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This paper analyses environmental regulation under corruption and explores the possibility to attain the first best – 'no corruption and no pollution', with a special focus on implications of non-monetary incentives for firms to adapt green technology. It first demonstrates that (a) the effect of corruption control policies on the environment is not always positive, and (b) stricter environmental regulation intensifies the problem of corruption – implying a trade-off between environmental protection and corruption control. Next, it characterizes the 'minimum environmental regulation', involving least-subsidy to green technology seller and minimum-tax on brown production, which implements the first best outcome in the equilibrium. Interestingly, by allowing for firm heterogeneity in terms of preferences for social reputation, it demonstrates that introduction of non-monetary incentives in a corrupt environment increases the burden on the government's exchequer, unlike as in absence of corruption possibilities. These results are robust, regardless of (a) whether corrupt transaction is initiated by bribee or briber and (b) whether bribe rate is exogenous or endogenous.

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JEL Code: H23, Q52, D73, Q58, K42

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The Environment and Corruption: Monetary vs. Non-monetary Incentives and the First Best

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This paper analyses environmental regulation under corruption and explores the possibility to attain the first best – 'no corruption and no pollution', with a special focus on implications of non-monetary incentives for firms to adapt green technology. It first demonstrates that (a) the effect of corruption control policies on the environment is not always positive, and (b) stricter environmental regulation intensifies the problem of corruption – implying a trade-off between environmental protection and corruption control. Next, it characterizes the '*minimum environmental regulation*', involving least-subsidy to green technology seller and minimum-tax on brown production, which implements the first best outcome in the equilibrium. Interestingly, by allowing for firm heterogeneity in terms of preferences for social reputation, it demonstrates that introduction of non-monetary incentives in a corrupt environment increases the burden on the government's exchequer, unlike as in absence of corruption possibilities. These results are robust, regardless of (a) whether corrupt transaction is initiated by bribee or briber and (b) whether bribe rate is exogenous or endogenous.

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1. Introduction

In response to externalities, designing appropriate incentives, standards and regulations play a key role in improving welfare at the local and global level (see, e.g., Greenstone and Hanna 2014). Designing and implementing such policy instruments is challenging—perhaps due to the hard-to-mitigate asymmetric information about the true marginal costs and benefits (Coase 1960; Weitzman 1974; Millock et al 2002) and the potential rooms for corruption, i.e., abuse of public office for private gain by lobbying the government or bribing bureaucrats (Gordon and Hafer, 2015; Damania et al, 2004; Acemoglu and Verdier 2000).[1] It is well documented in the literature that higher levels of corruption make environmental laws less stringent or less effective, e.g., greater corruptibility reduces the stringency of energy policy by shifting the government's relative weight from welfare to the reduction of bribes (Fredriksson et al. 2004; Damania et al. 2004; Fredriksson and Svensson 2003); corruption level is the most important factor in explaining the variance in environmental policies in the enlarged EU (Pellegrini and Gerlagh 2006); and so on. In response, a costly monitoring system (e.g., Duflo, Hanna, and Ryan 2012; Stranlund et al 2009) can be prescribed to align the motive of the polluting firms and the interest of the society. Evidence exists that suggests that controlling the levels of corruption can limit the effect of the shadow economy on pollution (Biswas et al. 2012), i.e., the increased corruption in the formal sector expands the shadow economy which is accompanied by higher pollution levels (also see, Feng and Liao 2016).[2]

A recent development in behavioural economics suggests that feasible and less costly behavioural instruments, e.g., nudges (e.g., Fisman and Miguel 2007; Alcott 2011; Kuhfuss et al. 2016) can reduce the social costs of corruption, pollution, and public funds because firms with pro-environmental preferences may sacrifice economic rents to enjoy their, e.g., altruistic satisfaction, or to ensure a reputational gain (see, e.g., Banerjee et al. 2021; Banerjee and Shogren 2010, 2012; Ariely et al 2009; Bowels and Hwang 2008; Benabou and Tirole 2006). Evidence suggests that people and firms care about their social reputation and invest more efforts (privately costly) without any explicit incentives[3] or sometimes with non-

[1] Games of bribery are more common and more difficult to comprehend than games of lobbying. Elected officials can be removed from power while the bureaucrats are there to stay for longer. Thus, bribing the bureaucrat may be a longer-term solution than lobbying the incumbent political party (Damania, et al. 2004).

[2] Feng and Liao (2016) show that an increase in the number of anti-corruption cases tends to drive down SO_2 emissions in China.

[3] 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,

monetary incentives only, e.g., green certificates (Besley and Ghatak 2008, 2005; Kosfeld and Neckermann 2011; Ashraf et al. 2014).[4]

The willingness to gain such social reputation by firms to fulfil their exterior goals, e.g., higher profit/market share, may also trigger engagement in corrupt practices. In their experimental study, Charness et al. (2014) found that individuals invest in "status seeking activities" even when there is no expected monetary gain from such activity. The concern for relative position/recognition drives individuals/firms to pay not only for an artificial increase in their own relative performance but also for sabotaging others' output (also see Tran and Zeckhauser 2012). We do not know sufficiently, however, the effectiveness of the existing schemes of green certificates in a corrupt environment. This paper makes a modest attempt to fill this gap in the literature.

Herein we build a theoretical model to examine how heterogeneity in preferences for reputation, that one derives from the non- monetary award, affects the technology choices of firms and what implications do such preferences have on corruption and the environment. Our model presents a three-tier hierarchy: the government, the bureaucrat and the firms. The government has a pre-determined role of setting the fine rates and the taxes (and/or subsidies). The type of the firm (green or brown) is not known to the government and so it hires bureaucrats to supervise the actions of the firms and report it. However, given the information asymmetry, the bureaucrats can either report the true type or hide the true type of the firm in exchange for a bribe. There exists a possibility that the bureaucrat can collude with the firm and distort or hide relevant information to further his/her own interest (see Tirole 1986).[5] The bureaucrat may also be an extortionist as well, i.e., demand bribe from green firms to report their type truthfully.[6]

1962; Milgrom and Roberts, 1986a), (iii) increase their access to the capital markets (Beatty and Ritter, 1986), (iv) to attract green consumers to increase revenues/profits (Klein 1990; Drumwright 1994) and (v) sometimes just signal their key characteristics to maximize their social status (Spence, 1974).

[4] In 2017, the Maharashtra Pollution Control Board (MPCB) launched a new Star Rating Programme to control air pollution from industries. Under this scheme, rating of the industries happens based on the density of fine particulate pollution coming from their smokestacks. The best performing industries are given five stars while the worse are given one star and this information is made public. Similar schemes are present in different regions as well. To name a few, like the United States Toxic Release Inventory (TRI), the Program for Pollution Control Evaluation and Rating (PROPER) in Indonesia, AKOBEN in Ghana and the India Centre for Science and Environment Green Rating Programme.

[5] Tirole (1986) shows how going from a simple two-tier principal/agent structure to a more complex ones introduces the possibility of collusion.

[6] See, for example, Hindricks et al (1999), Andianova and Melissas (2009), Drugov (2010), and Hong and Yin (2020).

In addition to setting a tax on brown production, the government uses *status incentives* such as green certifications to incentivize firms to take up green production and thereby, comply with the regulation. This certification, being observable to everyone, acts as a signal of pro-social behaviour that fetches reputation and honour. We explore firms' preferences for social comparisons when assessing the value of what they receive. We consider the net reputation that one receives when the firm gets the certification. We define net reputation as the distance between the honour one gets and the stigma one avoids once the certification reward is made public.

We exploit the fact that the firms are heterogenous in types in terms of their preferences for reputation. Some value it and invest privately costly efforts as they do not want to be seen as socially irresponsible. These firms might invest in environmental protection to "buy" a green reputation. They may even reduce efforts given monetary incentive as taking money for doing the right thing may harm their reputation—i.e., the classic crowding out effect (Benabou and Tirole 2006; Bowels 2008; Ariely et al 2009; Banerjee and Shogren 2010, 2012). Other firms, however, do not have strong reputational preferences—they are either purely altruistic or entirely money-oriented.

We first examine whether by imposing only a tax on brown production will ensure a cleaner as well a corruption free environment, in absence of any non-monetary incentives. We find that the answer is affirmative unless the extra cost that is associated with the green technology is sufficiently high. Also, we demonstrate that in case the extra cost of green technology is sufficiently high, a combination of a tax on brown production and a subsidy to the green technology seller can solve both problems—corruption and pollution. This result lend support to arguments of Tinbergen (1952) and Arrow (1958): it is necessary to have at least as many policy instruments as the number of policy targets to achieve the socially desirable outcome, except in special cases. Moreover, we explore the effectiveness of environmental policies in solving both problems together contingent on who initiates the corrupt transaction. We find that in cases where bribe taker initiates the transaction, the tax instrument is less effective in curbing both pollution and corruption than it is in the case where the bribe-giver initiates the transaction. Interestingly, these results go through even in the presence of non-monetary incentives such as a green certification award and firm heterogeneity in terms of their concern for reputation.

Our work is in similar line to Mookherjee and Png. (1995) study which talks about instruments for controlling corruption to improve environmental quality by considering bribery in the context of environmental audit. They devise an optimal compensation policy for a corrupt official who monitors pollution levels of a factory and find that an increase in penalty for corruption might increase the level of pollution. In our model of bribery, the government can reduce the incidence of bribing either by increasing the fine rates on engaging in corrupt practices or by increasing the efficiency of the audit mechanism that catches the corrupt parties. We find that increasing fine rates does not have any effect on the firms' decision to choose an environmentally friendly technology. However, improving the efficiency of its audit mechanism reduces corruption as well as incentivizes more firms to go for a greener production technology. We show how pollution control policies can have an impact on the corruption levels. We find that the answer to this depends again on the extra cost associated with cleaner production technologies.

We make the following contributions to the literature on behaviour-based incentive designing to improve efficiency. Existing literature suggests that a monetary incentive mechanism coupled with non-monetary incentive is cost-effective and helps to attain higher level of efficiency in the presence of asymmetric information. In contrast, we argue and show that reputation-seeking firms will go that far to bribe the officials to buy reputation which in turn will add a new layer of market inefficiency. We demonstrate that pure monetary incentives can do a better job in correcting market failure in a corrupt society. This result holds true (a) regardless of who initiates corrupt transactions – briber or bribee, and (b) whether bribe rate is considered to be exogenously given or is endogenously determined through bargaining.

Further, existing studies on market failure due to (a) negative environmental externalities created by firm and (b) imperfect competition seem to suggests that there must be at least two policy instruments to tackle the two problems. [7] In contrast, considering the first best as no corruption and green production by each firm, we demonstrate that the first best equilibrium outcome can be achieved by imposing only a tax on brown production alone, unless the extra cost of green technology is sufficiently large. This result holds true regardless of (a) the type of possible corrupt transactions - briber initiated or bribee initiated, and (b) whether there is

[7] For example, by considering alternative scenarios in polluting oligopoly, Cato (2010) and Pal and Saha (2014) show that at least two policy instruments are necessary to address the problems due to imperfect competition and negative environmental externalities created by firms. However, unlike the present study, they sidestep the issue of corruption, do not allow for reputation concerns of firms, and consider only monetary instruments.

any non-monetary incentive or not. The first best outcome can also be achieved through an appropriately designed green-technology-subsidy and brown-production-tax. This is true regardless of (a) who initiates corrupt transactions - briber or bribee, (b) whether there is any possibility for firms to gain (attract) social reputation (stigma) by being marked as green (brown) or not, and (c) the extra cost of green technology.

The rest of the paper is organized as follows. The following section presents the benchmark model, wherein firms are homogeneous, there is no non-monetary incentive, corrupt transactions are initiated by firms and bribe rate is exogenously determined. Section 3 examines the roles of non-monetary incentive in the form of green certification award when firms are heterogeneous in terms of their concerns for reputation. Section 4 analyses robustness of our results in an alternative scenario in which government officials initiate corrupt transactions. Section 5 discusses implications of endogenizes the bribe rate. Section 6 concludes. All proofs are relegated to Appendix.

2. The Benchmark Model: No Non-Monetary incentives

Consider an economy with n risk neutral firms. Each firm can choose one of the two technologies, 'green' or 'brown' from technology sellers. Both technologies generate the same level of output equal to y (> 0). However, green technology emits less pollutants than the brown technology: $0 \leq e_g < e_b$; where e_g and e_b denote emissions from production by using green and brown technologies, respectively. A green firm (which uses green technology) contributes to creation of a public good (better environmental quality) by reducing emission by the amount $e_g - e_b$.

We assume that the brown technology is cheaper than the green one. Without any loss of generality, we normalize the cost of brown technology to be equal to zero and the cost of green technology to be c, where, $0 < c < y$. In other words, 'c' can be interpreted as the extra cost of production through green technology.

Let v_T (> 0) be a firm's intrinsic valuation for money and $v_E(> 0)$ be their intrinsic valuation for public good creation. We assume, for now, that the firms are homogenous. Both v_E and v_T are positive and same for all firms. We also assume that $v_T\, c - v_E(e_b - e_g)$ is always positive. This implies that the effective cost of green production, that is, monetary cost minus the intrinsic gain, is always positive.

There is a benevolent social planner who seeks to influence firms' technology choices in favour of the green technology by imposing a tax t (≥ 0) on brown firms, i.e. on firms which use brown technology (henceforth, *brown tax*). The planner may also offer a per-unit subsidy s $(0 \leq s \leq c)$ to the seller of the green technology (henceforth, *green technology subsidy*), if necessary, which reduces the price of the green technology from c to $c - s$.

It is assumed to be costly to observe each firm's level of emission. To this effect, the planner hires officials at a fixed wage w, to collect the information necessary to identify each firm's type – green or brown. However, these officials may be self-interested and engage in corruption. The bureaucratic official may be corrupt or honest based on his intrinsic motives, which is his private information. We assume that with probability λ $(0 < \lambda < 1)$ the official is honest and with probability 1- λ the official is corrupt.

An honest official carries out the job diligently and reports firms' types truthfully. However, the corrupt official reports a firm as brown, if no bribe is offered to him; otherwise, if bribe is offered to him, he reports a firm as green. We first consider that a corrupt official does not ask for a bribe upfront. Owners of firms, who are uncertain about the type of the official, need to decide whether to offer a bribe or not. That is, we first consider the scenario in which bribers initiate corrupt transactions a la Bayer (2005).

Following Amir and Burr (2015), we assume that if a firm decides to bribe the official, the firm offers a fixed amount of bribe b (> 0) regardless of its type – green or brown. The fixed amount of bribe offered is equal to the corrupt official's reservation price which is common knowledge. Note that different types of firms offer bribes for different reasons. A green firm bribes because of the fear of being reported as brown, while the brown firm bribes to evade the brown tax. Each type of firms faces the risk of bribing an honest official. If a firm offers bribe to an honest official, that firm is fined according to a given fine rate $f^R(\geq 0)$, regardless of whether the firm is green or brown.

The planner conducts random audits to get hold of the parties who indulge in corruption. With probability ρ $(0 < \rho < 1)$, corrupt officials get off safely, while with probability 1- ρ they are caught. Once caught, the official loses all his income. We assume that officials are risk neutral and, given w, b and ρ, a dishonest official's expected payoff from engaging in corrupt activity is greater than the payoff from behaving as an honest official. Whereas an honest official suffers from guilt in case he engages in corrupt practices and such guilt is sufficiently high such that his expected payoff from being honest is always greater than payoff from being corrupt. In other words, honest officials are not corruptible. Green firms caught bribing are fined according to given rate $f^G (\geq 0)$.[8] Brown firms caught bribing are fined too at the same rate f^G and in addition they have to pay the brown tax t.[9]

The government's objective is to minimize the environmental damage and reduce the corruption level in the economy by designing an appropriate tax-subsidy scheme, which involves (a) the lowest possible government expenditure on green technology subsidy and (b) given the green technology subsidy, the corresponding brown tax is at its minimum necessary level (henceforth, '*lowest-subsidy minimum-tax*').

Let us first analyze the implications of the brown tax in absence of any green technology subsidy (i.e., when $s = 0$). Suppose that the stages of the game are as follows.

Stage 1: The social planner/government decides the brown tax t (≥ 0) to be imposed on each brown firm.

Stage 2: The firms decide which technology to use for production – green or brown.

Stage 3: An official inspects the firm and discovers whether it has chosen the green or the brown technology. Upon this inspection by the official, the firms decide whether to offer a bribe or not. Simplistic

If the official is corrupt and if a bribe is offered, the firm is reported as green, otherwise it is reported as brown. If the official is honest and a bribe is offered, the firm is fined.

Stage 4: After the official submits the report, the planner conducts random audits. If a corrupt official is caught, both the official and the firms who paid the bribe are fined.

We solve the game via backward induction. Note that the last stage (i.e., Stage 4) is trivial. In Stage 3, each firm compares its payoff with and without bribing and accordingly decides whether to bribe the official or not. Let $\pi_{B,B}$ denote expected payoff of a brown firm when it

[8] $f^G \gtreqless f^R$. We do not impose any a priori restriction on relative magnitudes of f^G and f^R.

[9] We do not impose any limited liability constraint on firms. Thus, the only departure from a frictionless world is the externality and the noisy detection technology. While such a scenario may be quite simplistic, it helps to identify the problem of pollution control in a corrupt society in a clearer manner.

bribes, $\pi_{B,NB}$ denote expected payoff of a brown firm when it does not bribe, $\pi_{G,B}$ denote expected payoff of a green firm when it bribes, and $\pi_{G,NB}$ denote expected payoff of a green firm when it does not bribe. Then, we have the following.

$$\pi_{B,B} = (v_T y - v_E e_b - v_T t - v_T f^R)\lambda + (v_T y - v_E e_b - v_T b)(1-\lambda)\rho \\ + (v_T y - v_E e_b - v_T t - v_T b - v_T f^G)(1-\lambda)(1-\rho), \quad (1)$$

$$\pi_{B,NB} = v_T y - v_E e_b - v_T t, \quad (2)$$

$$\pi_{G,B} = \left(v_T y - v_E e_g - v_T c - v_T f^R\right)\lambda + \left(v_T y - v_E e_g - v_T c - v_T b\right)(1-\lambda)\rho \\ + \left(v_T y - v_E e_g - v_T c - v_T b - v_T f^G\right)(1-\lambda)(1-\rho), \quad (3)$$

and

$$\pi_{G,NB} = \left(v_T y - v_E e_g - v_T c\right)\lambda + \left(v_T y - v_E e_g - v_T c - v_T t\right)(1-\lambda)\rho \\ + \left(v_T y - v_E e_g - v_T c\right)(1-\lambda)(1-\rho). \quad (4)$$

We consider that a firm will choose to offer the bribe, if its expected payoff from bribing is strictly higher than that from not bribing. Therefore, incentive compatibility conditions of brown and green firms to bribe are as in (5) and (6), respectively.

Incentive Compatibility Conditions to Bribe

Brown Firm: $\pi_{B,B} > \pi_{B,NB} \iff t > \frac{b(1-\lambda)+f^R\lambda + f^G(1-\lambda)(1-\rho)}{\rho(1-\lambda)} = \underline{t^C}$ (5)

Green Firm: $\pi_{G,B} > \pi_{G,NB} \iff t > \frac{b(1-\lambda)+f^R\lambda + f^G(1-\lambda)(1-\rho)}{\rho(1-\lambda)} = \underline{t^C}$ (6)

From firms' incentive compatibility conditions for bribing, i.e. from (5) and (6), it is evident that a firm's Stage 3 equilibrium strategy, regardless of its type – green or brown, is "bribe the official", if $t > \underline{t^C}$; otherwise, if $t \leq \underline{t^C}$, "do not offer bribe". That is, if the brown tax is greater than (less than or equal to) the critical level $\underline{t^C}$, each firm (no firm) bribes, regardless of whether the firm is green or brown, in the equilibrium in Stage 3 of the game.

Next, in Stage 2, firms decide which technology to choose – green or brown. While doing so, firms correctly anticipate that each firm (no firm) will offer bribe in Stage 3, if $t > \underline{t^C}$ ($t \leq \underline{t^C}$). Now, for any given brown tax, a firm chooses the green technology, if its expected payoff from being green is no less than that from being brown. Thus, a firm's incentive compatibility condition to choose the green technology can be written as follows.

Incentive Compatibility Condition to Choose Green Technology

Bribe: $\pi_{G,B} \geq \pi_{B,B} \iff \mathrm{t} \geq \frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{v_T(1-\rho(1-\lambda))} = \underline{t^G}\,(c)$ (7)

No Bribe: $\pi_{G,NB} \geq \pi_{B,NB} \iff \mathrm{t} \geq \frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{v_T(1-\rho(1-\lambda))} = \underline{t^G}(c)$ (8)

The first inequality of (7) states that, if $t > \underline{t^C}$, i.e. if it is optimal for a firm to bribe following its technology choice, the firm's expected payoff from choosing the green technology is at least as much as that from choosing the brown technology. Similarly, the first inequality of (8) states that, if $t \leq \underline{t^C}$, i.e. if it is optimal for a firm not to offer any bribe following its technology choice, the firm's expected payoff from choosing the green technology is at least as much as that from choosing the brown technology. It turns out that a firm's technology choice does not depend on whether, subsequent to technology choice, it is optimal for the firm to bribe or not to bribe. If $\mathrm{t} \geq \underline{t^G}(c)$, i.e. if the brown tax is greater than or equal to the critical level $\underline{t^G}(c)$, it is incentive compatible for all firms to choose to be green. Otherwise, if the brown tax is less than that critical level ($\mathrm{t} < \underline{t^G}(c)$), all firms will choose to be brown.

Since the firms are homogenous in all aspects and face identical situations (bribe rate, fine rates, intrinsic valuation and monetary valuations are all considered to be same for both types of firms), both (a) the condition for bribing and (b) the condition for technology choice are same for each firm. Now, it is easy to check the following.

$$\left.\begin{array}{l} t > \underline{t^C} \Leftrightarrow \rho > \dfrac{b(1-\lambda) + f^R\lambda + f^G(1-\lambda)}{(1-\lambda)(v_T t + f^G)} = \underline{\rho^C} \quad \text{and} \\ t \geq \underline{t^G}(c) \;\Leftrightarrow \rho \leq \left[1 - \dfrac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{t v_T}\right] \dfrac{1}{(1-\lambda)} = \underline{\rho^G}\,. \end{array}\right\} \qquad (9)$$

Therefore, (a) for $t > \underline{t^C}$ to be satisfied we must have $\rho > \underline{\rho^C}$, and (b) for $t \geq \underline{t^G}$ to be satisfied we must have $\rho \leq \underline{\rho^G}$.

From comparative statics analysis of critical levels of brown tax, $\underline{t^C}$ and $\underline{t^G}(c)$, and of critical levels of inefficiency in audit mechanism, $\underline{\rho^C}$ and $\underline{\rho^G}$, we obtain the following. (See Appendix for details).

First, given environmental regulations, stricter corruption control by increasing the probability of corruption detection $(1-\rho)$, *reduces corruption as well as enhances firms' incentive to produce green. However, higher penalties imposed on bribe giver when detected,* *reduces the incentive to bribe but does not affect firms' incentive to produce green.* That is, keeping all things that incentivise a firm to go green constant, an increase in the audit efficiency gives an added incentive to the firm to go green. This is because it would provide a direct safety to the firm against extortion by corrupt officials, wherein corrupt officials can hide the true type of the firm and impose the brown tax if not given a bribe. A brown tax in addition to cost of production increases the total effective cost of the green firms in the corrupt environment. Thus, any policy instrument that provides a buffer against corrupt officials would incentivise the firm to go green. However, an increase in the fine rates reduces the incentives of the firms to bribe and does not have any direct impact of their decision to go green. Nonetheless, we note here that it is often quite difficult and costly for the government to enhance the probability of corruption detection in short-to-medium-run periods, which is particularly the case in societies plagued with corruption.

Second, given the corruption control mechanism, i.e., given the efficiency of the audit mechanism of the government and rates of fines, a higher brown tax makes green production more attractive. However, it also makes bribing more attractive. Clearly, the government faces a trade-off between environmental protection and corruption reduction while intervening through the policy instrument 'brown tax'. The question then arises that how large should be the penalty for brown production.

2.1 The First Best Equilibrium Outcome

It is often argued that efficiency of audit system crucially depends on individuals' behavioural traits, social norms and cultural factors, which can change only gradually and, thus, it is difficult for the social planner to enhance audit efficiency at least in the short run. Further, penalties for corrupt behaviour are often left for the judiciary to decide. Therefore, it seems reasonable to consider that available policy instruments that aim to control corruption directly is rather limited and costly for the social planner. On the other hand, the social planner enjoys greater degrees of freedom to design tax-subsidy schemes. Given this backdrop, it seems to be important to examine the feasibility to achieve the first best equilibrium outcome (see Definition 1) through tax-subsidy scheme, given the institutional and legal framework that determine audit efficiency and penalties for corrupt behaviour.

Definition 1 (The First Best)*: An equilibrium outcome is the first best equilibrium outcome, if in that equilibrium no firm bribes and all firms choose the green technology.*

First note that $\underline{t^C} \geq (<)\ \underline{t^G}(c) \iff c \leq (>)\ \underline{c}$, where

$$\underline{c} = \frac{\left(1-\rho(1-\lambda)\right)}{\rho(1-\lambda)}\ [b(1-\lambda) + f^R\lambda\ + f^G(1-\lambda)] + \frac{v_E}{v_T}\left(e_b - e_g\right) > 0 \qquad (10)$$

Thus, if $c \leq\ \underline{c}$, there exists a $t \in \left[\underline{t^G}(c), \underline{t^C}\right]$. Further note that, since in this case $\underline{t^C} \geq \underline{t^G}(c)$ holds true, any $t \in \left[\underline{t^G}(c)\ , \underline{t^C}\right]$ would guarantee that each firm produces green and none bribes, considering that in the case of indifference, firms choose the action which is better for the society. Thus, $t = \underline{t^G}(c)$ is the lowest possible brown tax which guarantees that each firm will choose the most desirable action from the social planner's point of view, i.e., produce green and do not offer bribe.

If $c > \underline{c}$, we have $\underline{t^C} < \underline{t^G}(c)$, implying that there does not exist any brown tax t such that both $t \leq \underline{t^C}$ and $t \geq \underline{t^G}(c)$ are satisfied. In this case we have a complete trade-off between environment and corruption. To induce firms to produce via green technology $t \geq \underline{t^G}(c)$ must hold. But then firms' incentive compatibility constraint for not offering any bribe is violated and then each firm ends up bribing. If $t \leq \underline{t^C}$, then no firm bribes. In such a scenario, given the extra cost of green production (c) and corruption detection probability (ρ), there does not exist any brown tax (t) which induces firms to produce green as well as not to engage in corrupt practices. Therefore, the following proposition is immediate.

Proposition 1: (a) *When the extra cost of green technology is less than or equal to a critical level ($\underline{c}$), the government can implement the first best equilibrium outcome, which ensures that all firms choose to be green and no firm bribes, by setting the brown tax equal to* $t^*=\underline{t^G}(c)$ *and there does not exist any brown tax* $t < \underline{t^G}(c)$ *that alone implements the first best outcome; where* $\underline{c}$ *and* $\underline{t^G}(c)$ *are as in (10) and (8), respectively.*

(b) *When the extra cost of green technology is greater than a critical level ($\underline{c}$), the government cannot implement the first best equilibrium outcome using a tax policy alone.*

Since a brown tax alone does not lead to the first best outcome in the equilibrium in case the extra cost of green production is greater than $\underline{c}$ (Proposition 1b), it is natural to ask the following. Does there exist any tax-subsidy scheme such that all firms choose the green technology and none bribes in the equilibrium in case $c > \underline{c}$?

Note that $\frac{\partial \underline{t^G}}{\partial c} > 0$ and $\frac{\partial \underline{t^C}}{\partial c} = 0$. Therefore, we have $\frac{\partial(\underline{t^G} - \underline{t^C})}{\partial c} > 0$. Now, suppose that there is a green technology subsidy s, which reduces the price of green technology and that in turn reduces the extra cost of green production from c to $\underline{c}$. It is easy to check that, if $s = s^* = c - \underline{c}$, then $\underline{t^G}\left(\underline{c}\right) = \underline{t^C}$. It follows that, the first best outcome, i.e., each firm produces green and no one bribes, in the equilibrium can be achieved by a combination of penalty for brown production and a green technology subsidy that reduces the price of green technology. The optimal, i.e. the 'lowest-subsidy minimum-tax', policy calls for the brown tax $t^* = \underline{t^C}$ and the green technology subsidy $s^* = c - \underline{c}$.

Proposition 2: *When the extra cost of green production is greater than $\underline{c}$, the brown tax $t^*=\underline{t^C} = \underline{t^G}\left(\underline{c}\right)$ along with the green technology subsidy $s^*=c - \underline{c}$ guarantees the first best equilibrium outcome, where $\underline{t^G}\left(\underline{c}\right) = \frac{\underline{c} - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))}$ and $\underline{c}$ is given by (10). $(t^* = \underline{t^C} = \underline{t^G}\left(\underline{c}\right),\ s^* = c - \underline{c})$ is the 'lowest-subsidy minimum-tax' policy.*

Proof: Follows directly from the above discussions.

Remarks: Note that the green technology subsidy is given to the green technology seller and not to the firms producing via green technology. If the subsidy is offered to firms directly, then brown firms will have an additional incentive to bribe the official to hide their true identity, while the green firm will not get the subsidy in case the official is corrupt, and no bribe is offered. Therefore, firms' incentive compatibility constraints to offer bribe will be distorted. Similarly, firms' incentive compatibility constraints to choose the green technology will also be distorted. It can be checked that the two critical values of the brown tax, $\underline{t^C}$ and $\underline{t^G}$, will be changed to $\underline{t^C}(s) = \underline{t^C} - s$ and $\underline{t^G}(s) = \underline{t^G} - s$, respectively, if subsidy s is offered directly to firms. Clearly, $c > \underline{c} \Leftrightarrow \underline{t^C}(s) < \underline{t^G}(s)$, which implies that the first best equilibrium outcome cannot be ensured by any such tax-subsidy scheme, unlike as in case the subsidy is offered to the technology seller.

3. Non-Monetary Incentives and Firms' Concern for Social Reputation

Suppose that the government makes use of non-monetary incentives, such as a green certification award to incentivize firms to go for green production, along with a brown tax and a green technology subsidy. For firms, such a status rewards brings with its reputation and social respect. The one who acquires it gets honor and respect in the society and the one who fails to get his hands on the certification is stigmatized by the society. In this section we analyze implications of non-monetary incentives offered to firms and their reputational concerns. Firms are considered to be heterogeneous with respect to their valuation for reputation, which is denoted by $\theta \in \{0,1\}$. Assume that $\beta \in (0,1)$ proportion of firms care about their reputation ($\theta = 1$), while $1-\beta$ proportion of firms do not care about reputation ($\theta = 0$).

Suppose that $x \in [0, n]$ number of firms out of total $n(> 0)$ firms received the green certification and are perceived to be green by fellow members of the society. Remaining $n - x$ firms did not get the green certification and, thus, are perceived to be brown. Each of these x green certified firms gets the honor, while other $n - x$ firms are stigmatized, in the society. Then, reputational payoff of a green certified firm, $R(\cdot)$, is as follows.

$$R(x) = [H(x) - S(n-x)]\,,$$

where $H(x)$ denotes the honor of a green certified firm and $S(n-x)$ denotes the stigma of a brown certified firm. We consider that

(a) $H(x) > 0$ and $H'(\cdot) < 0\ \forall\, x \in [0, n]$, and

(b) $S(n-x) < 0$ and $\frac{\partial S(n-x)}{\partial x} = \frac{\partial S(n-x)}{\partial (n-x)}(-1) = -S'(\cdot) > 0\ \forall\, x \in [0, n]$.

It implies that when more firms are awarded the green certification, the honour value of green certification drops and at the same time the stigma of being a brown firm increases (e.g., see Benabou and Tirole 2006, p. 1665-1667). The net reputational payoff of green certifications, $R(x)$, is the distance between the gain in honor value and the stigma avoided. It follows that $R(x) > 0\ \forall\, x \in [0, n]$ [10].

[10] We assume that the common man cannot assess the probabilities of corrupt officials and the probability of the efficiency of the audit mechanism, i.e., they are naive and infer about the greenness of firms only on the basis of the certification, which remains their only source of information. In such a scenario, the consideration of green certification having full credibility seems to be valid. Alternatively, one may consider a scenario in which the common man, who confers honour and stigma on firms, may be able to use the information regarding corrupt practices between firms and officials in order to assess the credibility of the green certification. Then given the probabilities of an official to be corrupt and the probability of penalizing them once caught, there are different probabilities with which honour and stigma is conferred upon firms. For example, when the firms get a green certification, they get honour with probability $\lambda + (1-\lambda)(1-\rho)$ and stigma with probability $(1-\lambda)\,\rho$. However, when the firms do not get the certification and are termed as brown they still get honor with probability $(1-\lambda)\,\rho$ and stigma with $\lambda + (1-\lambda)(1-\rho)$. This is because the public is aware that with probability $(1-\lambda)\,\rho$ they were falsely denied certification by a corrupt official who did not got caught. Then the number of perceived true green firms, $\widetilde{x}$, say, will be different than the number of green certifications given out, which is given by x.

Now, note that $\frac{\partial R(x)}{\partial x} = \frac{\partial H(x)}{\partial x} - \frac{\partial S(n-x)}{\partial(n-x)}\left(\frac{\partial(n-x)}{\partial x}\right) = \frac{\partial H(x)}{\partial x} + \frac{\partial S(n-x)}{\partial(n-x)}$. Clearly, $R' < 0 \Leftrightarrow -H' > S'$. It implies that net reputational value of green certification falls as a greater number of firms get green certification if the decrease in honour is more than the increase in stigma. On the other hand, if $R' > 0$, it implies that the net reputation increases as a greater number of firms get green certification if the decrease in honour is less than the increase in stigma.

Examples of honour and stigma functions that satisfy the set of desired properties are as follows. $H(x) = T - \psi x$ and $S(n-x) = \alpha(n-x) - K$, where $T, \psi, \alpha, K > 0, T > \psi n$ and $K > \alpha n$. Clearly, if $\psi < \alpha$, $R' > 0$. Otherwise, if $\psi > \alpha$, $R' < 0$.

We consider the scenario in which fines imposed on firms for bribing are *not observable* by citizens.[11] Thus, a firm's reputational payoff does not get affected if it is caught bribing or not. The only thing that matters are (a) whether the firms receive green certification or not and (b) how many firms receive green certificates. Stages of the game and all other things remain the same as in Section 2.

Now, in the third stage, firms' decision of whether to bribe the official, who may be honest or corrupt with high or low probability of getting caught, depends on their relative payoffs. Let $\pi^R_{G,B}(\theta)$, $\pi^R_{G,NB}(\theta)$, $\pi^R_{B,B}(\theta)$ and $\pi^R_{B,NB}(\theta)$, respectively, denote expected payoffs of a (i) green firm in case it bribes, (ii) green firm when it does not bribe, (iii) brown firm in case it bribes and (iv) brown firm in case it does not bribe, given the firm's valuation for social reputation θ. We can express these expected payoffs as follows.

$$\tilde{x} = [\lambda + (1-\lambda)(1-\rho)]x + [(1-\lambda)\,\rho\,](n-x)$$

In this case the net reputational payoff will be given as follows. $R(\tilde{x}) = \gamma\big[[\lambda + (1-\lambda)(1-\rho)]H(\tilde{x}) - (1-\lambda)\,\rho\,S(n-\tilde{x})\big]$

We are interested in the scenario where the certification has some credibility. For this we need that once the firms get the certification, the probability of getting honor is strictly higher than the probability of getting stigma, that is, $\lambda + (1-\lambda)(1-\rho) > (1-\lambda)\,\rho$. This implies that $(1-\lambda)\,\rho < 0.5$. It means that if corruption is not to widespread and the audit mechanism is efficient to the extent that the corrupt officials get caught with higher probability, then the certification holds credibility and the qualitative results holds true. However, if corruption is too rampant and corrupt officials get off easily, then the certification will lose its credibility. Hence, when the common man is not naive, we need the additional assumption that $(1-\lambda)\,\rho < 0.5$.

[11] Note that, while information on firms convicted for bribing government officials is generally available from courts' records, such information often does not attract media attention, except in high profile cases. As a result, whether a firm has been fined for bribing or not remains largely unnoticed by others. In contrast, firms often take proactive action to publicise any award, such as green certification, star rating, etc, that they have received.

$$\pi^{R}_{G,B}(\theta) = \left[\mathrm{v_T\,y - v_E\,e_g} + \theta\{\mathrm{H(E(x)+1) - S(E(n-x)-1)}\} - v_T\mathrm{c} - v_T f^R\right]\lambda + \left[\mathrm{v_T\,y - v_E\,e_g} + \theta\{\mathrm{H(E(x)+1) - S(E(n-x)-1)}\} - v_T\mathrm{c} - v_T\mathrm{b}\right](1-\lambda)\rho + \left[\mathrm{v_T\,y - v_E\,e_g} + \theta\{\mathrm{H(E(x)+1) - S(E(n-x)-1)}\} - v_T\mathrm{c} - v_T\mathrm{b} - v_T f^G\right](1-\lambda)(1-\rho) \quad (11)$$

$$\pi^{R}_{G,NB}(\theta) = \left[\mathrm{v_T\,y - v_E\,e_g} + \theta\{\mathrm{H(E(x)+1) - S(E(n-x)-1)}\} - v_T\mathrm{c}\right]\lambda + \left[\mathrm{v_T\,y - v_E\,e_g} - \mathrm{v_T\,t} - \theta\{\mathrm{H(E(x)) - S(E(n-x))}\} - v_T\mathrm{c}\right](1-\lambda)\rho + \left[\mathrm{v_T\,y - v_E\,e_g} + \theta\{\mathrm{H(E(x)+1) - S(E(n-x)-1)}\} - v_T\mathrm{c}\right](1-\lambda)(1-\rho) \quad (12)$$

$$\pi^{R}_{B,B}(\theta) = \left[\mathrm{v_T\,y - v_E\,e_b - v_T\,t} - \theta\{\mathrm{H(E(x)) - S(E(n-x))}\} - f^R\right]\lambda + \left[\mathrm{v_T\,y - v_E\,e_b} + \theta\{\mathrm{H(E(x)+1) - S(E(n-x)-1)}\} - \mathrm{b}\right](1-\lambda)\rho + \left[\mathrm{v_T\,y - v_E\,e_b - v_T\,t} - \theta\{\mathrm{H(E(x)) - S(E(n-x))}\} - \mathrm{b} - f^G\right](1-\lambda)(1-\rho) \quad (13)$$

$$\pi^{R}_{B,NB}(\theta) = \mathrm{v_T\,y - v_E\,e_b - v_T\,t} - \theta\{\mathrm{H(E(x)) - S(E(n-x))}\} \quad (14)$$

In right hand sides of equations (11)-(14), x represents how many other firms besides oneself have received the reward of green certification out of the total n firms in the market. Firms are uncertain about the actual value of x and hence form expectations. If the green firm bribes, though it would face fines when caught by the honest official or in the government's audit, it will still get the certification of being green. Thus, the net reputational payoff gets added in the payoff with bribing (equation (11)), as it provides extra utility, which is valued at $\theta \in \{0,1\}$. However, if the green firm does not bribe, in the event of meeting a corrupt official he is reported as brown and does not get the green certification, though it truly deserves that. As a result, it will be treated as a brown firm by citizens and thus, will be stigmatized, which results in a negative reputational payoff (the 2nd term in the right-hand side of equation (12)). On the other hand, if the brown firm bribes, he would acquire the certification only if he meets the corrupt official who does not get caught in the government's audit process. Thus, the net reputational payoff gets added in the brown firm's payoff with bribing (equation 13) only with probability$(1-\lambda)\rho$. However, if the brown firm does not bribe, in no circumstance it will get access to the certification and hence receives a disutility. Subtracting the net reputational payoff from the total payoff shows this (equation (14)).

Note that $1-\beta$ proportion of firms do not care about reputation, i.e. $\theta = 0$. Therefore for these $1-\beta$ proportion of firms we have $\pi^{R}_{B,B}(\theta = 0) = \pi_{B,B}$, $\pi^{R}_{B,NB}(\theta = 0) = \pi_{B,NB}$,

$\pi^R_{G,B}(\theta = 0) = \pi_{G,B}$ and $\pi^R_{G,NB}(\theta = 0) = \pi_{G,NB}$, which are same as in equations (1), (2), (3) and (4), respectively, in Section 2.

On the other hand, for β proportion of firms, who care about the reputation, $\theta = 1$. Let $\pi^R_{B,B}(\theta = 1) = \pi^R_{B,B}$, $\pi^R_{B,NB}(\theta = 1) = \pi^R_{B,NB}$, $\pi^R_{G,B}(\theta = 1) = \pi^R_{G,B}$ and $\pi^R_{G,NB}(\theta = 1) = \pi^R_{B,NB}$, which we get from equations (13), (14), (11) and (12), respectively, by substituting $\theta = 1$.

Now, given the technology choice, in Stage 3 the incentive compatibility condition (IC) of a firm, who cares about social reputation ($\theta = 1$), to bribe is as follows.

Reputation concerned Brown Firm's IC to Bribe:

$$\pi^R_{B,B} > \pi^R_{B,NB} \Leftrightarrow t > \underline{t^C} - \frac{(P+Q)}{\mathrm{v_T}} = \underline{t^{RC}}, \tag{15}$$

Reputation Concerned Green Firm's IC to Bribe:

$$\pi^R_{G,B} > \pi^R_{G,NB} \Leftrightarrow t > \underline{t^C} - \frac{(P+Q)}{\mathrm{v_T}} = \underline{t^{RC}}, \tag{16}$$

where $\underline{t^C} = \frac{b(1-\lambda)+f^R\lambda+f^G(1-\lambda)(1-\rho)}{\rho(1-\lambda)}$ as in (5) and (6), $P = H\big(E(x)\big) - S\big(E(n-x)\big) > 0$, and $Q = H(E(x)+1) - S\big(E(n-x-1)\big) > 0$. Clearly, $\underline{t^C} > \underline{t^{RC}}$.

On the other hand, if a firm does not care about social reputation ($\theta = 0$), his incentive compatibility condition to bribe in Stage 3, given his technology choice, remains the same as in Section 2 (conditions (5) and (6)).

From conditions (5), (6), (15) and (16), it follows that a firm's incentive compatibility condition to bribe does not depend on his technology choice, green or brown, regardless of whether that firm cares about social reputation or not. However, in the presence of non-monetary incentives, a firm's concern for social reputation provides an additional incentive to bribe. A brown tax t, which is strictly higher than $\underline{t^C}$, incentivizes the firms to bribe, irrespective of whether they are producing using green technology or brown technology and whether they care or do not care about reputation. However, it is optimal for a reputation concerned firm to bribe even if brown tax t is less than $\underline{t^C}$, unlike as that of a non-reputation concerned firm. To illustrate the reason behind $\underline{t^C} > \underline{t^{RC}}$ note that, in the presence of non-monetary incentives, a reputation concerned firm bribes, not only to avoid the brown tax, but also to acquire the certification award that brings reputation. Thus, reputation concerned firms bribe even when the brown tax is less than the critical level of brown tax that induces non-reputation concerned firms to bribe. In other words, in the equilibrium, β proportion of firms that care about social reputation ($\theta = 1$) bribe for a larger range of brown tax compared to $1 - \beta$ proportion of firms that do not care about social reputation ($\theta = 0$).

Now, given the brown tax, if a firm anticipates that it is optimal to bribe (not to bribe) in Stage 3, that firm will go for green production if the payoff of green firm from bribing (not bribing) is at least as much as the payoff of brown firm from bribing (not bribing). For $1 - \beta$ proportion of firms with $\theta = 0$, the incentive compatibility constraints for green production remain the same as in Section 2 (condition (7) in case the firm anticipates bribing will be incentive compatible in Stage 3; otherwise, condition (8)). On the other hand, for β proportion who care about reputation ($\theta = 1$), the incentive compatibility conditions to choose the green technology can be written as follows.

Reputation concerned Firm's IC to Choose Green Technology:

Bribe: $\pi^R_{G,B} \geq \pi^R_{B,B} \Leftrightarrow \mathrm{t} \geq \frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{v_T(1-\rho(1-\lambda))} - \frac{(\mathrm{P+Q})}{\mathrm{v_T}} = \underline{t^G}(c) - \frac{(P+Q)}{\mathrm{v_T}} = \underline{t^{RG}}(c);$ (17)

No Bribe: $\pi^R_{G,NB} \geq \pi^R_{B,NB} \Leftrightarrow \mathrm{t} \geq \frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{v_T(1-\rho(1-\lambda))} - \frac{(\mathrm{P+Q})}{\mathrm{v_T}} = \underline{t^G}(c) - \frac{(P+Q)}{\mathrm{v_T}} = \underline{t^{RG}}(c);$ (18)

where $\underline{t^G}(c) = \frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{v_T(1-\rho(1-\lambda))}$ as in conditions (7)-(8), $P = H(E(x)) - S(E(n-x)) > 0$, and $Q = H(E(x)+1) - S(E(n-x-1)) > 0$ as in conditions (15)-(16). Clearly, $\underline{t^{RG}}(c) < \underline{t^G}(c)$.

It is intuitive to observe, from conditions (7)-(8) and (17)-(18), that a less stringent environmental regulation ($t \geq \underline{t^{RG}}(c)$) coupled with non-monetary incentives for green production can induce reputation concerned firms to produce green, compared to what is necessary ($t \geq \underline{t^G}(c) > \underline{t^{RG}}(c)$) to induce non-reputation concerned firms to choose green technology. Thus, a reputation concerned firm is more likely, not only to choose the green technology, but also to bribe.

From the above discussion we observe that in the presence of non-monetary incentives and heterogeneity across firms in terms their valuation for social reputation there are four critical values of brown tax, $\underline{t^{RC}}$, $\underline{t^C}$, $\underline{t^{RG}}(c)$ and $\underline{t^G}(c)$. For any given brown tax (t), the extent on corruption and green technology adoption in the equilibrium would depend on relative magnitudes of these four critical values of brown tax, which in turn depends on the extra cost to adopt green technology for production, ceteris paribus.

Now, from conditions (5)-(8) and (15)-(18) it follows that (a) none of the firms bribe, if brown tax $t \leq Min\{\underline{t^{RC}}, \underline{t^{C}}\} = \underline{t^{RC}}$, and (b) all firms choose the green technology, if brown tax $t \geq Max\{\underline{t^{RG}}(c), \underline{t^{G}}(c)\} = \underline{t^{G}}(c)$. Therefore, if $\underline{t^{G}}(c) \leq \underline{t^{RC}}$ holds true and brown tax t is such that $\underline{t^{G}}(c) \leq t \leq \underline{t^{RC}}$ is satisfied, in the equilibrium all firms will be green and none will bribe, i.e. the equilibrium outcome will be the first-best.

Proposition 3: *Suppose that some firms care about social reputation, while others do not. Then, in the presence of non-monetary incentive the following is true. The first best equilibrium outcome can be achieved through the combination of the* brown *tax t^{R*}on each brown firm and the green technology subsidy s^{R*}, which is the lowest-subsidy minimum-tax policy; where $t^{R*}$and $s^{R*}$are as follows.*

(a) $t^{R*} = \underline{t^{G}}(c)$ *and* $s^{R*} = 0$, *if* $c \leq \hat{c} = \underline{c} - \Delta$;

(b) $t^{R*} = \underline{t^{G}}(\hat{c})$ *and* $s^{R*} = c - \hat{c}$, *if* $c > \hat{c} = \underline{c} - \Delta$;

where $\underline{c}$ *and* $\underline{t^{G}}(c)$ *are given by (10) and (8), respectively,* $\Delta = 2\gamma \left[H\left(n\left(1-\rho(1-\lambda)\right)\right) - S\left(n\rho(1-\lambda)\right)\right]\frac{(1-\rho(1-\lambda))}{v_T} > 0$, *and* $\underline{t^{G}}(\hat{c}) = \frac{v_T\hat{c} - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))}$.

Proof: See Appendix

Proposition 3 implies that in the presence of non-monetary incentives and firm heterogeneity it may not be possible to implement the first best equilibrium outcome only by imposing a brown tax on each brown firm even if the extra cost of green production is less than the critical level $\underline{c}$, unlike as in absence of non-monetary incentives. For the tax instrument alone to be effective to implement the first best in the presence of non-monetary incentives, the extra cost of green production must be even lower than $\underline{c}$ ($c \leq \underline{c} - \Delta < \underline{c}$). Otherwise, if $\underline{c} - \Delta < c < \underline{c}$, a green technology subsidy along with a brown tax is necessary to achieve the first best equilibrium outcome in the presence of non-monetary incentives, which is in sharp contrast to Proposition 3. Further, if the extra cost of green production (c) is greater than the critical level ($c > \underline{c}$), the first best solution cannot be achieved in the presence of non-monetary incentives and firm heterogeneity in terms of reputational concerns through the green technology subsidy $s^* = c - \underline{c}$ and brown tax rate $t^* = \underline{t^{C}} = \underline{t^{G}}(\underline{c})$, unlike as in the case of no non-monetary incentives. In other words, the tax-subsidy policy, which ensures the first best equilibrium output in absence of non-monetary incentives, is ineffective to do so in the presence of non-monetary incentives, unless $c \leq \underline{c} - \Delta$.

Now by comparing optimal policies that ensure the first best outcome in the two alternative scenarios- (a) no non-monetary incentives, and (b) non-monetary incentives and firm heterogeneity in terms of reputational concerns, we obtain the following**.**

Lemma 1: *(a) $s^{R*} > s^* \geq 0$ and $t^{R*} < t^*$, if $c > \hat{c} = \underline{c} - \Delta$; and (b) $s^{R*} = s^* = 0$ and $t^{R*} = t^*$, if $c \leq \hat{c} = \underline{c} - \Delta$.*
Proof: See Appendix.

Lemma 1 implies that the non-monetary incentives to discipline firms' behaviour calls for a higher green technology subsidy and lower brown tax, unless the extra cost of green technology is sufficiently less ($c \leq \underline{c} - \Delta$). In other words, non-monetary incentives put an extra burden on government exchequer in the presence of corruption, whenever the green technology sufficiently costly ($c > \underline{c} - -\Delta$).

Proposition 4: *Non-monetary incentives in the presence of corruption does not help to reduce the burden on the government exchequer to implement the first best equilibrium outcome. Implementation of the first best equilibrium outcome through a combination of monetary and non-monetary incentives calls for higher expenditure on green technology subsidy and a lower brown tax compared to that under monetary incentives alone, unless the extra cost of green technology is sufficiently less.*
Proof: Follows from Lemma 1.

The intuition behind Proposition 4 is as follows. Non-monetary incentive in the presence of corruption induces a reputation concerned firm to bribe, not only to avoid the brown tax, but also to acquire the certification award that brings social reputation. Thus, reputation concerned firms bribe even when the brown tax is less than what is necessary to induce non-reputation concerned firms to bribe. Thus, to induce all firms, reputation concerned as well as non-reputation concerned, not to bribe, the planner needs to set a lower brown tax. However, a lower brown tax rate reduces a firm's incentive to opt for the green technology. While reputation concerned firms have an incentive to choose the green technology due to probable reputational gain in the presence of non-monetary incentive, non-reputation concerned firms have no such gain from choosing the green technology. Thus, a lower tax on brown firm calls for a higher green technology subsidy in order to induce non-reputation concerned firms as well to opt for the green technology. This is true, unless the extra cost of acquiring the green technology is sufficiently less. In case the cost differential between green and brown technologies is sufficiently low, the brown tax that is necessary to induce a non-reputation concerned firm to choose the green technology is less than the brown tax necessary to satisfy even a reputation concerned firm's incentive compatibility condition to bribe. As a result, in the latter case, the planner can ensure the first-best equilibrium outcome only by setting the brown tax on each brown firm at the level $\underline{t^G}(c)$, which is the lowest brown tax that induces both reputation concerned and non-reputation concerned firms to choose the green technology, without offering any subsidy. [12]

4. An Alternative Scenario: Bribee Initiated Corrupt Transaction

In Sections 2 and 3 we have considered that corrupt transactions, if any, are initiated by bribers (i.e., firms). However corrupt officials may also demand for bribe upfront. Does it matter who initiates corrupt transactions? In this section we answer this question by considering that corrupt transactions, if any, are initiated by bribees, i.e., by corrupt officials, ceteris paribus (Bayer, 2005). Note that, in bribee initiated corrupt transactions, firms do not face any uncertainty regarding the type of the official. The reason is, corrupt officials themselves ask for the bribe, while the honest officials do not. Thus, there does not exist any risk of bribing the honest official, unlike as in the case briber initiated corrupt transactions.

Let us consider that, while dishonest officials initiate corrupt transactions by demanding bribe from each firm, the bribe amount $b(> 0)$ demanded from each firm is exogenously given as before. Corrupt officials make a take-it-or-leave it offer to firms, and firms can either accept

[12] In the hypothetical scenario of no corruption in the society, i.e. each and every official is honest ($\lambda = 1$), in absence of any non-monetary incentive all firms will be green, if that $t \geq \underline{t^G}(c)\big|_{\lambda=1} = \frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{\mathrm{v_T}}$ holds true. Introducing non-monetary incentive of green certification calls for the tax $t \geq \underline{t^{RG}}\big|_{\lambda=1} = \underline{t^G}\big|_{\lambda=1} - \left(\frac{(P+Q)}{\mathrm{v_T}}\right)\Big|_{\lambda=1}$ to induce reputation concerned firms to be green. Thus, to induce all firms, reputation concerned as well as non-reputation concerned, to choose the green technology by imposing a non-discriminatory tax on brown firms in the presence of non-monetary incentive and firm heterogeneity it is necessary and sufficient to set the tax equal to $\underline{t^G}(c)\big|_{\lambda=1}$. It implies that non-monetary incentives in absence of corruption does not impose excess burden on the society, unlike as in a corrupt society.

the offer 'pay amount b and get reported as green' or reject the offer and get reported as brown. The stages of the game are as follows.

Stage 1. The government announces the policy to implement the first best equilibrium outcome, if possible, which involves the least expenditure on green technology subsidy and the corresponding brown tax is the lowest possible.

Stage 2. Each firm decides which technology to use for production, green or brown.

Stage 3. An official inspects and discovers whether a firm has chosen the green or brown technology. If the official is honest, he decides not to demand bribes and makes a truthful report. If the official is corrupt, a bribe is asked, and his report depends on the firm's response. If the firm accepts the offer, the agreed report is made. If the firm rejects, the official reports the firm as brown.

Stage 4. Officials' reports are inspected by the government auditors. If the report turns out to be false, both the parties who engaged in corruption are fined according to a fine ratef^G .

We solve this game by backward induction method considering two alternative scenarios: (a) non-monetary incentive of green certification for green firms and (b) no non-monetary incentive.

4.1 No Non-monetary Incentives

First consider the scenario in which there is no non-monetary incentive and firms are identical. Note that firms are not subject to any risk of being penalized by offering bribe to an honest official, which is synonymous to the case of no penalty for bribing an honest official ($f^R = 0$). It implies that firms' expected payoffs from bribing will be higher in this case than in the case of briber (i.e. firm) initiated corruption, while expected payoffs from not bribing will remain the same, regardless of firms' technology choices. Thus, in Stage 3, firms' incentive compatibility conditions to bribe will now be different. To illustrate it further, in the present scenario, if in Stage 3 the official demands bribe to a firm, the firm becomes certain that the official is corrupt ($\lambda = 0$) and thus its incentive compatibility condition to accept the demand and pay bribe b implies the following, regardless of whether the firm is green or brown.

$$t > \frac{b+f^G(1-\rho)}{\rho} = t_b \tag{19}$$

Condition (19) can be obtained by substituting $\lambda = 0$ and $f^R = 0$ in conditions (5) and (6). It is evident that $t_b < \underline{t}^C$. That is, if bribee initiates the corrupt transaction, corruption will take place even for a lower brown tax compared to that in the case of briber initiated corrupt transactions. Needless to mention here that a corrupt official reports a firm as green (brown), if he gets (does not get) bribe from that firm, regardless of the firm's true technology choice.

Now, for any given tax rate t, incentive compatibility conditions for adopting the green technology will remain the same as before (conditions (7) and (8)), since at the technology choice stage (Stage 2) a firm does not know whether he will meet an honest official or a corrupt official in Stage 3. Thus, in the present scenario, the first best equilibrium outcome can be ensured only by a brown tax, if and only if, $\underline{t}^G(c) \leq t_b$ and $t \in [\underline{t}^G(c), t_b]$. It is easy to check that $\underline{t}^G(c) \leq t_b \Leftrightarrow c \leq \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1-\rho)] + \frac{v_E}{v_T}(e_b - e_g) = c_b$ and $c_b < \underline{c}$. Thus, following same arguments as before, the 'least-cost minimum-tax' regulation that ensures the first best equilibrium outcome in the case of bribee initiated corruption is as in Lemma 2.

Lemma 2: *Suppose that corrupt transactions, if any, are initiated by bribees, i.e. by corrupt officials and the bribe rate is exogenously given. Then, in absence of non-monetary incentives, the 'lowest-subsidy minimum-tax' policy to implement the first best outcome in the equilibrium sets the brown tax t^{*O} and the green technology subsidy s^{*O} as follows.*

(i) $t^{*O} = \underline{t}^G(c)$ *and* $s^{*O} = 0$, *if* $c \leq c_b$; *otherwise*

(ii) $t^{*O} = \underline{t}^G(c_b)$ *and* $s^{*O} = c - c_b$, *if* $c > c_b$; *where*

$c_b = \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1-\rho)] + \frac{v_E}{v_T}(e_b - e_g)$ *and* $\underline{t}^G(c) = \frac{v_T c - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))}$.

Proof: See Appendix.

Now, comparing Lemma 2 with Proposition 1 and Proposition 2, we get the following.

Lemma 3: $s^{*O} > s^* \geq 0$ and $t^{*O} < t^*$, if $c > c_b$. Otherwise, if $c \leq c_b$, $s^{*O} = s^* = 0$ and $t^{*O} = t^*$.

Proof: See Appendix.

Therefore, in absence of non-monetary incentives, implementation of the first best equilibrium outcome under bribee initiated corrupt transactions calls for (i) a lower brown tax and (ii) a higher green technology subsidy to the seller of the green technology than under briber initiated corrupt transactions, whenever $c > c_b$. In other words, it is more difficult to ensure the first best equilibrium outcome when corrupt transactions are initiated by bribee compared to the scenario in which briber initiates corrupt transactions, unless the extra cost of green technology is less than a critical level. This is because, firms do not face the risk of being penalized for offering bribe to an honest official under bribee initiated corrupt transactions.

4.2 Non-monetary Incentives

Let us now consider that the government offers non-monetary incentive in the form of green certification to adopt the green technology in addition to the tax-subsidy policy, as in Section 3. Note that firms are heterogeneous in terms of their valuations for social reputation. While $\beta \in (0, 1)$ proportion of firms care about social reputation ($\theta = 1$), remaining $1 - \beta$ proportion of firms do not care about it ($\theta = 0$). In such a scenario, a reputation concerned firm's incentive compatibility condition to 'accept bribe demand from a corrupt official and pay bribe b' in Stage 3, regardless of the technology choice, is satisfied if and only if condition (20) is satisfied, which is obtained from conditions (15) and (16) by substituting $\lambda = 0$ and $f^R = 0$.

$$t > \frac{b+f^G(1-\rho)}{\rho} - \frac{(P+Q)}{\mathrm{v_T}} = t_b - \frac{(P+Q)}{\mathrm{v_T}} = t_b^R \ , \qquad (20)$$

where

$P = H(E(x)) - S(E(n-x)) > 0$, and $Q = H(E(x)+1) - S(E(n-x-1)) > 0$. On the other hand, incentive compatibility conditions of non-reputation concerned firms to accept bribe demand from corrupt officials are satisfied if and only if condition (19) is satisfied. The reasons are same as discussed in the case of no non-monetary incentives. It is evident that $t_b^R < t_b$. Thus, to ensure that none of the n firms bribe in the equilibrium, regardless of their valuation for social reputation, we must have $t \leq t_b^R$.

It is easy to observe that, in Stage 2, firms incentive compatibility conditions to adopt the green technology under bribee initiated corrupt transactions remain same as those under briber initiated corrupt transactions, as in absence of no non-monetary incentives. This is because, firms do not know the type of the official, honest or corrupt, while choosing the technology in Stage 2, regardless of whether corrupt transactions in Stage 3 will be initiated by bribee or briber. Thus, following the analysis of Section 3, we can say that each firm will choose the green technology in Stage 2 if and only if $t \geq \frac{v_T c - \mathrm{v_E}(\mathrm{e_b} - \mathrm{e_g})}{v_T(1-\rho(1-\lambda))} = \underline{t}^G(c)$ is satisfied, regardless of whether a firm is reputation concerned or non-reputation concerned. Overall, it follows that the first best equilibrium outcome can be achieved, if and only if $\underline{t}^G(c) \leq t_b^R$ and $t \in [\underline{t}^G(c), t_b^R]$. Now, $\underline{t}^G(c) \leq t_b^R \Leftrightarrow c \leq c_b - (1-\rho(1-\lambda))\frac{(P+Q)}{v_T}$, where $c_b = \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1-\rho)] + \frac{\mathrm{v_E}}{v_T}(\mathrm{e_b} - \mathrm{e_g})$. Therefore, we have the following.

Lemma 4: *Suppose that corrupt transactions, if any, are initiated by bribees, i.e., by corrupt officials and the bribe rate is exogenously given. Then, in the presence of non-monetary incentives, the 'lowest-subsidy minimum-tax' policy that implements the first best equilibrium outcome is as follows.*

(i) $t^{*OR} = \underline{t}^G(c)$ and $s^{*OR} = 0$, if $c \leq c_b^R$; otherwise

(ii) $t^{*OR} = \underline{t}^G(c_b^R)$ and $s^{*OR} = c - c_b^R$, if $c > c_b^R$; where

$c_b^R = \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1-\rho)] + \frac{\mathrm{v_E}}{v_T}(\mathrm{e_b} - \mathrm{e_g}) - \Delta = c_b - \Delta$, $\Delta = 2\gamma\left[H\left(n(1-\rho(1-\lambda))\right) - S(n\rho(1-\lambda))\right]\frac{(1-\rho(1-\lambda))}{v_T} > 0$ and $\underline{t}^G(c) = \frac{v_T c - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))}$. *$t^{*OR}$ and s^{*OR} denote, respectively, the lowest possible brown tax on each brown firm and the lowest green technology subsidy in the presence of non-monetary incentive, when corrupt transactions are initiated by officials.*

Proof: See Appendix.

From Proposition 3, Lemma 2 and Lemma 4, we get the following.

Lemma 5: (a) $s^{*OR} > s^{R*} \geq 0$ and $0 < t^{*OR} < t^{R*}$, if $c > c_b^R$. Otherwise, if $c \leq c_b^R$, $0 < t^{*OR} = t^{R*}$ and $s^{*OR} = s^{R*} = 0$.

(b) $s^{*OR} > s^{*O} \geq 0$ and $0 < t^{*OR} < t^{*O}$, if $c > c_b^R$. Otherwise, if $c \leq c_b^R$, $0 < t^{*OR} = t^{*O}$ and $s^{*OR} = s^{*O} = 0$.

Proof: See Appendix

From Lemma 5(a) it is evident that, in the presence of non-monetary incentives, the scope to achieve the first best equilibrium outcome only by imposing a brown tax under bribee initiated corrupt transactions is less than that under briber-initiated corruption. Further, bribee initiated corruption calls for a higher green technology subsidy and a lower brown tax, unless the extra cost of adopting the green technology is less than a critical level. The intuition is same as in the case of no non-monetary incentive. From Lemma 5(a) and Lemma 3, it follows that implications of bribee initiated corruption on required 'lowest-subsidy and minimum-tax policy' to implement the first best equilibrium outcome in the presence of non-monetary incentives are similar to those in absence of non-monetary incentives.

Lemma 5(b) and Lemma 1 together implies that qualitative effects of introduction of non-monetary incentives on the 'lowest-subsidy and minimum-tax' policy required to achieve the first best outcome in the equilibrium in the case of bribee initiated corruption are the same as those in the case of briber-initiated corruption. Thus, Proposition 6 remains valid regardless of whether corrupt transactions are initiated by firms or corrupt officials.

Proposition 7:

(a) Implementation of the first best outcome in the equilibrium requires a higher green technology subsidy and a lower brown tax in the scenario in which corrupt transactions are initiated by bribee compared to those in the scenario of briber initiated corrupt transactions, unless the extra cost of green technology is less than a critical level. This is true both in the presence and in absence of non-monetary incentive. However, the critical level of extra cost of green technology is lower in the presence of non-monetary incentives compared to that in absence of non-monetary incentives.

(b) In a corrupt society, the first best outcome can be achieved in the equilibrium at a lower cost through appropriately designed tax-subsidy policy alone compared to that when the tax-subsidy policy is coupled with non-monetary incentives, regardless of whether corrupt transactions are initiated by bribees or bribers.

Proof: Follows directly from Lemma 1, Lemma 3 and Lemma 5.

5. Endogenous Bribe Rate

In this section we discuss the implications of endogenous determination of bribe rate (b) at Stage 3 of the game, through independent bargaining between each pair of corrupt official and a firm. Suppose that the bargaining power of corrupt official is $\gamma \in [0, 1]$, while firm's bargaining power is $1 - \gamma$. Let $\underline{b}$ (> 0) be a corrupt official's minimum acceptable bribe rate and $\overline{b}$ (≥ 0) be a firm's maximum willingness to pay as bribe. γ, $\underline{b}$ and $\overline{b}$ are assumed to be common knowledge. Then, if $\underline{b} < \overline{b}$, the generalized Nash bargaining problem between a 'firm – corrupt official' pair can be written as $\max_{b\in[\underline{b},\overline{b}]}\left[\left(b-\underline{b}\right)^{\gamma}\left(\overline{b}-b\right)^{1-\gamma}\right]$, since a corrupt official's (firm's) objective is to get (pay) as much more (less) bribe as possible over and above $\underline{b}$ (than $\overline{b}$). Solving this problem, we get the bargained bribe rate $b^0 = \gamma\, \overline{b} + (1-\gamma)\underline{b} \in [\underline{b},\ \overline{b}]$. However, if $\overline{b} < \underline{b}$, there will not be any corrupt transaction. Therefore, it is feasible to ensure that no corrupt transaction takes place in the equilibrium if and only if it is feasible to ensure that $\overline{b} < \underline{b}$ holds true. While it turns out that the minimum acceptable bribe rate of a corrupt official ($\underline{b}$) does not depend on the tax-subsidy policy or on the norm regarding corrupt transaction – bribee initiated of briber initiated or on whether there is any non-monetary incentive for firms or not, a firm's maximum willingness to pay as bribe ($\overline{b}$) is always decreasing in brown tax (t). In fact, it can be checked that the planner can always ensure that $\overline{b} < \underline{b}$ is satisfied by choosing the brown tax appropriately. On the other hand, at the technology choice stage (Stage 2) firm's incentive compatibility condition for choosing the green technology under endogenous bribe rate remains the same as that under exogenously given bribe rate, since at this stage firms cannot update their beliefs regarding the official's type and the incentive compatibility condition for going green does not depend on the bribe rate. As a result, Proposition 4 and Proposition 5 hold true even in the case of endogenously determined bribe rate, regardless of whether bribee or briber initiates corrupt transactions. (See Appendix for details.)

6. Conclusion

In this paper we have developed a theoretical model to analyse optimal environmental regulation in the presence of corruption, with a special focus on efficacies of non-monetary incentives for firms to go green. Our analysis offers several new insights. First, we have characterized the 'minimum environmental regulation', which calls for the lowest possible subsidy to green technology seller and the lowest possible tax on brown production, that implements the first best equilibrium outcome wherein all firms adopt the green technology, and none pays bribe to officials. We have demonstrated that it is possible to achieve the first best equilibrium outcome only through a tax on brown production, unless the cost of the green technology is sufficiently higher than the cost of brown technology. If the extra cost of green technology is sufficiently high, then also the first best equilibrium outcome can be implemented by imposing a brown tax and a subsidy to green technology seller. These are robust results. Second, and more interestingly, we explore the effectiveness of one behavioural incentive, i.e., green certificates, on firms' pro-environmental behaviour in terms of choice of technology in a corrupt environment. Recent developments in behavioural environmental economics (see, Shogren et al. 2010; Carlsson et al. 2021) suggest that a policy maker can make a good environmental policy better by adding human elements to standard homo economicus models. Both theoretical and empirical work shows that behavioural incentives can help design better incentives, e.g., social reward, green certificates, that can change behaviour cost-effectively, i.e., more protection at a less use of public funds. In contrast to this wisdom, we have demonstrated that the introduction of non-monetary incentive schemes in a corrupt environment increases the burden on the government's exchequer, unlike as in absence of corruption possibilities. It suggests that social-reward (and other related non-monetary incentives to motivate people and firms motivated by social preferences) should be used cautiously as this could increase the spending of public fund with less environmental protection, since corruption exists in most (if not all) countries in the world.

In this paper we have considered that the efficiency of audit mechanism, which determines the probability of detecting corrupt behaviour, and penalties for bribing if detected are exogenously given. We do so due to following reasons. First, corruption control mechanisms and environmental regulation are often designed by separate authorities/departments. Second, it is costly and often politically infeasible for a government to improve efficiency of corruption control mechanisms in the short to medium run. Third, our results hold true for any given probability of detecting corrupt practices and fine rates for bribing. Nonetheless, it seems to be interesting to extend the present analysis by endogenizing the instruments aimed to reduce corruption. Such an analysis would be useful to assess the need for designing corruption control mechanisms and environmental regulation in tandem with each other. Next, in this paper we have assumed uniform fine rate for bribing imposed on firms – regardless of whether the firm is green or brown. It would be interesting to examine the implication of discriminatory fine rates for bribing based on firm's type – green or brown. This is part of our ongoing research agenda. Finally, in close conformity with the existing practice, we have assumed that law enforcing agencies do not take proactive measures to publicise identities of firms, which were caught for bribing. However, it is easy to observe that negative publicity of firms for being engaged in corrupt practices may harm their social reputation and, hence, would reduce the incentive of reputation concerned firms to offer bribe or to comply with extortion demands of corrupt officials. However, given a firm's decision regarding bribing, its incentive compatibility condition for adopting the green technology would remain unchanged. Thus, intuitively we can say that it is likely to be feasible to implement the first best equilibrium outcome at a lesser cost in case firms suffer from loss in reputation for being corrupt with a positive probability compared to that in absence of such a possibility. Implying that non-monetary incentives to go green, e.g., green certification award, coupled with non-monetary disincentive to be corrupt, e.g., negative publicity, would be more effective compared to only non-monetary incentives to go green. However, it is not straightforward to infer whether such dual non-monetary incentive-disincentive scheme will fare better compared to only monetary incentives. It depends on societal perceptions regarding importance of green production vis-à-vis desirability of being honest. To illustrate it further, how does the society compare a brown-but-honest firm with a green-but-corrupt firm? It also depends on how reputation concerned firms value social reputation of being green with that of being honest. This is beyond the scope of the present paper, and we leave it for future research.

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Appendix

A.1. Comparative Statics Analysis

A) Instruments for Corruption Control:

Let us first look at the corruption control mechanism of the government, given environmental regulations. To control corruption, the government has three instruments: (i) efficiency of audit mechanism, i.e. the probability $(1-\rho)$ of detecting corrupt act ex-post (e.g. by increasing the audit frequency), (ii) amount of fine (f^G) imposed on a firm in case that firm is found to have bribed the official (which can be imposed only if the official is corrupt and is caught by the auditor), and (iii) amount of fine (f^R) imposed on a firm in case it offers bribe to the official (which can be imposed only if the official is honest).

Lemma A1: (a) $\frac{\partial \underline{t^C}}{\partial \rho} < 0$ and $\lim_{\rho \to 0} \underline{t^C} = \infty$.

(b) $\frac{\partial \underline{t^C}}{\partial f^R} > 0$ and $\frac{\partial \underline{t^C}}{\partial f^G} > 0$.

Proof: We have $\underline{t^C} = \frac{b(1-\lambda)+f^R\lambda + f^G(1-\lambda)(1-\rho)}{\rho(1-\lambda)}$ (from (5)), where $\lambda \in (0,1),\ \rho \in (0,1), b > 0, f^R > 0, f^G > 0\,, v_T > 0$. Therefore,

$$\frac{\partial \underline{t^C}}{\partial \rho} = -\frac{b(1-\lambda)+f^R\lambda+f^G(1-\lambda)}{v_T(1-\lambda)\rho^2} < 0,$$

$$\lim_{\rho \to 0} \underline{t^C} = \lim_{\rho \to 0} \frac{b(1-\lambda)+f^R\lambda + f^G(1-\lambda)(1-\rho)}{\rho(1-\lambda)} = \lim_{\rho \to 0} \frac{1}{\rho}\left[b + \frac{f^R\lambda}{(1-\lambda)} + f^G\right] - f^G = \infty,$$

$$\frac{\partial \underline{t^C}}{\partial f^R} = \frac{\lambda}{v_T\rho(1-\lambda)} > 0,\ \textit{and}\ \frac{\partial \underline{t^C}}{\partial f^G} = \frac{(1-\rho)}{v_T\rho} > 0. \quad \text{[QED]}$$

Lemma A1(a) states that, if ρ decreases, i.e., the corrupt official gets caught with higher probability, then $\underline{t^C}$ will increase. Therefore, it will be less likely that $t > \underline{t^C}$ is satisfied for a given *t*, which implies that the possibility of bribing reduces. Further, for any given *t*, the social planner can ensure that $t \leq \underline{t^C}$ holds by reducing ρ sufficiently. That is, the social planner can ensure that no firm bribes by choosing ρ aprropriately. However, one should note that, given the institutional setup, reducing ρ can be very costly for the planner.

Lemma A1(b) states that, if f^R or f^G increase, i.e., the fines imposed on briber increase, then $\underline{t^C}$ will increase. This again implies that the possibility of bribing will reduce if the fines rates are increased.

Lemma A2: (a) $\frac{\partial \underline{t}^G(c)}{\partial \rho} > 0$ and $\lim_{\rho\to 0} \underline{t}^G(c) = \frac{v_T c - v_E(e_b - e_g)}{v_T}$.

(b) $\frac{\partial \underline{t}^G(c)}{\partial f^R} = 0$ and $\frac{\partial \underline{t}^G(c)}{\partial f^G} = 0$.

Proof: From (7), $\underline{t}^G(c) = \frac{v_T c - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))}$. Since $\lambda \in (0,1)$, $\rho \in (0,1), c > 0, e_b - e_g > 0, v_E > 0$ and $v_T > 0$, we get the following.

$\frac{\partial \underline{t}^G(c)}{\partial \rho} = \frac{(v_T c - v_E(e_b - e_g))(1-\lambda)}{v_T(1-\rho(1-\lambda))^2} > 0$, $\lim_{\rho\to 0} \underline{t}^G(c) = \frac{v_T c - v_E(e_b - e_g)}{v_T}$ and $\frac{\partial \underline{t}^G}{\partial f^R} = \frac{\partial \underline{t}^G}{\partial f^G} = 0$.

[QED]

Lemma A2(a) states that, if ρ decreases, i.e., if corrupt officials get caught with higher probability, then $\underline{t}^G$ will decrease. Therefore, it will be more likely that $t \geq \underline{t}^G(c)$, which implies that the possibility of green production is more. Further, unless $t < \frac{v_T c - v_E(e_b - e_g)}{v_T}$, by choosing ρ appropriately, the social planner can induce each firm to produce green. It implies that coordination between authorities deciding ρ and t is needed to ensure 'no corrupt transaction and full green'. Lemma A2(b) implies that higher penalties on the briber will not affect firms' incentive to produce green.

From Lemma A1 and Lemma A2, it follows that, *given environmental regulations, stricter corruption control by increasing the probability of corruption detection* $(1-\rho)$*, reduces corruption as well as enhances firms' incentive to produce green. However, higher penalties imposed on bribe giver when detected, reduces the incentive to bribe but does not affect firms' incentive to produce green*

B) Brown Tax:

Let us now turn to examine the implications of the policy instrument 'brown tax' on technology choice by firms and corruption, if any, ceteris paribus. Lemma A3 is immediate from the expressions for $\underline{\rho}^C$ and $\underline{\rho}^G$, which are given by (9) .

Lemma A3: $\frac{\partial \underline{\rho}^C}{\partial t} < 0$ and $\frac{\partial \underline{\rho}^G}{\partial t} > 0$.

Proof: From (9), $\underline{\rho}^C = \frac{b(1-\lambda) + f^R\lambda + f^G(1-\lambda)}{(1-\lambda)(v_T t + f^G)}$. Since $\in (0,1), b > 0, f^R > 0, f^G > 0, v_T > 0$ and $t > 0$, we get

$\frac{\partial \underline{\rho^C}}{\partial t} = -\frac{\left(b(1-\lambda)+f^R\lambda+f^G(1-\lambda)\right)v_T}{(1-\lambda)\left(v_T t+f^G\right)^2} < 0$ and $\frac{\partial \underline{\rho^G}}{\partial t} = \frac{v_T \mathrm{c}-\mathrm{v_E}\left(\mathrm{e_b}-\mathrm{e_g}\right)}{t^2 v_T(1-\lambda)} > 0.$ [QED]

Inequalities in (9) and Lemma A3 together imply that, for any given efficiency of the audit system $(1-\rho)$ and fine rates, a higher brown tax (t) makes both the inequalities $\rho > \underline{\rho^C}$ and $\rho \leq \underline{\rho^G}$ to be more likely to be satisfied. If the planner imposes a higher brown tax, not only the incentive compatibility conditions to choose the green technology are more likely to be satisfied, but also firms are more likely to find it optimal to bribe. From Lemma A3, we can state the following. *Given the corruption control mechanism, i.e., given the probability of efficiency of the audit mechanism of the government and rates of fines, a higher brown tax makes green production more attractive. However, it also makes bribing more attractive.*

A2. Proof of Proposition 3

By construction, there are total n firms, out of which β proportion of firms are reputation concerned $(i.e. \theta = 1)$ and remaining $1-\beta$ proportion of firms do not care about reputation$(i.e. \theta = 0)$.

A non-reputation concerned (i.e. $\theta = 0$) firm's optimal decisions in Stage 3 and Stage 2 are, respectively, as follows.

(a) Do not offer bribe, if $t \leq \underline{t^C} = \frac{1}{(1-\lambda)\rho}[b(1-\lambda)+f^R\lambda+f^G(1-\lambda)(1-\rho)]$, from conditions (5) and (6).

(b) Opt for the green technology, if $t \geq \underline{t^G}(c) = \frac{v_T \mathrm{c}-\mathrm{v_E}\left(\mathrm{e_b}-\mathrm{e_g}\right)}{(1-\rho(1-\lambda))\mathrm{v_T}}$, from conditions (7) and (8).

A reputation concerned (i.e. $\theta = 1$) firm's optimal decisions in Stage 3 and Stage 2 are, respectively, as follows.

(a) Do not offer bribe, if $t \leq \underline{t^C} - \frac{(P+Q)}{\mathrm{v_T}}$, where $P = H\big(E(x)\big) - S\big(E(n-x)\big) > 0, Q = H(E(x)+1) - S\big(E(n-x-1)\big) > 0$ and x is the actual number of firms getting the green certification, from conditions (15) and (16).

(b) Opt for the green technology, if $t \geq \underline{t^G}(c) - \frac{(P+Q)}{\mathrm{v_T}}$, from conditions (17) and (18).

It is evident that $\underline{t}^{RC} < \underline{t}^{C}$, $\underline{t}^{RG}(c) < \underline{t}^{G}(c)$, $\frac{\partial \underline{t}^{RG}(c)}{\partial c} = \frac{\partial \underline{t}^{G}(c)}{\partial c} > 0$ and $\frac{\partial \underline{t}^{RC}}{\partial c} = \frac{\partial \underline{t}^{C}}{\partial c} = 0$.

Next, note that the first-best equilibrium outcome calls for 'no firm bribes and all firms choose the green technology' (by Definition 1).

From the above discussion it follows that (a) none of the firms bribe, if tax on brown firm $t \le Min\{\underline{t}^{RC}, \underline{t}^{C}\} = \underline{t}^{RC}$, and (b) all firms choose the green technology, if tax on brown firm $t \ge Max\{\underline{t}^{RG}(c), \underline{t}^{G}(c)\} = \underline{t}^{G}(c)$. Therefore, if $\underline{t}^{G}(c) \le \underline{t}^{RC}$ holds true and tax on brown firm t is such that $\underline{t}^{G}(c) \le t \le \underline{t}^{RC}$ is satisfied, the equilibrium outcome will be the first best.

Now,

$\underline{t}^{G}(c) \le \underline{t}^{C}$

$\Leftrightarrow c \le \frac{(1-\rho(1-\lambda))}{\rho(1-\lambda)} [b(1-\lambda) + f^R\lambda + f^G(1-\lambda)] + \frac{v_E}{v_T}(e_b - e_g) = \underline{c}$, and

$\underline{t}^{G}(c) \le \underline{t}^{RC}$

$\Leftrightarrow \underline{t}^{G}(c) \le \underline{t}^{C} - \frac{(P+Q)}{v_T} \Leftrightarrow c \le \underline{c} - \frac{(P+Q)}{v_T}\left(1-\rho(1-\lambda)\right) < \underline{c}$; since $P, Q > 0$.

Therefore, if $c \le \underline{c} - \frac{(P+Q)}{v_T}\left(1-\rho(1-\lambda)\right)$, $\forall\, t \in [\underline{t}^{G}(c),\ \underline{t}^{RC}]$ the equilibrium outcome will be the first best.

Note that $\rho(1-\lambda)$ is the probability that 'the official is corrupt and the act of corruption remains undetected'. So, if a green firm does not offer any bribe, then that green firm gets the award of green certification with probability $\left(1-\rho(1-\lambda)\right)$. Implying that, if all firms have chosen the green technology and no firm bribes, the expected number of firms getting the award of green certification is $n\left(1-\rho(1-\lambda)\right)$. Therefore, in the first best equilibrium the net reputational payoff of each firm is given by

$R = \gamma\left[H\left(n\left(1-\rho(1-\lambda)\right)\right) - S\left(n - n\left(1-\rho(1-\lambda)\right)\right)\right] > 0$ (by construction).

Now, note that $(-P)$ is the reputational payoff of firm in case that firm does not get the green certification and Q is the reputational payoff of a firm in case that firm gets the green certification. In any equilibrium we must have $P = Q$, and in the first best equilibrium we must have $P = Q = R = \gamma\left[H\left(n\left(1-\rho(1-\lambda)\right)\right) - S\left(n - n\left(1-\rho(1-\lambda)\right)\right)\right] > 0$. Therefore, in the first best equilibrium $\frac{(P+Q)}{\mathrm{v_T}}\left(1-\rho(1-\lambda)\right) = 2\gamma\left[H\left(n\left(1-\rho(1-\lambda)\right)\right) - S\left(n\rho(1-\lambda)\right)\right]\frac{(1-\rho(1-\lambda))}{v_T} = \Delta > 0$. It follows that, if $c \leq \underline{c} - \Delta = \hat{c}$, the first best equilibrium can be implemented by any $t \in [\underline{t^G}(c),\ \underline{t^{RC}}]$, without offering any subsidy to the green technology seller. However, since $t = \underline{t^G}(c)$ corresponds to the minimum penalty on each brown firm, we propose that the social planner will choose $t = \underline{t^G}(c) = t^{R*}$and $s^{R*} = 0$, which ensures the first best equilibrium outcome.

Now, if $c > \underline{c} - \Delta = \hat{c}$ and $s = 0$, $\nexists$ any t which induces all firms to be green and not to offer any bribe, since the necessary condition to ensure the first best equilibrium $\underline{t^G}(c-0) \leq \underline{t^{RC}}$ is not satisfied. For the necessary condition to be satisfied, the extra cost of green technology must be reduced to at least to $\hat{c} = \underline{c} - \Delta$, i.e. at the minimum we must have $s = c - \hat{c}$; since $\frac{\partial \underline{t^G}(c)}{\partial c} > 0$, $\frac{\partial \underline{t^{RC}}}{\partial c} = 0$ and $\underline{t^G}(\hat{c}) = \frac{v_T\hat{c} - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))} = \underline{t^{RC}}$. Implying that, if $c > \underline{c} - \Delta = \hat{c}$, the first best outcome can be implemented by setting $s = c - \hat{c} = s^{R*} > 0$ and $t = \underline{t^G}(\hat{c}) = t^{R*} > 0$.

Note that, if $c > \underline{c} - \Delta = \hat{c}$, the tax-subsidy scheme ($t^{R*} = \underline{t^G}(\hat{c})$, $s^{R*} = c - \hat{c}$) involves the minimum expenditure on subsidy necessary to ensure the first best equilibrium outcome. This is because, in this case the first best equilibrium outcome can be implemented by a tax subsidy pair (t, s) provided that $t \in [\underline{t^G}(c-s),\ \underline{t^{RC}}]$ and $s \geq c - \hat{c}$. [QED]

A3. Proof of Lemma 1

First consider that $c > \underline{c}$. Then, $s^{R*} = c - \left(\underline{c} - \Delta\right) = \left(c - \underline{c}\right) + \Delta$ and $s^* = \left(c - \underline{c}\right)$, by Proposition 3 and Proposition 2. Clearly $s^{R*} > s^*$, since $\Delta > 0$. Further, in this case $t^{R*} = \underline{t^G}(\hat{c})$ and $t^* = \underline{t^G}\left(\underline{c}\right)$, by Proposition 3 and Proposition 2. We have $\hat{c} = \underline{c} - \Delta < \underline{c}$ and $\frac{\partial \underline{t^G}(c)}{\partial c} > 0\ \forall\ c$. It follows that $t^{R*} < t^*$.

Next, consider that $\underline{c} - \Delta < c < \underline{c}$, then $s^{R*} = c - \left(\underline{c} - \Delta\right) > 0 = s^*$, by Proposition 3 and Proposition 2. Also, $t^{R*} = \underline{t^G}(\hat{c})$ and $t^* = \underline{t^G}(c)$. Since $\hat{c} = \underline{c} - \Delta < c$ and $\frac{\partial \underline{t^G}(c)}{\partial c} > 0\ \forall\ c$, we have $t^{R*} < t^*$.

If $c \leq (\underline{c} - \Delta)$, it is evident from Proposition 3 and Proposition 2 that $s^{R*} = s^* = 0$ and $t^{R*} = t^* = \underline{t^G}(c)$. [QED]

A4. Proof of Lemma 2

Condition (19) implies that firms will accept the bribe demand from official and bribe, if and only if $t > t_b = \frac{b+f^G(1-\rho)}{\rho}$. That is, firms will not pay any bribe, if $t \leq t_b$. It follows that to implement the first best equilibrium outcome we must have $t \leq t_b$.

Next, from incentive compatibility conditions (7) and (8), all firms will choose the green technology, if $t \leq \underline{t^G}(c)$=$\frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b}-\mathrm{e_g})}{v_T(1-\rho(1-\lambda))}$.

Therefore, the first best equilibrium outcome is implementable, if $\underline{t^G}(c) \leq t_b$ and $\in [\underline{t^G}(c)\,, t_b]$. Now, $\underline{t^G}(c) \leq t_b \Leftrightarrow c \leq \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1-\rho)] + \frac{\mathrm{v_E}}{v_T}(\mathrm{e_b} - \mathrm{e_g}) = c_b$. It implies that, if $c \leq c_b$, any $t \in [\underline{t^G}(c)\,, t_b]$ implements the first best outcome. Clearly, if $c \leq c_b$, $t = \underline{t^G}(c)$ and $s = 0$ implements the first best, which is the 'lowest technology subsidy and minimum tax on brown firms' regulation that implements the first best equilibrium outcome.

Finally, note that $c > c_b \Leftrightarrow \underline{t^G}(c) > t_b$. Therefore, if $c > c_b$ and $s = 0$, there does not exist any tax t that ensures the first best outcome in the equilibrium. In this case, if $s \geq c - c_b$, then $\underline{t^G}(c - s) \leq t_b$ holds. It implies that "$s = c - c_b$ and $\underline{t^G}(c_b)$" the 'lowest technology subsidy and minimum tax on brown firms' regulation that implements the first best equilibrium outcome. [QED]

A5. Proof of Lemma 3

We have $c_b = \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1-\rho)] + \frac{\mathrm{v_E}}{v_T}(\mathrm{e_b} - \mathrm{e_g})$, $\underline{c} = \frac{(1-\rho(1-\lambda))}{\rho(1-\lambda)}[b(1-\lambda) + f^R\lambda + f^G(1-\lambda)] + \frac{\mathrm{v_E}}{v_T}(\mathrm{e_b} - \mathrm{e_g})$ and $\underline{t^G}(c) = \frac{v_T \mathrm{c} - \mathrm{v_E}(\mathrm{e_b}-\mathrm{e_g})}{v_T(1-\rho(1-\lambda))}$. Thus, $\underline{c} - c_b = \frac{(1-\rho(1-\lambda))}{\rho(1-\lambda)} f^R\lambda > 0$ and $\frac{\partial \underline{t^G}(c)}{\partial c} > 0$.

Now, from Lemma 2, Proposition 1 and Proposition 2 we have the following, since $c_b < \underline{c}$ and $\frac{\partial \underline{t}^G(c)}{\partial c} > 0$.

(i) If $0 < c \leq c_b$, $s^{*O} = s^* = 0$ and $0 < t^{*O} = t^* = \underline{t}^G(c)$.

(ii) If $c_b < c \leq \underline{c}$, $s^{*O} = c - c_b > 0 = s^*$ and $0 < t^{*O} = \underline{t}^G(c_b) < \underline{t}^G(c) = t^*$.

(iii) If $\underline{c} < c$, $s^{*O} = c - c_b > c - \underline{c} = s^* > 0$ and $0 < t^{*O} = \underline{t}^G(c_b) < \underline{t}^G(\underline{c}) = t^*$.

[QED]

A6. Proof of Lemma 4

We know, the first best equilibrium outcome can be achieved, if and only if $\underline{t}^G(c) \leq t_b^R$ and $t \in [\underline{t}^G(c), t_b^R]$. Also, $\underline{t}^G(c) \leq t_b^R \Leftrightarrow c \leq c_b - (1 - \rho(1 - \lambda))\frac{(P+Q)}{v_T}$, where $c_b = \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1 - \rho)] + \frac{v_E}{v_T}(e_b - e_g)$. Now, in the first best equilibrium, we have $\frac{(P+Q)}{v_T}(1 - \rho(1 - \lambda)) = 2\gamma\left[H\left(n(1 - \rho(1 - \lambda))\right) - S(n\rho(1 - \lambda))\right]\frac{(1-\rho(1-\lambda))}{v_T} = \Delta > 0$ (see Proof of Proposition 3). Therefore, we can state the following.

(i) If $c \leq c_b^R = c_b - \Delta$, any (t, s) combination such that $t \in [\underline{t}^G(c), t_b^R]$ and $s \geq 0$ implements the first best equilibrium outcome. Clearly, '$s = 0$ and $t = \underline{t}^G(c)$' is the *'the lowest technology subsidy and the minimum tax on brown firms'* that implements the first best outcome in the equilibrium.

(ii) If $c > c_b^R = c_b - \Delta$, the minimum technology subsidy necessary to ensure that $\underline{t}^G(c - s) \leq t_b^R$ holds true is given by $s = c - c_b + (1 - \rho(1 - \lambda))\frac{(P+Q)}{v_T}$. Therefore, *'the lowest technology subsidy and the minimum tax on brown firms'* that implements the first best outcome in the equilibrium is given by '$s = c - c_b + \Delta = c - c_b^R$ and $t = \underline{t}^G(c - s) = \underline{t}^G(c_b^R)$'.

[QED]

A7. Proof of Lemma 5

We have the following.

$$c_b^R = c_b - \Delta$$

$$c_b = \frac{(1-\rho(1-\lambda))}{\rho}[b + f^G(1 - \rho)] + \frac{v_E}{v_T}(e_b - e_g) > 0$$

$$\hat{c} = \underline{c} - \Delta$$

$$\underline{c} = \frac{(1-\rho(1-\lambda))}{\rho(1-\lambda)}[b(1 - \lambda) + f^R\lambda + f^G(1 - \lambda)] + \frac{v_E}{v_T}(e_b - e_g) > 0$$

$$\Delta = 2\gamma\left[H\left(n(1 - \rho(1 - \lambda))\right) - S(n\rho(1 - \lambda))\right]\frac{(1-\rho(1-\lambda))}{v_T} > 0$$

Clearly, $c_b^R < c_b < \underline{c}$ and $\hat{c} < \underline{c}$. It follows that $c_b^R < \hat{c}$, since $c_b < \underline{c}$.

Now, from Lemma 4 and Proposition 3 we get the following, since $c_b^R < \hat{c}$.

(i) If $c \leq c_b^R$, $s^{*OR} = s^{R*} = 0$ and $0 < t^{*OR} = t^{R*} = \underline{t}^G(c)$

(ii) If $c_b^R < c \leq \hat{c}$, (a) $s^{*OR} = c - c_b^R > 0 = s^{R*}$ and (b) $0 < t^{*OR} = \underline{t}^G(c_b^R) < \underline{t}^G(c) = t^{R*}$, since $\frac{\partial \underline{t}^G(c)}{\partial c} < 0$ and $c_b^R < c$.

(iii) If $c > \hat{c}$, (a) $s^{*OR} = c - c_b^R > c - \hat{c} = s^{R*}$ and (b) $0 < t^{*OR} = \underline{t}^G(c_b^R) < \underline{t}^G(\hat{c}) = t^{R*}$, since $\frac{\partial \underline{t}^G(c)}{\partial c} < 0$.

Next, form Lemma 2 and Lemma 4 we get the following, since $c_b^R < c_b$.

(i) If $c \leq c_b^R$, $s^{*OR} = s^{*O} = 0$ and $0 < t^{*OR} = t^{*O} = \underline{t}^G(c)$

(ii) If $c_b^R < c \leq c_b$, (a) $s^{*OR} = c - c_b^R > 0 = s^{*O}$ and (b) $0 < t^{*OR} = \underline{t}^G(c_b^R) < \underline{t}^G(c) = t^{*O}$, since $\frac{\partial \underline{t}^G(c)}{\partial c} < 0$ and $c_b^R < c$.

(iii) If $c > c_b$, (a) $s^{*OR} = c - c_b^R = c - c_b + \Delta = s^{*O} + \Delta > s^{*O} > 0$, since $\Delta > 0$; and (b) $0 < t^{*OR} = \underline{t}^G(c_b^R) < \underline{t}^G(c_b) = t^{*O}$, since $\frac{\partial \underline{t}^G(c)}{\partial c} < 0$.

[QED]

A8. Endogenous Bribe Rate

Assuming that all officials are risk neutral and are identical to each other, except that $\lambda \in (0,1)$ proportion of them are honest while $1 - \lambda$ proportion are dishonest, a dishonest official's incentive compatibility condition to accept bribe b is satisfied if his expected payoff from accepting bribe b is no less than his payoff from not accepting it: $\rho(b + w) + (1 - \rho)0 \geq w \Leftrightarrow b \geq w\frac{1-\rho}{\rho}$. That is, a corrupt official's minimum acceptable bribe rate is given by $\underline{b} = w\frac{1-\rho}{\rho}$, which does not depend on tax-subsidy policy or on the norm regarding corrupt transaction – bribee initiated of briber initiated or on whether non-monetary incentives are in place or not.

Next, given the tax rate and technology choice, let b^j and b^{Oj} denote a type-j firm's maximum willingness to pay as bribe (i) in case briber initiates corrupt transactions and (ii) in case bribee (i.e. official) initiates corrupt transactions, respectively, in absence of non-monetary incentives; where $j \in \{G, B\}$, $j = G$ indicates 'green' and $j = B$ indicates 'brown'. Similarly, in the presence of non-monetary incentives, type-j firm's maximum willingness to pay as bribe are denoted by b^{jR} and b^{OjR} (i) in case briber initiates corrupt transactions and (ii) in case bribee initiates corrupt transactions, respectively.

Note that in case bribee initiates corrupt transactions, if a firm faces a bribe demand at Stage 2, firms become certain that the official is corrupt. Then, the firm updates her belief and sets $\lambda = 0$ and does not face any risk of being subject to penalty f^R, at Stage 2 (as in Section 4). Further, a firm's maximum willingness to pay as bribe is such that the firm is indifferent between paying that amount as bribe and not paying any bribe. Therefore, by using equations (1)-(4) and (11)-(14), we get b^j, b^{Oj}, b^{jR} and b^{OjR} as in equations (21), (22), (23) and (24), respectively; where $P = H(E(x)) - S(E(n-x)) > 0$, $Q = H(E(x)+1) - S(E(n-x-1)) > 0$ and $j = G, B$.

Type-j Firm's Maximum willingness to pay as bribe:

(i) No non-monetary incentive

(a) Briber initiated corrupt transactions

$$\pi_{j,B}\big|_{b=b^j} = \pi_{j,NB}\big|_{b=b^j} \Leftrightarrow b^j = t\rho - f^G(1-\rho) - \frac{f^R\lambda}{(1-\lambda)} \tag{21}$$

(b) Bribee initiated corrupt transactions

$$\pi_{j,B}\big|_{\lambda=f^R=0, b=b^{Oj}} = \pi_{j,NB}\big|_{\lambda=f^R=0, b=b^{Oj}} \Leftrightarrow b^{Oj} = t\rho - f^G(1-\rho) \tag{22}$$

(ii) Non-monetary incentives

(a) Briber initiated corrupt transactions

$$\pi^R_{j,B}\big|_{b=b^{jR}} = \pi^R_{j,NB}\big|_{b=b^{jR}} \Leftrightarrow b^{jR} = t\rho - f^G(1-\rho) - \frac{f^R\lambda}{(1-\lambda)} + \frac{(P+Q)}{\mathrm{v_T}} \tag{23}$$

(b) Bribee initiated corrupt transactions

$$\pi^R_{j,B}\big|_{\lambda=f^R=0, b=b^{OjR}} = \pi^R_{j,NB}\big|_{\lambda=f^R=0, b=b^{OjR}} \Leftrightarrow b^{OjR} = t\rho - f^G(1-\rho) + \frac{(P+Q)}{\mathrm{v_T}} \tag{24}$$

Clearly, a firm's maximum willingness to pay as bribe does not depend on technology choice, ceteris paribus: $b^G = b^B, b^{GR} = b^{BR}$, $b^{OG} = b^{OB}$, and $b^{OGR} = b^{OBR}$. However, it depends on (a) the type of policy intervention (only monetary or both monetary and non-monetary) and magnitude of tax on brown firm t and (b) the prevailing norm regarding corruption (bribee initiated or briber initiated).

For any given brown tax t, a firm's maximum willingness to pay as bribe is less in the case of briber initiated corrupt transactions than that in the case of bribee initiated corrupt transactions, regardless of whether the firm is green or brown and whether there is any non-monetary incentive or not: $b^j < b^{Oj}$ and $b^{jR} < b^{OjR}$, $j = G, B$. This is because firms do not face the risk of offering bribe to an honest official, which results in higher expected payoff of firms from paying the bribe amount, in the former case. Also, for any given brown tax t, a firm's maximum willingness to pay as bribe is more in the presence of non-monetary incentive than that in case there is no non-monetary incentive, regardless of whether the firm is green or brown and whether corrupt transactions are initiated by bribee or briber: $b^{jR} > b^j$ and $b^{OjR} > b^{Oj}$, $j = G, B$. The reason is, in the former case, the green firm is willing to pay higher bribe to get the reward of being green, while the brown firm is willing to pay higher bribe to buy social reputation. It follows that $b^j < b^{jR} < b^{OjR}$ and $b^j < b^{Oj} < b^{OjR}$.

Since $\frac{\partial b^j}{\partial t} = \frac{\partial b^{Oj}}{\partial t} = \frac{\partial b^{jR}}{\partial t} = \frac{\partial b^{OjR}}{\partial t} = \rho > 0$, $j = G, B$, a firm's maximum willingness to pay as bribe can be reduced by setting a lower tax on brown firm. Now, to ensure that no corrupt transaction takes place, $\overline{b} < \underline{b}$ must hold true, where $\overline{b} \in \{b^j, b^{jR}, b^{Oj}, b^{OjR}\}$. Therefore, we have the following.

i) In absence of non-monetary incentives, brown tax t ensures that no corrupt transaction takes place, if

$$t < \begin{cases} \frac{1}{\rho}\left[\underline{b} + f^G(1-\rho) + \frac{f^R\lambda}{(1-\lambda)}\right] = \underline{t^C_{endo}}, & \text{if briber initiates corrupt transactions;} \\ \frac{1}{\rho}\left[\underline{b} + f^G(1-\rho)\right] = t_{b,endo}, & \text{if bribee initiates corrupt transactions;} \end{cases}$$

where $\underline{b} = w\frac{1-\rho}{\rho}$.

ii) In the presence of non-monetary incentives, brown tax t ensures that no corrupt transaction takes place, if

$$t < \begin{cases} \frac{1}{\rho}\left[\underline{b} + f^G(1-\rho) + \frac{f^R\lambda}{(1-\lambda)} - \frac{(P+Q)}{v_T}\right] = \underline{t^{CR}_{endo}}, & \text{if briber initiates corrupt transactions;} \\ \frac{1}{\rho}\left[\underline{b} + f^G(1-\rho) - \frac{(P+Q)}{v_T}\right] = t^R_{b,endo}, & \text{if bribee initiates corrupt transactions;} \end{cases}$$

where $\underline{b} = w\frac{1-\rho}{\rho}$.

Clearly, $t_{b,endo}^{R} < t_{b,endo} < \underline{t_{endo}^{C}}$ and $t_{b,endo}^{R} < \underline{t_{endo}^{CR}} < \underline{t_{endo}^{C}}$.

In Stage 2, i.e., at the technology choice stage, firms' incentive compatibility conditions for choosing the green technology under endogenous bribe rate remains the same as that under exogenously given bribe rate. This is because, at Stage 2 firms cannot update their beliefs regarding the official's type and incentive compatibility conditions for choosing the green technology does not depend on the bribe rate. Therefore, at Stage 2, each firm will find it optimal to choose the green technology, if $t \geq \underline{t^{G}}(c) = \frac{v_T c - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))}$, regardless of whether (a) corrupt transactions are initiated by bribee or by briber, (b) there is non-monetary incentive or not, and (c) bribe rate is endogenous or exogenous. Further, it is easy to check that, if we consider $b = \underline{b}$ in (5), (15), (19) and (20), we get $\underline{t_{endo}^{C}} = \underline{t^{C}}$ (as in (5)), $t_{b,endo} = t_b$ (as in (18)), $\underline{t_{endo}^{CR}} = \underline{t^{CR}}$ (as in (14)) and $t_{b,endo}^{R} = t_b^{R}$ (as in (20)).

Overall, it follows that the quantitative results of the analysis under exogenous bribe rate also remain unchanged in the case of endogenous bribe rate, if the exogenously given bribe rate is equal to the minimum acceptable bribe rate to a corrupt official ($b = \underline{b}$). However, if $b > \underline{b}$, it is fairly straightforward to observe that $\underline{t_{endo}^{C}} < \underline{t^{C}}$, $t_{b,endo} < t_b$, $\underline{t_{endo}^{CR}} < \underline{t^{CR}}$ and $t_{b,endo}^{R} < t_b^{R}$. It implies that, in the later case, implementation of the first best equilibrium outcome under endogenous bribe rate (a) only through a brown tax is feasible for a lower range of the extra cost of green technology compared to that under exogenous bribe rate, (b) calls for a lower brown tax and higher green technology subsidy, when only a brown tax is not sufficient to ensure the first best outcome, compared to that under exogenous bribe rate. This is true, regardless of (a) whether corrupt transactions are initiated by bribee or by briber and (b) whether there is non-monetary incentive or not. Nevertheless, Proposition 4 and Proposition 5 remains valid always regardless of whether bribe rate is exogenously given or endogenously determined in the model.

Remarks: In this paper it is considered that, if $\overline{b} < \underline{b}$, (a) in the case of briber initiated corrupt transactions, the firm offers bribe $b \leq \overline{b}$, but the dishonest official does not accept it and reports the firm as brown regardless of the true type of the firm, and (b) in the case of bribee initiated corrupt transactions, the dishonest official asks for bribe if $b \geq \underline{b}$, but the firm does not accept the bribe demand and gets reported as brown regardless of whether the firm is truly brown or green. That is, while $\overline{b} < \underline{b}$ ensures that no corrupt transaction takes place, it does not rule out the possibility of misreporting of firm's true type, green or brown, by corrupt officials.

An alternative possible scenario is as follows. The dishonest official asks for bribes only in case he can expect to get that, i.e., only in case his minimum acceptable bribe rate is less than or equal to the firm's maximum willingness to pay ($\underline{b} \leq \overline{b}$); otherwise, the dishonest official behaves as an honest official, i.e. he does not ask for any bribe and reports firms technology choice truthfully. In such a scenario, if the norm is such that bribee initiates corrupt transactions, (a) the required brown tax t to ensure that no corrupt transaction takes place will remain unchanged and (b) at the technology choice stage (Stage 2) firms can correctly anticipate that there will not be any bribe demand or misreporting by any official, if brown tax is such that $\overline{b} < \underline{b}$ holds true. It implies that, in the alternative scenario with bribee initiated corrupt transactions, if t is such that $\overline{b}(t) < \underline{b}$ is satisfied, the relevant incentive compatibility condition of firms to choose the green technology will be modified to $v_T y - v_E e_g - v_T c \geq v_T y - v_E e_b - v_T t \Leftrightarrow t \geq \frac{v_T c - v_E(e_b - e_g)}{v_T} = \underline{t^g}(c)$, since this case is equivalent to the case of $\lambda = 1$. Now, since $\underline{t^g}(c) < \underline{t^G}(c) = \frac{v_T c - v_E(e_b - e_g)}{v_T(1-\rho(1-\lambda))}$, both $\overline{b}(t) < \underline{b}$ and $t \geq \underline{t^g}(c)$ will be satisfied for a lower range of c compared to that in the earlier scenario (in which corrupt official always misreports unless bribe is paid). It follows that, *under bribee initiated corrupt transactions in the alternative scenario* (a) *the scope for implementation of the first best equilibrium outcome through the tax instrument alone is less and (b) the 'lowest-subsidy minimum-tax' policy to implement the first best equilibrium* outcome calls for *a lower brown tax a higher green technology subsidy compared to that in the earlier scenario. This is true, regardless of whether there is any monetary incentive or not. Further, implications of non-monetary incentives on the required 'lowest-subsidy minimum-tax' policy remains the same in both the scenarios. Interestingly, in the alternative scenario, implementation of the first best equilibrium outcome under bribee initiated corrupt transactions also guarantees that there will not be any misreporting in the equilibrium.*

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