consumer's preference affected a firm's reputation seeking behavior. We believe this is a useful insight to better link a firm's reputation seeking behavior to how a consumer values the firm's green reputation.

5. Concluding remarks

We examine how to design an effective incentive mechanism for climate protection given the interaction between consumers and producers when both material interests and moral sentiment motivate a firm (see Smith 1759). This work extends our previous work (Banerjee and Shogren, 2010) by examining firms' adaptation to climate protection when their preference of gaining moral reputation is endogenous – it depends on consumers' green preference. Once we add this into the mechanism design model, three interesting implications emerge: (i) a firm's voluntary over-compliance with environmental standard is motivated by the consumer's willingness to buy from a climate-responsible firm; (ii) a reputation-seeking firm buys its reputation; and (iii) a firm will tend to exploit a consumer's green preference to capture positive information rents. Our result suggests a private firm which has a green reputation already will spend too much on climate adaptation to protect their own good reputation relative to the optimum. Secondly, accounting for moral sentiments in the form of *reputation* could save public resources when compared to a traditional mechanism which focuses strictly on material interests. A brown firm will sacrifice their information rent to "buy" a good reputation. Finally, both a brown and green firm might try to extract positive information rents by exploiting a consumer with very strong green preferences toward the source of the product.

We recognize two main caveats and possible extensions. We hold constant the free riding between firms on their mitigation. Traditional economic literature predicts inefficient provision of public good at the optimal Nash solution (Olson 1965) when firms engage in competition. Increasing free-riding incentive leads to sub-optimality. Firms might increase mitigation efforts when others do the same, however, if there is a strategic interaction between firms (Cornes and Sandler, 1984; Shogren 1987; Kverndokk et al. 2004). Future research would devote to investigate mechanism design considering such positive spillover effect of mitigation exercise. Second, it would also be interesting to examine the interaction between adaptation and mitigation at a deeper level within a firm's decision making – i.e., whether adaptation and mitigation are technical substitutes or complements. The open question is how to design an incentive mechanism that promotes the optimal and heterogeneous mix of adaptation and mitigation (see Kane and Shogren 2000; Wilbanks et al. 2003).

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Table 1. Firm types under asymmetric information on consumers' preference and reputation

		Consumers' preference: High	Consumers' preference: Low
Firm's Reputation	Green	*(G, H)*	*(G, L)*
	Brown	*(B, H)*	*(B, L)*

Appendix 1 (For the Reviewers)

The objective function of the regulator is,

$$W = V + U = S - \big(1 - n\pi(1)\big)E - (1+\lambda)\big(\beta - e_1 + \psi(e_1+1)\big) - \lambda U \qquad (3)$$

Under full information, the regulator maximizes W by choosing e and U subject to the constraint $U \geq 0$. Assuming interior solution, optimal regulation implies: (i) $\frac{\partial\psi(e_1+1)}{\partial e_1} = 1$ (MB = MC); and (ii) $U = 0$ (zero rents for firms). The compensation ensures a firm is exactly compensated for its loss in rents.

Under asymmetric information, the regulator cannot observe β and e ex-ante but can observe the cost and if a catastrophe takes place ex-post. Assume two types of firms exist, low or high cost $\left(i.e., \beta \in \left\{\underline{\beta}, \overline{\beta}\right\}\right)$, and ω is the probability the firm is a low-cost. According to Revelation Principle, the regulator offers a contract to a firm $(t^c(\beta), t^{nc}(\beta), C(\beta))$.

The firm's expected utility when it reveals its $\beta = \tilde{\beta}$ is,

$$U\big(\beta, \tilde{\beta}, e_2\big) = \pi(e_2)t^{nc}\big(\tilde{\beta}\big) + \big(1 - \pi(e_2)\big)t^c\big(\tilde{\beta}\big) - \psi(\beta - C\big(\tilde{\beta}\big) + e_2)$$

Assume again E is so large that $e_2 = 1$.

The regulator considers the incentive compatibility constraints:

$U(\underline{\beta}, \underline{\beta}, 1) \geq U(\underline{\beta}, \overline{\beta}, 1)$ *(L1a)*

$U(\underline{\beta}, \underline{\beta}, 1) \geq U(\underline{\beta}, \underline{\beta}, 0)$ *(L2a)*

$U(\underline{\beta}, \underline{\beta}, 1) \geq U(\underline{\beta}, \overline{\beta}, 0)$ *(L3a)*

$U(\overline{\beta}, \overline{\beta}, 1) \geq U(\overline{\beta}, \underline{\beta}, 1)$ *(H1a)*

$U(\overline{\beta}, \overline{\beta}, 1) \geq U(\overline{\beta}, \overline{\beta}, 1)$ *(H2a)*

$U(\overline{\beta}, \overline{\beta}, 1) \geq U(\overline{\beta}, \underline{\beta}, 0)$ *(H3a)*

and participation constraints:

$U(\underline{\beta}, \underline{\beta}, 1) \geq 0$ *(L4a)*

$U(\overline{\beta}, \overline{\beta}, 1) \geq 0$ *(H4a)*

The regulator's challenge is to choose a contract to maximize social welfare given the firms' voluntarily participation. The regulator maximizes the following objective function by choosing $\left(\underline{e_1},\ \overline{e_1},\ U\left(\underline{\beta}\right), U\left(\overline{\beta}\right)\right)$ subject to the binding participation and incentive compatibility constraints,

$$W = \omega\left[S - \left(1 - n\pi(e_2)\right)E - (1+\lambda)\left(\underline{\beta} - \underline{e_1} + \psi\left(\underline{e_1} + e_2\right)\right) - \lambda U(\underline{\beta})\right] + (1-\omega)\left[S - \left(1 - n\pi(e_2)\right)E - (1+\lambda)\left(\overline{\beta} - \overline{e_1} + \psi(\overline{e_1} + e_2)\right) - \lambda U(\overline{\beta})\right] \quad (4)$$

The binding constraints are: (i) participation or individual rationality constraint of the high type firm (the inefficient firm),

$$U\left(\overline{\beta}, \overline{\beta}, 1\right) = 0 \quad (5)$$

and (ii) incentive compatible constraint of the low type firm (the efficient firm),

$$U\left(\underline{\beta}, \underline{\beta}, 1\right) = \Phi(\overline{e}), \text{ with } \Phi(x) = \psi(x) - \psi(x - \Delta\beta) \quad (6)$$

The expression (5) explains the inefficient has no incentive to mimic an efficient firm because it would incur a loss. It will participate if the utility from participation is at least as good as not taking part in the project. The efficient firm, however, has the incentive to hide its private information as it could capture some positive rent (expression (6)). The other constraints can be satisfied at no additional social cost. Solving the problem, we have,

$$\psi'(\underline{e}_1 + 1) = 1 \quad (7)$$

$$\psi'(\overline{e}_1 + 1) = 1 - \frac{\lambda}{1+\lambda}\frac{\omega}{1-\omega}\, \Phi'(\overline{e}_1) \quad (8)$$

Compared to the full information case, the expressions (7) and (8) imply the low cost firm invests the optimal level of effort $\underline{e}_1 = e^*$ and captures some information rents, $U\left(\underline{\beta}, \underline{\beta}\,, 1\right) = \Phi(\overline{e}_1)$. The high cost firm under-invests and captures no information rent.

Appendix 2 (For the Reviewers)

We can show $\frac{\partial^2\theta}{\partial e_1 \partial t} < 0$ following Benabou and Tirole (2006):

The general result of conditional mean of random normal variable yields,

$$E\left(\theta_{e_1} \middle| e_1, t\right) = \overline{\theta}_{e_1} + \rho(e_1 - \overline{e_1})$$

$$E(\theta_t \mid e_1, t) = \overline{\theta}_t + \tau(e_1 - \overline{e_1})$$

where $\rho = \frac{cov\,(e_1, \theta_{e_1})}{var\,(e_1)}$ and $\tau = \frac{cov\,(e_1, \theta_t)}{var\,(e_1)} = \frac{1-\rho}{t}$. The marginal reputational value is,

$$\frac{\partial\theta}{\partial e_1} = \frac{\partial E\left(\theta_{e_1} \middle| e_1, t\right)}{\partial e_1} - \frac{\partial E(\theta_t \mid e_1, t)}{\partial e_1} = k(e_1, t).$$

As a firm's choice of e_1 reveals its marginal revenue, $\frac{\partial R}{\partial e_1}$, which equals $\frac{\partial \psi(.)}{\partial e_1}$, we can rewrite,

$$E\left(\theta_{e_1} \middle| e_1, t\right) = \overline{\theta_{e_1}} + \rho\left(\frac{\partial \psi(.)}{\partial e_1}\right)$$

$$E(\theta_t \mid e_1, t) = \overline{\theta}_t + \tau\left(\frac{\partial \psi(.)}{\partial e_1}\right)$$

where $\rho = \frac{{\sigma_{e_1}}^2 + T\sigma_{e_1 t}}{{\sigma_{e_1}}^2 + 2T\sigma_{e_1 t} + T^2 {\sigma_{e_1 t}}^2}$, and $\sigma_{e_1 t}$ is covariance of θ_{e_1} and θ_t.

Now the expression of reputational value is rewritten as,

$$\theta = \left[\bar{\theta}_{e_1} + \rho\left(\frac{\partial \psi(.)}{\partial e_1}\right)\right] - \left[\bar{\theta}_t + \tau\left(\frac{\partial \psi(.)}{\partial e_1}\right)\right]$$

and the marginal reputational value is now,

$$\frac{\partial\theta}{\partial e_1} = \frac{\partial^2 \psi(.)}{\partial {e_1}^2}(\rho - \tau) > 0$$

We see the marginal reputational value is positive, $\frac{\partial\theta}{\partial e_1} > 0$, since $\frac{\partial^2\psi(.)}{\partial e_1{}^2} > 0$ and $\rho < 1$.

Now differentiate $\frac{\partial\theta}{\partial e_1}$ $(= \frac{\partial^2\psi(.)}{\partial e_1{}^2}(\rho - \tau))$ again with respect to *t*, to capture how monetary transfers affect the marginal reputational value:

$$\frac{\partial^2\theta}{\partial e_1 \partial t} = \frac{\partial^2\psi(.)}{\partial e_1{}^2}\left(\frac{\partial\rho}{\partial t} - \frac{\partial\tau}{\partial t}\right)$$

Assuming θ_{e_1} and θ_t are not correlated, $\sigma_{e_{1t}} = 0$, we have,

$$\frac{\partial\rho}{\partial t} = \frac{-2t\omega^2}{(1+t^2\omega^2)^2} \text{ and } \frac{\partial\tau}{\partial t} = \frac{\omega^2 - t^2\omega^4}{(1+t^2\omega^2)^2}, \text{ where } \omega^2 = \frac{\sigma_t{}^2}{\sigma_{e_1}{}^2}.$$

$$\frac{\partial^2\theta}{\partial e_1 \partial t} < 0 \text{ if } \frac{-2t\omega^2}{(1+t^2\omega^2)^2} - \frac{\omega^2 - t^2\omega^4}{(1+t^2\omega^2)^2} < 0, \text{ which implies } |t| > \frac{1}{\omega}.$$