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Abstract

This paper examines the implications of various forms of corruption—namely, grand corruption, petty corruption, and the cut-money culture—on the formulation and enforcement of regulatory policies. Focusing on quota regulation in the context of natural resource extraction, it demonstrates the following. In absence of cut-money culture, upward distortion in extraction quota in the equilibrium under only grand corruption is less (more) than that in case only petty corruption is possible, when the reduction in the firms' expected effective price under petty corruption is less (more) than the 'discounted net marginal environmental damage' to price ratio under grand corruption. Interestingly, in absence of cut-money culture, petty corrupt never occurs in the equilibrium regardless of whether the policy maker is honest or corrupt. The threat of petty corruption induces the policy maker to inflate the quota, unless the policy maker is corrupt and he sufficiently discounts environmental damage due to extraction. Grand corruption occurs only in the later case. In contrast, when there is cut-money culture, corruption of at least one type always occur in the equilibrium. While the presence of cut-money culture reduces the equilibrium quota in some cases, in each of those cases it results in higher total extraction, greater environmental damage and lower welfare. Our results have important implications for designing corruption control mechanisms and the governance of natural resource extraction.

Keywords: Quota Regulation, Grand Corruption, Petty Corruption, Cut-Money Culture, Natural Resource Extraction, Environmental Damage, Bribe

JELCode: D73, P28, P37

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1 Introduction

Across the globe, many industrial sectors operate under comprehensive regulatory regimes. In several sectors, including mining and forestry, policymakers formulate quota-based regulatory policies, while distinct enforcement bodies are tasked with overseeing compliance.[1] Although the aim of such governance structure is to ensure accountability and improve efficiency, it also serves as a fertile ground for corrupt practices. In such scenarios, corruption typically operates through distinct institutional pathways involving the policy makers or the enforcement agencies. These pathways manifest in two forms of corruption: *grand* corruption and *petty* corruption.[2] In the present context, grand corruption refers to the abuse of high-level authority by policymakers who manipulate regulatory frameworks to favour select large corporations in exchange for bribes.[3] In contrast, petty corruption arises when enforcement agencies accept bribes to overlook regulatory violations.

Natural resource extraction is a salient example of a heavily regulated sector[4], which is plagued by persistent corruption – both *grand* and *petty*.[5] Grand corruption often

[1]In China, the Fisheries Bureau sets total allowable catch quotas, while enforcement is carried out by the Coast Guard (Shen and Heino, 2014; Su et al., 2021; He and Zhang, 2022; Wu et al., 2023). Brazil's Ministry of Environment and Climate Change formulates regulations for timber logging, while the Brazilian Institute of the Environment and Renewable Natural Resources is responsible for enforcement of the regulation (NEPCon, 2017). Nigeria's Electricity Regulatory Commission sets electricity quotas and licensing terms, while implementation is handled by the Transmission Company of Nigeria (Ufondu and Ibeku, 2023; Federal Ministry of Power, 2025; TCN, 2023).

[2]For more details on different corruption typologies, see Amundsen (1999) and Bussell (2015).

[3]Note that lobbying by mining corporations remains largely unregulated, opaque, and illegal in most parts of the world, except for a few Global North nations (Gupta, 2017).

[4]For instance, In Indonesia's mining sector, the Ministry of Energy and Mineral Resources sets annual extraction quotas via the RKAB (Work Plan and Budget Report) approval process, while enforcement is carried out by multiple agencies including national ministries and local government bodies (World Bank, 2018; Market, 2025b). For 2025, Indonesia set a nickel ore mining quota of around 200 million tonnes (Reuters, 2025). Similarly, In China's mining sector, the Ministry of Industry and Information Technology, in coordination with the Ministry of Natural Resources, sets annual production quotas for rare earth mining and smelting through a centralized allocation system to state-owned enterprises, while enforcement is carried out by separate agencies including the National Mine Safety Administration and the Ministry of Ecology and Environment (Global, 2025; Market, 2025a). For 2024, China's first two batches of rare earth production quotas totaled 270,000 tonnes for mining and 254,000 tonnes for smelting and separation, representing year-on-year increases of 5.9% and 4.2% respectively (Lo, 2025).

[5]Several studies identify corruption as a critical mechanism through which resource wealth undermines economic and institutional development, giving rise to what is widely referred to as the *resource curse* (Leite and Weidmann, 1999; Kolstad and Søreide, 2009; Collier and Hoeffler, 2009; Badeeb et al., 2017). Empirical evidence further reinforces the notion that influx of resource rents weakens institutional accountability, heightens rent-seeking incentives, and fosters persistent corruption (Petermann et al., 2007; Vicente, 2010; Arezki and Brückner, 2011; Knutsen et al., 2017). Also see, for example, Kleinschmit et al. (2021) and Resimić (2023).

remains hidden from public view but plays a crucial role in legitimizing over-extraction through regulatory manipulation.[6] In contrast, petty corruption is more visible and typically involves enforcement officials accepting bribes to facilitate illegal mining. Several reports and media articles highlight instances of illegal mining and petty corruption across countries.[7] Beyond the direct bribes tied to grand corruption, growing evidence suggests that corrupt policy makers may also benefit from illegal mining enabled by petty corruption. In particular, when enforcement agencies routinely share a portion of bribes collected through petty corruption with policymakers, the phenomenon of *cut money culture* emerges, contributing to the persistence of illegal mining and the entrenchment of corrupt networks within the regulatory apparatus.[8]

It is important to recognise that, although extraction of natural resources is often essential to the maintenance of modern economies reliant on advancing technologies, it frequently results in considerable environmental damage.[9] The environmental impact of

[6]Al Hasan (2024) and Jong (2022) report that policymakers in Indonesia doubled the tin extraction quota and allowed mining in protected zones by subverting due approval processes. Interestingly, Indonesia rolled out an amnesty scheme that pardoned 18 mining companies operating illegally inside forest areas under the 2020 Job Creation Act, which was deemed unconstitutional by the Constitutional Court in 2021. Similarly, Yurisch Toledo et al. (2024) reports that a major mining company successfully lobbied to secure 350,000-tonne increase in lithium extraction quota in Chile.

[7]For instance, the Justice M.B. Shah Commission uncovered over 12,000 cases of illegal iron ore mining in Karnataka's Bellary district. Between 2003–04 and 2009–10, 77.5 million tonnes of high-grade iron ore were exported against the official quota of 47 million tonnes (Shah, 2012). In China, illegal coal mines operate through routine bribes to local inspection authorities (Homer, 2009; Zhan, 2017). It is argued that illegal mining of coal was carried out with impunity for 14 years in the Qilian Mountains of Qinghai Province in China. Around 26 million tonnes of coal was illegally extracted which severly damaged the water conservation areas that are the upper sources of the Yellow River (Tibetan Review, 2020). Similarly, illegal gold mining along Brazil's Puruê River remains unhindered due to collusion of miners with the Amazonas Millitary Police (Ebus and Pedroso, 2023).

[8]Analysing data from a survey of politicians, ranging from village councillors to members of the Parliament, in Bihar, Jharkhand and Uttar Pradesh in India, Bussell (2013) finds that in cases of policy implementation involving mid-level bureaucrats, a portion of the bribe received is often shared with the policymakers. In Jharkhand and Tamil Nadu, enforcement officials extract bribes from coal and sand miners and distribute them to political intermediaries or policymakers, thereby sustaining a system of coordinated non-enforcement of mining regulations (Singh and Harriss-White, 2019; Jeyaranjan, 2019). Similar collusive arrangements exist in Ghana, where proceeds from illegal gold mining are shared along the political-bureaucratic hierarchy (Crawford and Botchwey, 2017).

[9](Jong, 2025) documents that on Manuran Island in Indonesia, nickel mining has cleared 109 hectares of forests and caused damage to coastal ecosystems through wastewater discharge. (Khomo, 2024) argues that acid mine drainage from abandoned gold mines near Johannesburg, South Africa, has contaminated the Klip River's groundwater and irrigation sources with uranium, arsenic, and lead, which destroys aquatic ecosystems and also enters the food chain via contaminated agricultural produce. Further, local communities get exposed to heavy metal dust from dried deposits. Peñaloza Pacheco et al. (2025) report that lithium extraction around Chile's Atacama Salt Flat has caused significant groundwater depletion and vegetation loss. In China, open-pit coal mining in the Qilian Mountains has led to extensive degradation of alpine meadows and grasslands, severely polluting groundwater and the Datong River, a tributary of the Yellow River (Xu et al., 2023; Ottery, 2014). In Brazil, increased mining activity in the Amazon has deforested over $11,670\ km^2$, which has led to significant biodiversity loss (Gonzaga, 2025;

mining gets further exacerbated in case policymakers legalize over-extraction in exchange for kickbacks or enforcement officials overlook illegal mining in return for bribes.

Given this backdrop, it is important to understand implications of different types of corruption on formulation of resource extraction quotas by policymakers and enforcement of quota regulations, both to govern natural resource extraction more efficiently and to design welfare enhancing corruption control mechanisms. Does grand corruption leads to more extraction of natural resource and greater damage to the environment compared to petty corruption? Which type of corruption is more detrimental to social welfare? Can grand corruption and petty corruption coexist in the equilibrium? If yes, what are are implications of coexistence of both grand and petty corruption? Does cut-money culture enhance the possibility of grand corruption? What does cut-money culture affect the equilibrium extraction quota policy and its enforcement? In this paper, we attempt to answer these questions.

We consider a sequential move game involving three key players: a policy maker, an inspector and a firm. The firm is a pure profit maximizing agent, it extracts a natural resource and sells in the market. Extraction of the resource causes environmental damage. In absence of any regulation, it is optimal for the firms to extract more than the social welfare maximizing amount of the resource. The policy maker determines the extraction quota, i.e. the maximum amount of the resource that the firm can be permitted to extract, while the inspector is supposed to enforce the quota regulation. The policy maker is either honest or corrupt, and the true type of the policy maker is common knowledge. The inspector is also either honest or corrupt, but it is his private information. The policy maker and the firm has some prior belief regarding the true type of the inspector. Corrupt agents are assumed to be behaviourally corrupt, for simplicity. before setting the extraction quota, corrupt policy maker engages in generalized Nash bargaining with the firm to determine the bribe schedule and the firm commits to bribe the policy maker according to the agreed upon bribe schedule. After the policy maker announces the quota, the firm decides on extraction amount, based on prior beliefs regarding the inspector's type. If the inspector is corrupt, the firm can sell the over-extracted amount in the market by bribing the inspector according to pre-existing bribe rate a la Amir and Burr (2015). However, if the inspector is honest, any over-extracted amount of the resource

Sonter et al., 2017).

gets seized by the inspector, and the firm gets to sell only the quota amount of the resource. Moreover, if there is cut-money culture, the inspector shares a fixed proportion of his bribe income with the corrupt policy maker. Considering this set-up and fairly general functional forms of market demand, production cost and environmental damage, we demonstrate the following.

Corruption of any type inflates the equilibrium extraction quota, which results in higher environmental damage and lower welfare compared to those in absence of any corruption. In absence of cut-money culture, if there is possibility of only grand corruption, upward distortion in extraction quota is less (more) than in case only petty corruption is possible, provided that the reduction in the firms' expected effective price under petty corruption is less (more) than the 'discounted net marginal environmental damage' to price ratio under grand corruption.

Interestingly, petty corrupt never takes place in the equilibrium in absence of cut-money culture, regardless of whether the policy maker is honest or corrupt. However, the threat of petty corruption induces the policy maker to inflate the quota such that the firm has no incentive to over-extract as well as does not leave any room for grand corruption, unless the corrupt policy maker sufficiently discounts environmental damage due to extraction. In the later case, only grand corruption occurs – corrupt policy maker sets a very high quota and the firm directly bribes the policy maker alone. In contrast, in the presence of cut-money culture, corruption of at least one type always occur in the equilibrium. While the presence of cut-money culture reduces the equilibrium quota in some cases, in each of these cases it results in higher total extraction, greater environmental damage and lower welfare.

Our results suggest that any evidence of petty corruption is indicative of corrupt policy maker and prevalence of cut-money culture in the society. If it is feasible to refrain policy makers from engaging in corrupt practices, petty corruption can never occur. However, a corruption control mechanism that effectively rules out the possibility of grand corruption, but leaves room for petty corruption and cut money culture, welfare and environmental outcomes are likely to be worse than those in case corrupt policy makers can engage in grand corruption as well. This seems to provide some justification for legalizing lobbying aimed to influence government policies. We also identify conditions under which refraining policy makers to engage in any form of corruption would result in higher welfare and lower environmental damage compared to targetting petty corruption, and vice-versa.

1.1 Related Theoretical Literature and Our Contributions

This paper contributes to two strands of literature - (i) grand and petty corruption (ii) regulation of natural resource extraction under corruption.

Theoretical research on petty corruption often employs the principal-agent framework, where a benevolent principal faces informational asymmetry regarding the enforcement official's actions. Laffont and Tirole (1991) show that an optimal incentive scheme that compensates the official for potential bribes can mitigate petty corruption. However, Burguet et al. (2016) and Kofman and Lawarrée (1996) demonstrate that informational asymmetry between firms and enforcers perpetuates petty corruption in equilibrium. In contrast, grand corruption is analyzed through the special interest group model, where policymakers design policies in exchange for bribes. Grossman and Helpman (1992) and Aidt (1998) illustrate how lobbying by interest groups distorts trade and environmental policy. Damania and Yalçin (2008) show how political competition intensifies such lobbying, sustaining grand corruption in equilibrium. While these studies have examined grand and petty corruption separately, our paper contributes to this strand of literature by comparing environmental and welfare outcomes of regulation under grand and petty corruption, allowing for possible coexistence of grand and petty corruption, and considering the possibility of cut-money culture, which makes the analysis more close to real-life experiences.

We note here that a few studies have attempted direct comparison between grand and petty corruption. In the context of public service delivery, Bardhan and Mookherjee (2006) compare welfare outcomes under centralized petty corruption and local grand corruption. They find that while decentralization can potentially improve delivery of public goods, it may reduce overall welfare if local officials increasingly become susceptible to elite capture– echoing our finding that targeting grand corruption while minimizing the perception of petty corruption can mitigate overall corruption and reduce welfare losses. Damania et al. (2004) examine how firms strategically bribe high-level policymakers to weaken regulatory frameworks, thereby sustaining grand corruption while creating an environment that fosters petty corruption. In contrast, our results suggest that the presence of cut money culture that sustains both grand and petty corruption in equilibrium. Harstad and Svensson (2011) compare lobbying and petty bribery, showing that bribery leads to a poverty trap whereas lobbying signals development. They also find that firms lobby to remove 'bad' regulations rather than 'good' ones. Our results diverge: we examine a monopolist lobbying to relax the extraction quota, an environmentally harmful "bad" regulation, and show that under certain conditions, grand corruption results in lower welfare and higher environmental damage than petty corruption.

As mentioned before, our paper also contributes to the literature on natural resource regulation under corruption. Prior research in environmental economics has largely focused on policy design to mitigate corruption's effects. Barbier et al. (2005) show how corrupt policymakers relax environmental regulations in exchange for bribes, facilitating resource depletion. Wilson and Damania (2005) find that weak enforcement undermines the effectiveness of environmental policy, sustaining both grand and petty corruption. Amacher et al. (2012) demonstrate that even optimal concession policies cannot eliminate petty corruption in commercial logging. In contrast, we allow for possible existence of both petty and grand corruption as well as of cut-money culture, and we compare and contrast environmental and welfare outcomes under each possible scenarios.

Datt (2016) and Ranjan (2018) are the two studies more closely related to the present paper. Datt (2016) models illegal mining as under-reporting by state-level politicians, capturing petty corruption within a stratified federal structure, and argue that politicization of audit institutions increases illegal mining. Instead, we model grand corruption explicitly and show that petty corruption is sustained only when the policymaker colludes with enforcement officials for a cut of petty bribe. Ranjan (2018) considers a framework in which a corrupt politician accepts bribe from a mining firm to manipulate the regulatory framework by reducing environmental penalties and to overlook illegal mining as well. In contrast, our model distinguishes between bribes paid to the policy maker and the enforcement inspector, and allows for their collusion under the cut-money culture.

The rest of the paper is organized as follows. Section 2 presents the model, Section 2.1 analyses the implications of only grand corruption, Section 2.2 considers the possibility of only petty corruption, and Section 2.3 offers a comparison between grand and petty corruption. Section 3 examines implications of both grand and petty corruption in absence of cut-money culture. Section 4 analyses implications of cut-money culture, both in absence of grand corruption (Section 4.1) and in the presence of grand corruption (Section 4.2) , separately. Section 5 concludes.

2 The Model

Consider that there is a policy maker (SP), an inspector (I) and a large profit maximising firm (M), all of whom are risk-neutral. M extracts a natural resource and sells in the market. SP aims to regulate extraction of the natural resource by setting extraction quota e, which is the maximum permissible amount of extraction of the resource. Only M is capable of extracting the resource, i.e., M is the monopolist in the market for the resource. I's task is to enforce the quota regulation, i.e., to ensure that the firm does not extract more than the amount e of the natural resource.

The aggregate (inverse) market demand function and the monopolist's cost of extraction of the natural resource are, respectively, given by $p = p(q)$ and $C = C(q)$; where p and $q(\geq 0)$ are price and quantity of the natural resource, respectively. The natural resource serves as an input for the production of other goods and services, and its extraction generates an economy-wide multiplier effect. In other words, the extraction of the resource produces a spillover economic benefit. However, this process also results in environmental harm. Let $D(q)$ represent the net environmental damage caused by extraction of q amount, which is defined as the environmental harm minus the sum of spillover economic benefit and buyers' surplus.[10] We adopt the following assumption to ensure the analysis remains both tractable and meaningful.

Assumption 1. *(a) $p(q)$, $C(q)$ and $D(q)$ are twice continuously differentiable in $q(\geq 0)$.*

(b) $C'(q) > 0$, $C''(q) > 0$, $D'(q) > 0$, and $D''(q) > 0$ $\forall q \geq 0$; $C(0) = D(0) = 0$.

(c) $p'(q) < 0$ and $p''(q) < 0$ $\forall q \geq 0$. $p(0) > M$ and $p(K) = 0$, where $M(\geq C'(0)+D'(0))$ and K are sufficiently large finite positive numbers.

[10] We can write $D(q) = \tilde{D}(q) - \zeta G(q)$, where $\tilde{D}(q)$ is the environmental damage and $G(q)$ is the sum of spillover economic benefit and buyers' surplus created due to extraction of q amount of the natural resource. The parameter $\zeta \in [0, 1]$ measures the proportion of the total spillover economic benefit accrued to the domestic economy, which is inversely proportional to the share of the extracted amount of the natural resource sold in foreign market(s).

Assumption 1 states that M's marginal cost of extraction and the marginal net environmental damage due to extraction are positive and increasing in the amount of extraction. It also states that the market demand function is concave and, for arbitrarily small amount of extraction, market price is strictly greater than the marginal net social cost of extraction (defined as, marginal private cost of extraction plus marginal net environmental damage due to extraction), i.e, the market exists and is socially desirable.

Now, in absence of any regulation, M's profit ($\pi(q)$) and social welfare ($W(q)$), respectively, can be expressed as follows.

$$\pi(q) = qp(q) - C(q) \tag{1}$$

$$W(q) = qp(q) - C(q) - D(q) \tag{2}$$

By Assumption 1, $\pi(q)$ and $W(q)$ are concave functions. Thus, in absence of any regulation, M's optimal quantity of extraction $q^* = \underset{q(\geq 0)}{Argmax}\, \pi(q)$, i.e., q^* satisfies the following equation.

$$\underbrace{p(q^*) + q^* p'(q^*)}_{\text{marginal revenue}} = \underbrace{C'(q^*)}_{\text{marginal private cost}} \tag{3}$$

On the other hand, the welfare maximizing, i.e., the socially optimal, quantity of extraction is $q^{FB} = \underset{q(\geq 0)}{Argmax}\, W(q)$, i.e., q^{FB} is given by the following.

$$\underbrace{p(q^{FB}) + q^{FB} p'(q^{FB})}_{\text{marginal revenue}} = \underbrace{C'(q^{FB}) + D'(q^{FB})}_{\text{marginal net social cost}} \tag{4}$$

From equations 3 and 4, we get the following.

Lemma 1. *Suppose that Assumption 1 holds true. Then, we have the following.*

(a) $0 < q^{FB} < q^*$ *and* $\pi(q^{FB}) < \pi(q^*)$.

(b) $D(q^{FB}) < D(q^*)$ *and* $W(q^{FB}) > W(q^*)$.

Proof: See Appendix

Lemma 1(a) states that, in absence of any regulation, it is optimal for M to extract more amount of the natural resource compared to the socially optimal level. This is because the monopolist does not account for the net environmental damage caused by extraction, unlike in the case of welfare maximisation. Consequently, in the unregulated monopoly equilibrium, net environmental damage is higher, and social welfare is lower than at the socially optimal level of extraction (Lemma 1(b)).

Therefore, from both environmental and social welfare perspectives, it is essential to regulate the extraction of natural resources. To this end, we assume that the social planner seeks to regulate the monopolist by imposing an upper limit (i.e., quota) on extraction e. However, it is well-documented in the literature that regulation can give rise to the possibility of corruption, which may undermine its purpose. In the present context, if $e < q^*$, M may have an incentive to circumvent the quota regulation through corrupt practices.

Before examining the implications of corruption, let us first consider a hypothetical scenario in which there is no scope for corruption. In this scenario, SP first sets the quota e (≥ 0) to maximize welfare. Next, M chooses the amount of extraction $q \in [0, e]$ to maximize its profit. It is straightforward to observe that, in absence of corruption, in the equilibrium (a) SP sets the extraction quota $e = q^{FB}$, where q^{FB} is given by equation 4, (b) M fully complies with the quota regulation, extracts q^{FB} amount of the natural resource and earns profit $\pi(q^{FB})(< \pi(q^*))$, and (c) environmental damage and social welfare are at the socially optimal level.

Lemma 2. *(No Corruption Equilibrium) Suppose that Assumption 1 is true and there is no scope for corruption, then in the equilibrium we have the following. (a) The policy maker sets the socially optimal extraction amount as the quota:* $e = q^{FB}(> 0)$. *(b) The monopolist fully complies with the quota regulation and extracts* q^{FB} *amount of the natural resource.*

Proof: See Appendix

Suppose that SP and I may be susceptible to corruption. M, being concerned only about profit, engages in illegal practices whenever it proves to be more profitable. Let $\theta_i \in \{0, 1\}$ be an indicator variable such that $\theta_i = \begin{cases} 1, \text{ if agent } i \text{ is corrupt} \\ 0, \text{ if agent } i \text{ is honest} \end{cases}$, $i \in \{SP, I\}$. We consider that the following are common knowledge.

(a) Prior beliefs of M and I regarding SP's type is as follows. $Prob(\theta_{SP} = 1) = \mu$, $Prob(\theta_{SP} = 0) = 1 - \mu$; $\mu \in \{0, 1\}$

(b) Prior beliefs of M and SP regarding I's type is as follows. $Prob(\theta_I = 1) = \rho$, $Prob(\theta_I = 0) = 1 - \rho$; $\rho \in [0, 1]$

(c) The corruption control mechanism, which is exogenously determined by a third party, is ineffective in the following sense. Corrupt agents are behaviorally corrupt and they always engage in corrupt practices, given the corruption control mechanism. In contrast, an honest agent's intrinsic valuation of remaining honest is sufficiently high and an honest agent never deviates from honesty.

Now suppose that M extracts $q = e + x(e)$ amount of the resource, where $x(e)$ (≥ 0) denotes the amount of illegal extraction. I's technology of detecting the amount of illegal extraction is perfect, regardless of the type of I, honest $(\theta_I = 0)$ or corrupt $(\theta_I = 1)$. If $\theta_I = 0$, the entire amount of illegally extracted resource gets sized and sold in the market by SP. So, if $\theta_I = 0$, M cannot recover any part of the extra cost incurred, $C(e + x(e)) - C(e)$ $(> 0, \forall x(e) > 0)$, to extract the illegal amount $x(e)$. In contrast, if $\theta_I = 1$, M gets away with the illegally extracted amount $x(e)$ by paying bribe of amount $B_I = b[x(\cdot)p(e + x(\cdot))]$ to I – the case of *petty corruption*. Following Amir and Burr (2015), we consider that I can extract an exogenously fixed proportion, $b \in (0, 1)$, of M's revenue from illegal extraction $[x(\cdot)p(e + x(\cdot))]$ as bribe. Note that, if $x(e) = 0$, $B_I = 0$, i.e., a corrupt I can extract bribe only if M's extraction level has exceeded the quota. That is, for simplicity, we rule out the possibility of harassment of and extortion from lawful business owners by the inspector.

On the other hand, if SP is corrupt $(\theta_{SP} = 1)$, M may engage with SP to influence the policy decision, i.e., to influence SP's choice of quota e, by paying bribe according to a bribe schedule $S(e)$ – the case of *grand corruption*. Moreover, if both SP and I are corrupt and I takes bribe B_I from M, I needs to pass on a share, $\lambda \in [0, 1)$, of B_I to SP; where $\lambda > 0$ $(\lambda = 0)$ corresponds to the scenario in which *cut money culture* prevails (does not exist).

Suppose that, given $\rho \in [0, 1]$, $\lambda \in [0, 1)$ and $b > 0$, (i) e^{NG} denotes the optimal quota choice of SP in absence of grand corruption and $E\pi|_{e=e^{NG}} (> 0)$ denotes the corresponding expected profit of M, and (ii) in the presence of grand corruption, M's expected profit net of direct bribe payment to SP is denoted by $E\pi|_e - S(e)$. Then, M will agree to bribe schedule $S(e)$ if and only if $E\pi|_e - S(e) > E\pi|_{e=e^{NG}}$. On the other hand, SP can get bribe payment $S(e)$ from M only if it is profitable for M to pay $S(e)$, otherwise, SP does not receive any bribe from M.

We consider that $S(e)$ is determined through generalized Nash bargaining between corrupt SP and M. Let γ and $(1-\gamma)$ denote bargaining powers of SP and M, respectively, where $\gamma \in (0,1)$. Then, the bribe schedule is given by the following.

$$\begin{aligned} S(e) &= \underset{S(e)\geq 0}{Argmax}[S(e)-0]^{\gamma}[E\pi|_{e} - S(e) \; - E\pi|_{e=e^{NG}}]^{(1-\gamma)} \\ \Rightarrow S(e) &= \begin{cases} \gamma[E\pi|_{e} \; - E\pi|_{e=e^{NG}}], \;\text{ if } e \text{ is such that } E\pi|_{e} > E\pi|_{e=e^{NG}} \\ 0, \text{ otherwise} \end{cases} \end{aligned} \tag{5}$$

It folows that $EB_{SP} = S(e) + \lambda\rho B_I$ is the expected bribe income of corrupt SP, where $S(e)$ is given by equation 5. We consider that SP of type $\theta_{SP} \in \{0,1\}$ sets quota e to maximize $O_{\theta_{SP}}$, which is as follows.

$$O_{\theta_{SP}} = (1-\theta_{SP})W(q(e)) + \theta_{SP}[\alpha W(q(e)) + (1-\alpha)EB_{SP}], \text{ where } \alpha \in (0,1) \tag{6}$$

Equation 6 implies that, honest SP ($\theta_{SP} = 0$) sets the welfare maximizing level of quota, since $O_0 = W(q(e))$. However, if SP is corrupt, i.e, if $\theta_{SP} = 1$, extraction quota e is set to maximize a convex combination of welfare and corrupt SP's bribe income: $O_1 = \alpha W(q(e)) + (1-\alpha)EB_{SP}$, where the parameter $\alpha \in (0,1)$ measures the distortion due to corruption at the top. A lower value to α indicates larger deviation of a corrupt SP from welfare maximization, which is likely to cause more distortion in the choice of quota.

We consider a sequential move game involving SP, M and I as players, stages of which are as in Figure 1.

Figure 1: Stages of the Game

Stage 1: Mother Nature determines the types of SP and I, that is, θ_{SP} and θ_I. SP and I each learn their own type privately. That is, agent i observes the value of θ_i, which is agent i's private information; $i = SP, I$.

Stage 2: SP truthfully reveals his true type, i.e., SP's true type becomes common knowledge.[11]

[11]This may be due to the following. If SP is corrupt (honest), M and I receive an informative signal $\sigma = \sigma_1$ ($\sigma = \sigma_0 \neq \sigma_1$) from SP. Upon receiving the signal, M and I update their prior beliefs regarding the true type of SP as follows. (i)$Prob(\theta_{SP} = 0|\sigma_0) = 1$ and $Prob(\theta_{SP} = 1|\sigma_0) = 0$, and

Stage 3: If SP is corrupt (i.e., $\theta_{SP} = 1$), M commits to the bribe schedule $S(e)$, which is determined through generalized Nash bargaining between SP and M and is given by equation 5. Otherwise, if SP is honest (i.e., $\theta_{SP} = 0$), the game directly moves to Stage 4.

Stage 4: SP of type θ_{SP} chooses the level of quota e to maximize $O_{\theta_{SP}}$, which is given by equation 6. SP's choice of quota becomes common knowledge.

Stage 5: Given the quota e, M decides the level of extraction $q(e)$.

Stage 6: I caries out inspection and observes actual level of extraction, $q(e)$, carried out by M in Stage 5. If $x(e) = q(e) - e > 0$, the over extracted amount $x(e)$ gets seized in case I is honest. On the other hand, if I is corrupt and $x(e) > 0$, (i) I demands bribe of amount $B_I = bx(e)p(q(e))$ from M, where $b \in (0, 1)$, (ii) M can get away with the over extracted amount by committing to pay the bribe amount $B_I(< x(e)p(q(e)))$ to I, and (iii) I commits to pass on λB_I amount to SP in case I has received the signal $\sigma = \sigma_1$ in Stage 1, where $\lambda \in [0, 1)$.

Stage 7: Market transactions take place and payoffs are realized.

Note that we consider the scenario in which, unlike SP, I cannot reveal his true type before M carries out extraction activity. The uncertainty regarding the type of I gets resolved in Stage 6, i.e., after extraction of the natural resource has taken place. This is similar to the scenario in which there are many inspectors, of whom $\rho \in [0, 1]$ proportion are corrupt, and one of the inspectors is randomly assigned to inspect M's extraction level.

It is evident that, if $\rho = 0$, it is never optimal for M to carry out illegal extraction in Stage 5. In other words, if $\rho = 0$, in Stage 5 it is always optimal for M to set $q(e) = e$, i.e., to fully comply with the quota regulation determined by SP in Stage 4. Clearly, there is no scope for petty corruption if $\rho = 0$. On the other hand, if $\theta_{SP} = 0$, there is no scope for grand corruption either. Therefore, if $\theta_{SP} = 0 = \rho$, there does not exist any possibility of corruption, grand or petty, and no illegal extraction occurs in the equilibrium. The

(ii) $Prob(\theta_{SP} = 0|\sigma_1) = 0$ and $Prob(\theta_{SP} = 1|\sigma_1) = 1$. That is we consider a game under imperfect information, and not a game under incomplete information. We make this assumption for simplicity. It might be interesting to extend the present analysis by considering a cheap talk game, wherein SP may have an incentive not to reveal his true type.

equilibrium outcomes in this scenario ($\theta_{SP} = 0 = \rho$) of *no corruption* are as in Lemma 2. However, if $\rho = 0$ and $\theta_{SP} = 1$, *grand corruption* may occur. Alternatively, if $\rho > 0$, *petty corruption* is possible if $\theta_I = 1$. Thus, if $\rho > 0$, $\theta_I = 1$ and $\theta_{SP} = 0$, only *petty corruption* is possible. However, if $\rho > 0$ and $\theta_{SP} = \theta_I = 1$, both *petty corruption* and *grand corruption* are possible. In the latter case, *cut money culture* may also exist depending on whether $\lambda > 0$ or not.

In the subsequent sections, we examine the scenarios individually, focusing on: (a) grand corruption alone, (b) petty corruption alone, (c) both grand and petty corruption without the presence of 'cut money' culture, and (d) 'cut money' culture. We then compare and contrast the equilibrium outcomes across these scenarios.

2.1 Grand Corruption

Let us first consider the scenario in which only grand corruption is possible ($\theta_{SP} = 1$ and $\rho = 0$). Note that, when $\rho = 0$, i.e., when petty corruption is not possible, if grand corruption does not occur due to disagreement between M and SP of type $\theta_{SP} = 1$ over bribe schedule, corrupt SP's optimal choice of quota $e^{NG}|_{\rho=0} = q^{FB} = \underset{e \geq 0}{Argmax} W(e)$. This is because (i) $O_1 = \alpha W(e)$, where α is a positive constant, since $EB_{SP}|_{S(e)=0,\rho=0} = 0$, (ii) $W(e)$ is maximum at $e = q^{FB} < q^*$, and (iii) in absence of petty corruption, it is optimal for M to set $q(e)$ in Stage 5 as follows. [12]

$$q(e) = \begin{cases} e, \text{ if } e \leq q^* \\ q^*, \text{ if } e > q^* \end{cases} \tag{7}$$

It follows that, when $\rho = 0$ and $\theta_{SP} = 1$, in Stage 3 M commits to the bribe schedule $S(e) = \begin{cases} \gamma[\pi(e) - \pi(q^{FB})] > 0 \, if \, e \in (q^{FB}, q^*] \\ \gamma[\pi(q^*) - \pi(q^{FB})] > 0 \, if \, e > q^* \end{cases}$, from equation 5 and Lemma 1. It is evident that it is optimal for M not to bribe SP for any level of quota $e \leq q^{FB}$. Also, note that for all $e > q^*$, we have $q(e) = q^*$, $W(q(e)) = W(q^*)$ and $EB_{SP} = S(e) = S(q^*)$. Thus, from equation 6, we have the following.

(i) $O_1(e|\rho = 0)|_{e=q^*} = O_1(e|\rho = 0)|_{e>q^*}$.

[12]In case of disagreement over bribe schedule, SP does not receive any bribe payment from M, which is equivalent to setting $S(e) = 0$.

(ii) For all $e \in (q^{FB}, q^*]$,

$$O_1(e|\rho = 0) = \alpha W(e) + (1-\alpha)\gamma\big(\pi(e) - \pi(q^{FB})\big)$$
$$= \big(\alpha + (1-\alpha)\gamma\big)\Big(\pi(e) - \delta D(e)\Big) - (1-\alpha)\gamma\pi(q^{FB}),$$

where $\delta = \frac{\alpha}{\alpha+(1-\alpha)\gamma} \in (0,1)\,\forall \alpha, \gamma \in (0,1)$ is the factor by which corrupt SP discounts net environmental damage under grand corruption.

It follows that the corrupt SP's problem in Stage 4 can be written as follows.

$$\underset{e\in(q^{FB},q^*]}{Max} O_1(e|\rho = 0) = \alpha W(e) + (1-\alpha)\gamma[\pi(e) - \pi(q^{FB})] \equiv \underset{e\in(q^{FB},q^*]}{Max} [\pi(e) - \delta D(e)] \quad (8)$$

Note that (a) $\frac{\partial O_1(\rho=0)}{\partial e}|_{e=q^{FB}} = (1-\alpha)\pi'(q^{FB}) > 0$, since $W'(q^{FB}) = 0$, $\pi'(q) > 0$ for all $q < q^*$, and $q^{FB} < q^*$; (b) $\frac{\partial O_1(\rho=0)}{\partial e}|_{e=q^*} = (1-\alpha)W'(q^*) < 0$, since $\pi'(q^*) = 0$, $W'(q^*) < 0$; and (c) $\frac{\partial^2 O_1(\rho=0)}{\partial e^2} < 0$ by Assumption 1. Therefore, there exists a unique $e = e^{GC} \in (q^{FB}, q^*)$ such that $e^{GC} = \underset{e\in(q^{FB},q^*]}{Argmax} O_1(\rho = 0)$.

Lemma 3. *(Equilibrium under Grand Corruption) Suppose that Assumption 1 is true, the policy maker is corrupt and the monopolist believes that the inspector is honest ($\rho = 0$). Then the following is true.*

(a) In the equilibrium under grand corruption, the policy maker sets extraction quota e^{GC} such that $q^{FB} < e^{GC} < q^*$, and the monopolist extracts $q^{GC} = e^{GC}$ amount of the natural resource.

(b) Grand corruption occurs in the equilibrium. The monopolist pays bribe of amount $\gamma\big(\pi(q^{GC}) - \pi(q^{FB})\big)(> 0)$ to the policy maker.

Proof: Follows immediately from the above discussion.

Lemma 3 states that, in the equilibrium under grand corruption, SP sets the extraction quota at a higher (lower) level compared to the socially (privately) optimal level in absence of any corruption (regulation). The reason is, under grand corruption, corrupt SP under values net environmental damage $D(\cdot)$ compared to M's profit. To illustrate it further, corrupt SP sets quota e^{GC} such that

$$\underbrace{p(e^{GC}) + e^{GC}p'(e^{GC})}_{\text{marginal revenue}} = \underbrace{C'(e^{GC}) + \delta D'(e^{GC})}_{\text{discounted marginal social cost}}, \quad (9)$$

where $\delta = \frac{\alpha}{\alpha+(1-\alpha)\gamma} \in (0,1)$ is the factor by which corrupt SP discounts net environmental damage while deciding on the level of quota. In contrast, in absence of any corruption SP does not under value net environmental damage (see equation 4 and Lemma 2), M completely ignores net environmental damage and extracts at the privately optimal level in absence of any regulation (see equation 3).

Note that $\frac{\partial \delta}{\partial \alpha} > 0$ and $\frac{\partial \delta}{\partial \gamma} < 0$, i.e., if SP attaches a higher weight to bribe income or SP's bargaining power over the bribe schedule is higher, SP discounts net environmental damage to a larger extent and, thus, sets quota e^{GC} closer to (further away from) the unregulated privately optimal level q^* (socially optimal level in absence of any corruption q^{FB}).

Lemma 4. *(a)* $\frac{\partial e^{GC}}{\partial \alpha} = \frac{\partial q^{GC}}{\partial \alpha} < 0$ *and (b)* $\frac{\partial e^{GC}}{\partial \gamma} = \frac{\partial q^{GC}}{\partial \gamma} > 0$*; for all* $\alpha, \gamma \in (0, 1)$

Proof: See Appendix

From Lemma 3 and Lemma 4 it follows that (a) the greater the deviation of SP from welfare maximization (i.e., the lower the value of α) and/or (b) the higher the bargaining power of SP over the bribe schedule, the higher the distortion in the choice of quota and consequently, the greater the level of extraction by M in the equilibrium under grand corruption.

Lemma 5. $W(q^{FB}) > W(q^{GC}) > W(q^*)$ *and* $D(q^{FB}) < D(q^{GC}) < D(q^*)$

Proof: See Appendix.

Lemma 5 states that regulation under grand corruption leads to reduced environmental damage and increased welfare compared to the absence of regulation. However, when grand corruption occurs under regulation, the equilibrium environmental damage is greater, and welfare is lower, compared to that under regulation in absence of any potential for corruption. As previously noted, in the latter case, the equilibrium outcomes are socially optimal.

2.2 Petty Corruption

Suppose that SP is honest ($\theta_{SP} = 0$), I is corrupt ($\theta_I = 1$), and M and SP believes that I is corrupt with some positive probability ($\rho > 0$). Then, only petty corruption is possible. Also, since SP is honest, cut money culture cannot exist. In this scenario, given the extraction quota $e(> 0)$, if M over-extracts by an amount $x(\geq 0)$ in Stage 5,

M's expected profit can be written as follows.

$$E\pi(x|e) = (e+\rho x)p(e+x) - C(e+x) - \rho bxp(e+x), \tag{10}$$

where $x > 0$ corresponds to over-extraction and $x = 0$ corresponds to extraction at the level of quota.

Assumption 2. $1-\rho(1-b) < \frac{p(q^{FB})-C'(q^{FB})}{p(q^{FB})} - \frac{1}{\epsilon^d|_{q=q^{FB}}}$, *where* q^{FB} *is the socially optimal extraction in absence of any corruption (given by equation 4) and* $\epsilon^d|_{q=q^{FB}} = -\frac{\partial ln(q)}{\partial ln(p)}|_{q=q^{FB}}$ *is the absolute price elasticity of demand at* $q = q^{FB}$.

Note that the left hand side (LHS) of the inequality in Assumption 2, $1-\rho(1-b)$, can be interpreted as 'proportionate decrease in M's expected effective revenue (i.e, expected revenue net of bribe payment) from over-extraction due to quota regulation under petty corruption', since (i) $1-\rho(1-b) = \frac{xp(e+x)-\rho(1-b)xp(e+x)}{xp(e+x)}$, (ii) $xp(e+x)$ is the revenue from extracting amount x over and above amount e in absence of any regulation, and (iii) when the regulation under petty corruption stipulates extraction quota to be equal to e, M's expected effective revenue from over extraction by x amount is $\rho(1-b)xp(e+x)$. Clearly, $1-\rho(1-b)$ can also be interpreted as 'proportionate reduction in expected effective price (i.e., expected price net of bribe payment) of over-extracted amount in the presence of quota regulation under petty corruption'. Next, the first term in the right hand side (RHS) of the inequality in Assumption 2, $\frac{p(q^{FB})-C'(q^{FB})}{p(q^{FB})}$, is the monopolist M's markup if it extracts q^{FB} amount and extraction quota e is not less than q^{FB}; while the second term, $\frac{1}{\epsilon^d|_{q=q^{FB}}}$, is the inverse absolute price elasticity of demand at $q = q^{FB}$, which equals the markup if and only if $q = q^{FB} \leq e$ is M's optimum choice. Thus, the RHS can be interpreted as the excess markup of the monopolist when it extracts q^{FB} amount and $q^{FB} \leq e$. Therefore, Assumption 2 states that, if extraction quota is set at $e = q^{FB}$, M's excess markup at the level of quota is greater than proportionate reduction in expected effective price for over-extracted amount, if any.

Lemma 6. *Suppose that (i) Assumptions 1 and 2 hold true, and (ii)* $\theta_I = 1$ *and* $\rho > 0$. *Let* $x(e) = \underset{x\geq 0}{Argmax}\, E\pi(x|e)$. *Then, the following is true.*

(a) If SP sets $e = q^{FB}$, *it is optimal for M to over-extract the resource:* $x(e)|_{e=q^{FB}} > 0$.

(b) There exists a unique $e = e^{PC} \in (q^{FB}, q^*)$ *such that* $x(e) \begin{cases} > 0, \forall e < e^{PC} \\ = 0, \forall e \geq e^{PC} \end{cases}$ *; where*

e^{PC} is given by $e^{PC}p'(e^{PC}) + \rho(1-b)p(e^{PC}) - C'(e^{PC}) = 0$.

Proof: See Appendix.

Lemma 6 states that M has an incentive to over-extract the resource, if extraction quota e is less than the critical level $e^{PC} \in (q^{FB}, q^*)$. Otherwise, if extraction quota is no less than e^{PC}, i.e., if $e \geq e^{PC}$, M does not have any incentive to over-extract. It also states that by setting quota at the 'socially optimal level of extraction in absence of any corruption', i.e., by setting $e = q^{FB}$, SP cannot induce M not to engage in over-extraction of the resource.

Lemma 7. *Suppose that (i) Assumptions 1 and 2 hold true, and (ii) $\theta_I = 1$ and $\rho > 0$. Then, given the extraction quota $e(> 0)$, M's optimal level of extraction q^{PC} is as follows.*

$$q^{PC} = \begin{cases} e + x(e),\ if\ e \in (0, e^{PC}) \\ = e,\ if e \in [e^{PC}, q^*) \\ = q^*,\ if\ e \geq q^* \end{cases} ;\ where\ x(e) = \underset{x\geq 0}{Argmax}\, E\pi(x|e)\ and\ q^*\ is\ M\text{'s}$$

optimal quantity of extraction in absence of any regulation, which is given by equation 3.

Proof: See Appendix

If it evident from Lemma 7 that it is optimal for M to over-extract and engage in petty corruption, if the extraction quota chosen by SP is less than a critical level, i.e, if $e < e^{PC}$. Otherwise, if extraction quota e is sufficiently large ($e \geq e^{PC}$), over-extraction will not occur in the equilibrium, which implies that petty corruption will not occur in the equilibrium. In other words, over-extraction and petty corruption will occur in the equilibrium in Stage 5 and in Stage 6, respectively, if and only if SP sets quota $e < e^{PC}$ in Stage 4 of the game.

Lemma 8. *Suppose that (i) Assumptions 1 and 2 hold true, and (ii) $\theta_I = 1$ and $\rho > 0$. Also, suppose that SP sets extraction quota $e < e^{PC}$ in Stage 4 of the game. Then, the Stage 5 equilibrium amount of over-extraction $x(e)$ satisfies the following properties.*

(a) $\frac{\partial x(e)}{\partial \rho} > 0$ *and* $\frac{\partial x(e)}{\partial b} < 0$.

(b) $\frac{\partial x(e)}{\partial e} < 0$ *and* $\frac{\partial (e+x(e))}{\partial e} < 0$.

Proof: See Appendix

If the prior probability of I being corrupt (ρ) is higher or if bribe rate (b) is lower, M's expected revenue from over extraction is higher, ceteris paribus, and, thus, proportionate reduction in M's expected revenue loss from over-extraction due to petty corruption

$(1-\rho(1-b))$ is lower. Therefore, for any given $e \in (0, e^{PC})$, it is optimal for M to over-extract more in case ρ is higher or b is lower (Lemma 8(a)). Next, the higher the extraction quota (e), the lower the marginal expected profit from over-extraction, ceteris paribus. As a result, the the optimal amount of over extraction is decreasing in quota. Moreover, marginal revenue of extraction is higher if extraction is legal compared to that in case extraction level is above the quota, since the effective price received by M in case x amount is over extracted, $\rho(1-b)p(e+x$, is less that the market price $p(e+x)$. As a result, an increase in quota reduces over-extraction by a disproportionately higher amount: $\frac{\partial x(e)}{\partial e} < -1$ (Lemma 8(b)).

Now, since in the present scenario SP is honest ($\theta_{SP} = 0$), we have $O_0 = W(q(e))$ (from equation 6). Thus, SP's problem in Stage 4 can be written as follows.

$$\left.\begin{aligned} \underset{e\geq 0}{Max}\, W(q(e)) \quad &= q(e)p(q(e)) - C(q(e)) - D(q(e)) \\ &\text{subject to the constraint,} \\ &q(e) = q^{PC}, \text{where}\, q^{PC}\, \text{is as in Lemma 7} \end{aligned}\right\} \tag{11}$$

Solving the above problem, we get the following.

Lemma 9. *(Equilibrium under Petty Corruption) Suppose that (i) Assumptions 1 and 2 hold true, and (ii) $\theta_{SP} = 0$, $\theta_I = 1$ and $\rho > 0$. Then, the following is true in the equilibrium.*

(a) SP sets quota $e = e^{PC} \in (q^{FB}, q^*)$, where e^{PC} is given by $\frac{\partial E\pi(x|e=e^{PC})}{\partial x}|_{x=0} \Leftrightarrow e^{PC}p'(e^{PC}) + \rho(1-b)p(e^{PC}) - C'(e^{PC}) = 0$.

(b) M extracts $q^{PC} = e^{PC}$ amount of the natural resource.

(c) Neither over-extraction nor petty corruption takes place.

Proof: See Appendix

It is interesting to note that, albeit there is possibility of petty corruption, an honest policy maker can ensure that no corruption takes place by designing the quota regulation appropriately, and it is optimal for the honest policy maker to do so.

Lemma 10. *$W(q^{FB}) > W(q^{PC}) > W(q^*)$ and $D(q^{FB}) < D(q^{PC}) < D(q^*)$*

Proof: See Appendix.

Lemma 10 implies that, when there is possibility of petty corruption, quota regulation results in a lower environmental damage and a higher welfare, compared to those in absence of any regulation. However, the threat of petty corruption causes more environmental damage and reduces welfare compared to that in absence of any corruption possibility.

From Lemma 5 and Lemma 10, it follows that quota regulation results in both higher welfare and lower environmental damage, despite having regulation induced corruption possibilities – grand or petty, compared to that in free market without any regulation.

2.3 Grand Corruption versus Petty Corruption: A Comparison

Does regulation under grand corruption lead to greater environmental damage compared to regulation under petty corruption? Which type of corruption—grand or petty—is relatively less wasteful from a social welfare perspective? We endeavour to address these questions in this section.

Proposition 1. *If the policymaker is corrupt and petty corruption is not plausible, in the equilibrium grand corruption occurs and the policy maker distorts the extraction quota upward in exchange for bribes. Conversely, if the policy maker is honest but petty corruption is possible, corruption does not occur in the equilibrium. However, in the later case, the threat of petty corruption induces the policymaker to set a higher extraction quota.*

Proof: Follows directly from Lemma 2, Lemma 3 and Lemma 9.

The above proposition suggests that, regardless of the type of corruption—whether grand or petty—the equilibrium regulation stipulates a higher extraction quota than the socially optimal level. However, the underlying mechanism behind the upward distortion differs between grand and petty corruption. In the former case, the dishonest policy maker's greed for money leads him to discount environmental damage and set a higher quota in exchange for a bribe from the monopolist. In the latter case, however, the honest policymaker sets a higher quota to make over-extraction less profitable for the monopolist. It also highlights that eliminating the possibility of corruption at the top could be an effective way to prevent corruption at the lower levels, which is consistent with the empirical findings of Halim (2008).[13]

Proposition 2. *Suppose that Assumptions 1-2 are satisfied. Then, the following is true.*

[13] Exploiting cross-country longitudinal data Halim (2008) documents that good and honest politicians, who are elected in a parliamentary democracy with an effective judiciary, can prove to be important checks against petty corruption.

(a) $e^{GC} < e^{PC}$, $q^{GC} < q^{PC}$, $D^{GC} < D^{PC}$ and $W^{GC} > W^{PC}$, if $[1-\rho(1-b)] < \frac{\delta D'(e^{GC})}{p(e^{GC})}$; where $\delta = \frac{\alpha}{\alpha+(1-\alpha)\gamma} \in (0,1)$.

(b) $e^{GC} > (=) e^{PC}$, $q^{GC} > (=) q^{PC}$, $D^{GC} > (=) D^{PC}$ and $W^{GC} < (=) W^{PC}$, if $[1-\rho(1-b)] > (=) \frac{\delta D'(e^{GC})}{p(e^{GC})}$.

Proof: See Appendix.

Proposition 2 states that, if proportionate reduction in expected effective price of over-extracted resource under petty corruption is greater than (less than) the discounted net marginal environmental damage to price ratio under grand corruption, the equilibrium extraction quota, level of extraction and environmental damage are higher (lower), while welfare is lower (higher), under grand corruption than under petty corruption. The reason is as follows. The higher the proportionate reduction in expected effective price of over-extracted resource under petty corruption, the lower is the monopolist's gain from over extraction and, thus, it is sufficient to increase quota by a smaller amount to wipe out the monopolist's incentive for over extraction. As a result, the equilibrium extraction quota is lower. On the other hand, under grand corruption, it is optimal for the policy maker to set a higher extraction quota in case the discounted net marginal environmental damage to price ratio is lower. To illustrate it further, note that from Lemma 9(a) and equation (9) we have (a) $f(e^{PC}) = \big(1-\rho(1-b)\big)$ and (ii) $f(e^{GC}) = \delta\frac{D'(e^{GC})}{p(e^{GC})}$; where $f(e) = \frac{1}{p(e)}[ep'(e) + p(e) - C'(e)]$, $f'(e) < 0$.[14] Clearly, (i) a higher value of $\big(1-\rho(1-b)\big)$ calls for a lower e^{PC}, and (ii) if $\delta\frac{D'(e)}{p(e)}$ is lower, we must have a higher e^{GC}. Also, note that $e^{PC} = e^{GC}$ if and only if $\big(1-\rho(1-b)\big) = \delta\frac{D'(e^{GC})}{p(e^{GC})}$. Therefore, whenever $\big(1-\rho(1-b)\big) > (<) \delta\frac{D'(e^{GC})}{p(e^{GC})}$, $e^{GC} > (<) e^{PC}$. Now, since (i) in the equilibrium M always extracts at the level of quota, (ii) a higher amount of extraction results in a higher net environmental damage (Assumption 1), and (iii) $e^{GC}, e^{PC} \in (q^{FB}, q^*)$ (Lemma 3(a) and Lemma 9(a)) and welfare function is strictly concave in extraction level and has a unique maximum at $q = q^{FB}$, whenever $e^{GC} > (<) e^{PC}$, we have $q^{GC} > (<) q^{PC}$, $D(e^{GC}) > (<) D(e^{PC})$ and $W(e^{GC}) < (>) W(e^{PC})$.

Note that, if the prior probability of I being corrupt (ρ) is higher or the bribe rate (b) is lower, proportionate reduction in expected effective price of over-extracted resource under petty corruption is lower and, thus, $x(e)$ is higher (Lemma 8(a)), which induces

[14] $f'(e) = \frac{1}{p^2(e)}[ep(e)p''(e) + p(e)p'(e) + C'(e)p'(e) - C''(e)p(e) - e\big(p(e)'\big)^2] < 0$, by Assumption 1.

honest SP to set a higher quota so that no over extraction takes place (Lemma 8(b)). As a result, in such a scenario e^{PC} is higher. On the other hand, when SP is corrupt but I is believed to be honest, if SP cares more about his bribe income (i.e., α is lower) or his bargaining power over the bribe schedule (γ) is higher, SP discounts net environmental damage more (i.e., δ is lower) and, thus, e^{GC} is higher (Lemma 4). Therefore, from Lemma 8, Lemma 4 and Proposition 2, it follows that the equilibrium quota under the threat of petty corruption is more likely to be greater than that under grand corruption, if the prior probability of I being corrupt (ρ) is higher or the bribe rate (b) is lower or corrupt SP assigns a higher weight to net environmental damage (i.e., δ is higher).

While eliminating corruption at the top may be an effective approach to controlling petty corruption as well (Proposition 1). However, the threat of petty corruption induces the honest policy maker to set a quota higher than $e = q^{FB}$—and consequently, environmental damage is greater and welfare is lower—than the socially optimal level, even though no corrupt transactions occur in equilibrium (Lemma 10). Therefore, from Lemma 10 and Propositions 1-2, it follows that a corruption control mechanism aimed at eliminating opportunities for corruption at the top, when combined with policies designed to influence firms' perceptions of corruption (reducing ρ), could be more effective in reducing corruption while also safeguarding the environment.

3 Both Grand and Petty Corruption

Suppose that both SP and I are corrupt ($\theta_{SP} = \theta_I = 1$), both SP and I belive that SP is corrupt with probability $\rho > 0$, and I does not need to share his bribe income, if any, with SP (i.e., $\lambda = 0$). In this scenario, both grand and petty corruption are possible, but cut-money culture does not exist.

It is easy to observe that, for any given extraction quota e, M's optimal choice of extraction is the same as that in the scenario in which only petty corruption is possible. This is because, once the quota has been determined, M's choice of extraction amount depends only on whether there is a possibility of petty corruption or not, and not on whether SP is honest or corrupt.[15] Clearly, for any given e, Lemma 6, Lemma 7 and

[15]Given e, optimal choices in the last three stages of the game (Stages 5, 6 and 7) do not depend on whether M committed to any bribe schedule or not.

Lemma 8 hold true in the present scenario ($\theta_{SP} = \theta_I = 1$, $\rho > 0$ and $\lambda = 0$) as well, regardless of whether there is an agreement over bribe schedule between SP and M or not. The questions are as follows. What is SP's optimal choice of extraction quota in the current scenario? Does the possibility of petty corruption influence the quota choice of a corrupt SP? If so, how?

Lemma 11. *Suppose that (i) Assumptions 1 and 2 hold true, and (ii) $\theta_{SP} = \theta_I = 1$, $\rho > 0$ and $\lambda = 0$. Then, the social planner's optimal choice of extraction quota, denoted by e^{BC}, and the equilibrium amount extraction by M, denoted by q^{BC}, are as follows.*

$$q^{BC} = e^{BC} = \begin{cases} e^{PC}, \, if \, [1-\rho(1-b)] \leq \frac{\delta D'(e^{GC})}{p(e^{GC})} \\ e^{GC}, \, if \, [1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})} \end{cases} ;$$

where $e^{PC} \in (q^{FB}, q^*)$ is the equilibrium quota in case only petty corruption is possible and $e^{GC} \in (q^{FB}, q^*)$ is the equilibrium quota in case only grand corruption is possible.

Proof: See Appendix.

From Lemma 11 it is evident that, when both SP and I are corrupt, in the equilibrium M fully complies with the quota regulation, i.e. M does not over-extract resource: $x(e^{BC}) = q^{BC} - e^{BC} = 0$. As a result, petty corruption does not occur in the equilibrium, although petty corruption is feasible ($\theta_I = 1$ and $\rho > 0$). This is the same as that in the case of honest SP and corrupt I (Lemma 9). It follows that, regardless of whether SP is corrupt or honest, SP's optimal choice of quota is such that M does not find it profitable to over-extract and bribe.

Proposition 3. *(Non-existence of Petty Corruption) Suppose that Assumption 1 and Assumption 2 are satisfied. Also, suppose that petty corruption is feasible and cut-money culture does not exist. In the equilibrium the monopolist does not over-extract the resource and petty corruption does not take place, regardless of whether the policy maker is honest or corrupt.*

Proof: See Appendix.

Since $\frac{\partial(e+x(e))}{\partial e} < 0 \, \forall e < e^{PC}$, $e^{FB} < e^{PC}$ and $x(e^{PC}) = 0$ (by Lemma 8 and Lemma 9), if SP sets a quota lower than e^{PC}, it is optimal for M to extract more than the amount $q^{PC} = e^{PC}$ and that results in welfare less than $W(q^{PC})$. Thus, under the threat of petty corruption it is optimal for the honest SP to increase quota from e^{FB} to e^{PC}, which ensure that M does not over-extract. Next, when the policy maker is corrupt, either (a) grand corruption pushes the extraction quota at a sufficiently high level, which wipes out the monopolist's incentive for over-extraction or (b) the policy maker finds it optimal to set a sufficiently high quota to dissuade the monopolist from over-extracting. The latter occurs in case the corrupt policymaker discounts marginal environmental damage of extraction by a lesser extent and/or illegal extraction does not result in sufficient reduction in effective price for the monopolist.

Proposition 4. *(Vanishing Corruption) Suppose that Assumption 1 and Assumption 2 are satisfied. Also, suppose that both the policy maker and the inspector are corrupt, cut-money culture does not exist, and* $[1-\rho(1-b)] \leq \frac{\delta D'(e^{GC})}{p(e^{GC})}$*. In the equilibrium (a) the threat of petty corruption leaves no room for grand corruption and (b) no corrupt transaction takes place.*

Proof: See Appendix.

Note that grand corruption always occur in absence of any possibility for petty corruption (Lemma 3), unlike as in the present scenario. The underlying mechanism behind Proposition 4 is as follows. In absence of any possibility for petty corruption ($\theta_I = \rho = 0$), (a) it is optimal for SP to set $e = q^{FB}$ in case of disagreement with M over the bribe schedule and (b) it is never optimal for M to over extract. In contrast, when petty corruption is possible ($\theta_I = 1$ and $\rho > 0$), M has an incentive to over extract unless the quota is sufficiently high. The quota $e^{PC}(> q^{FB})$, which neutralizes M's incentive for over-extraction, is higher in case the probability of getting away with over-extraction by bribing is higher and/or the bribe rate is lower, i.e., if $[1-\rho(1-b)]$ is lower. Moreover, if SP sets a quota lower than e^{PC}, M extracts more than e^{PC} (Lemma 8). As a result, in the case of disagreement over the bribe schedule, it is optimal for SP to set quota at $e = e^{PC}$. It implies that, in absence of grand corruption, SP sets quota e^{PC}, which rules out the possibility of petty corruption. Now, if SP discounts net marginal environmental damage to price ratio at a lower rate, i.e., if $\frac{\delta D'(e^{GC})}{p(e^{GC})}$ is high, either because SP's bargaining power (γ) is low and/or because SP's valuation of bribe income is low (i.e., $(1-\alpha)$ is low), environmental damage increasing effect of extraction dissuades SP from setting a quota greater than e^{PC} in exchange of bribe income, although SP is corrupt. Therefore, under the threat of petty corruption, grand corruption does not occur in the equilibrium in case the proportionate reduction in effective price of over-extracted resource is less than the discounted net marginal environmental damage to price ratio.

Finally, if $\frac{\delta D'(e^{GC})}{p(e^{GC})} < [1-\rho(1-b)]$, i.e., if the discounted net marginal environmental damage to price ratio under grand corruption is less than the proportionate reduction in expected effective price of over-extracted resource under petty corruption, we have $e^{PC} < e^{GC}$, i.e., the minimum quota necessary to dissuade M from over-extracting the resource is less than the optimal quota under grand corruption (Proposition 2). In this case SP and M agrees over the bribe schedule $S(e) = \gamma(\pi(e) - \pi(e^{PC}))$, SP sets quota $e = e^{GC}$, M extracts $q = e^{GC}$ amount and pays $\gamma(\pi(e^{GC}) - \pi(e^{PC}))$ amount as bribe to SP in the equilibrium.

Proposition 5. *(Only Grand Corruption) Suppose that Assumption 1 and Assumption 2 are satisfied. Also, suppose that both the policy maker and the inspector are corrupt, cut-money culture does not exist, and* $[1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$. *Then, only grand corruption occurs in the equilibrium.*

Proof: See Appendix.

The intuition behind Proposition 5 is as follows. When M perceives that the probability to get away with over extraction by paying bribe is less and/or bribe rate is high, the effective price that M can expect to get for over extracted resource is less. In such a scenario, over extraction is preferred over compliance with the quota regulation, if the quota is sufficiently low. It implies that, when $[1-\rho(1-b)]$ is higher, it is sufficient to set a relativity lower quota to dissuade M from engaging in over extraction, i.e., e^{PC} is lower. On the other hand, if SP discounts environmental damage at a higher rate, $\frac{\delta D'(e^{GC})}{p(e^{GC})}$ is lower and it is optimal for SP to set a higher quota in exchange of bribe from M. Now, when $[1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$, $e^{PC} < e^{GC}$. Further, note that M does not have any incentive to over-extract in case quota is greater than e^{PC}. Clearly, when $[1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$, the threat of petty corruption is not binding for bribe schedule determination through bargaining between SP and M.

Proposition 6. *Suppose that Assumption 1 and Assumption 2 are satisfied. The quota (e), amount of extraction (q), environmental damage (D) and welfare (W) in the equilibrium under alternative scenarios are as follows.*

(a) Suppose that $[1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$. *Then, we have the following.*

(i) $q^{FB} < e^{PC} < e^{GC} = e^{BC} < q^*$

(ii) $q^{FB} < q^{PC} = e^{PC} < q^{GC} = e^{GC} = e^{BC} = q^{BC} < q^*$

(iii) $D(q^{FB}) < D(q^{PC}) < D(q^{GC}) = D(q^{BC}) < D(q^*)$

(iv) $W(q^{FB}) > W(q^{PC}) > W(q^{GC}) = W(q^{BC}) > W(q^*)$

(b) Suppose that $[1 - \rho(1 - b)] < (=) \frac{\delta D'(e^{GC})}{p(e^{GC})}$. *Then, we have the following.*

(i) $q^{FB} < e^{GC} < (=) e^{PC} = e^{BC} < q^*$

(ii) $q^{FB} < q^{GC} = e^{GC} < (=) q^{PC} = e^{PC} = e^{BC} = q^{BC} < q^*$

(iii) $D(q^{FB}) < D(q^{GC}) < (=) D(q^{PC}) = D(q^{BC}) < D(q^*)$

(iv) $W(q^{FB}) > W(q^{GC}) > (=) W(q^{PC}) = W(q^{BC}) > W(q^*)$

Proof: See Appendix.

Clearly, when both types of corruption, grand and petty, are possible, the equilibrium outcome coincides with the equilibrium outcome of the scenario in which only grand (petty) corruption is possible, if the proportionate reduction in effective price of over-extracted resource under petty corruption is greater (smaller) than the discounted marginal environmental damage to price ratio under grand corruption. The underlying condition for the equilibrium outcome under only grand corruption to be the same as that in case petty corruption is also possible is more likely to be satisfied when the probability of petty corruption is lower, and/or the corrupt inspector demands a higher bribe rate, and/or the policy maker exerts higher bargaining power, and/or the policy maker's valuation for bribe income is higher. While regulation of natural resource extraction through quota fails to implement the socially optimal level of extraction, it results in lower environmental damage and higher welfare compared to those in absence of any regulation. This is true regardless of the type of possible corruption – only grand corruption or only petty corruption or both grand and petty corruption.

3.1 Discussion

Proposition 6 suggests that, irrespective of whether proportionate reduction in expected effective price of over-extracted resource under petty corruption is higher or lower than discounted net marginal environmental damage-to-price ratio under grand corruption, in equilibrium the extraction quota is higher than the socially optimal quota. However, the underlying mechanism differs. When the discounted net marginal environmental damage-to-price ratio under grand corruption is higher, the social planner becomes worse off by setting a quota that would yield a positive bribe from the monopolist. In this situation, even though both grand and petty corruption are possible, the planner finds it optimal to choose a quota that prevents over-extraction and thus petty corruption ceases to exist, despite the fact that it also blocks the possibility of grand corruption. In contrast, when this ratio is lower, the planner finds it optimal to set an equilibrium extraction quota that secures a positive bribe income for him, thereby sustaining grand corruption, while still eliminating over-extraction and petty corruption. In essence, a high discounted net marginal environmental damage-to-price ratio under grand corruption constrains the planner's incentive for personal gain through bribe, forcing a quota that eliminates over-extraction and both forms of corruption, however, it may result in greater environmental damage relative to the socially optimal level. Conversely, a lower ratio enables the planner to legitimize extraction beyond the socially optimal level in exchange for a bribe from the monopolist. As a consequence, grand corruption prevails in equilibrium, with a higher environmental damage and lower welfare compared to the socially optimal level of extraction. This suggests that, given the choice, a corrupt planner would prefer underestimation of environmental damage due to illegal extraction of the resource.

4 The Cut-Money Culture

Suppose that both SP and I are corrupt ($\theta_{SP} = \theta_I = 1$), both SP and M believe that I is corrupt with probability $\rho > 0$, and I shares a cut $\lambda \in (0, 1)$ of the bribe received from M, if any, with the SP. In this scenario, grand corruption and petty corruption may coexist along with the culture of cut-money, i.e., the culture or norm of sharing bribe collected by I with SP. Note that, if either SP is honest or I is honest or both SP and I are honest, the possibility of cut-money culture ceases to exist.

As discussed in the previous section, once the quota has been determined, M's optimal extraction depends only on the possibility of petty corruption, and not on whether SP is honest or corrupt, or whether M has committed to a bribe schedule or not, or whether cut money culture exists or not. Thus, for any given quota e, Lemma 6, Lemma 7 and Lemma 8 hold true in the present scenario ($\theta_{SP} = 1, \theta_I = 1, \rho > 0,$ and $\lambda > 0$). Also note that, although SP is corrupt, grand corruption cannot take place unless SP and M agree on a bribe schedule $S(e)$. In this section, therefore, we ask the following questions. Does petty corruption occur in the equilibrium under cut-money culture, in case grand corruption cannot occur? Does cut-money culture induce co-existence of grand and petty corruption in the equilibrium? How does cut-money culture affect corrupt SP's optimal choice of extraction quota?

4.1 Disagreement over Bribe Schedule

Suppose that the corrupt SP and M fail to reach an agreement over bribe schedule. It implies that grand corruption cannot take place, i.e., SP does not get any direct bribe payment from M. Nonetheless, given the quota e, if M engages in over-extraction and bribing I, SP would get λ proportion of bribe I's bribe collection.

It is fairly intuitive that, if (i) cut-money culture does not exist and (ii) SP and M fail to reach an agreement over bribe schedule, SP cannot expect to get any bribe payment – neither directly from M nor indirectly through I. In such a scenario, despite being corrupt, SP's best interest is to maximize welfare. Therefore, it is optimal for SP to set quota $e = e^{PC}$, as in Lemma 9, and rule out the possibility of petty corruption in the equilibrium. On the contrary, the presence of cut-money culture opens up the possibility for SP to get a cut of I's bribe income, if any, which in turn might motivate the corrupt SP to set a lower quota and induce over-extraction and petty corruption.

Lemma 12. *Suppose that (i) Assumption 1 and Assumption 2 hold true, (ii) $\theta_{SP} = \theta_I = 1$ and $\rho > 0$, and (iii) grand corruption cannot occur. There exists a $\hat{\alpha}(\lambda) \in (0, 1)$, such that $\hat{\alpha}'(\lambda) > 0$ and in the equilibrium SP sets quota* $e = e^{CMNG} = \begin{cases} e^{CM} \in (0, e^{PC}), \text{ if } \alpha < \hat{\alpha}(\lambda) \\ e^{PC}, \text{ if } \alpha \geq \hat{\alpha}(\lambda) \end{cases}$; *where $e^{PC} \in (q^{FB}, q^*)$ is as in Lemma 6.*

Proof: See Appendix

Lemma 12 states that, given the SP's share of proceeds of petty corruption under cut-money culture, in absence of grand corruption SP's optimal choice of extraction quota is less than the 'no petty corruption enforcing quota' e^{PC}, if SP's concern for welfare is less than a critical level. Otherwise, setting the 'no petty corruption enforcing quota' e^{PC} is optimal for SP. The reason is as follows. When there is possibility of petty corruption, a reduction in quota from the 'no petty corruption enforcing quota' e^{PC} encourages over-extraction by M (Lemma 6), increases total extraction beyond $q^{PC} (= e^{PC} > q^{FB})$ (Lemma 8) and, thus, opens room for petty corruption and reduces welfare. A reduction in welfare has a detrimental effect on SP's payoff. However, the corresponding increase in SP's bribe income over compensates him for the loss due to reduction in welfare, if corrupt SP's payoff function is sufficiently distorted away from welfare maximization to his bribe income maximization.

Lemma 12 also states that, the higher the SP's share of proceeds of petty corruption under cut-money culture, SP is more likely to set less than e^{PC} level of quota. The reason is, when SP gets a larger share of proceeds of petty corruption, the marginal effect of quota reduction on SP's expected bribe is higher.

Proposition 7. *(Cut-Money Culture and Emergence of Petty Corruption) Suppose that Assumption 1 and Assumption 2 hold true and both the policy maker and the inspector are corrupt, but grand corruption cannot occur. The following is true in the equilibrium under cut-money culture, unless the policy maker's welfare concern is greater than a critical level.*

(a) The policy maker sets a less than 'no petty corruption enforcing' level of extraction quota e^{PC}.

(b) The firm over extracts the resource and petty corruption takes place.

(c) Total extraction and environmental damage are higher, while profit of the firm and welfare are lower, than those in absence of cut-money culture.

Proof: See Appendix.

Proposition 7 suggests that the presence of cut-money culture fundamentally alters a corrupt policy maker's incentive to eliminate petty corruption in the absence of grand corruption. If the SP's welfare concern is lower than a critical level, then the planner finds it optimal to trade off welfare in favour of his personal gain through the proceeds from over-extraction by setting a quota that is lower than the *no petty corruption enforcing* quota. As a consequence, over-extraction becomes profitable for M and petty corruption occurs in equilibrium. Furthermore, total extraction undertaken by M exceeds the *no petty corruption enforcing* quota, or q^{PC}. Hence, in the present scenario, environmental damage is higher and welfare is lower compared to the case when cut-money culture is absent.

4.2 Cut-money Culture under the possibility of Grand Corruption

In the present scenario ($\theta_{SP} = \theta_I = 1$, $\rho > 0$ and $\lambda \in (0, 1)$), M can gain from directly bribing SP only if SP returns the favour by committing to a greater than e^{CMNG} level of quota, where e^{CMNG} is as in Lemma 12.

First consider that, despite being corrupt, SP's welfare concern is higher than a threshold level: $\alpha \geq \hat{\alpha}(\lambda)$. Then, by Lemma 12, $e^{CMNG} = e^{PC}$, which is the disagreement quota, i.e., the SP's optimal choice of quota in the event of disagreement with M, in absence of cut-money culture as well. Further note that, whenever $e \geq e^{PC}$, M has no incentive to over-extract, i.e., $x(e^{PC}) = 0$ (Lemma 9 and Lemma 11), and petty corruption does not occur (Proposition 3). It implies that, when $\alpha \geq \hat{\alpha}(\lambda)$, the equilibrium analysis under cut-money culture remains the same as that in absence of cut-money culture (Section 3). Therefore, although both SP and I are corrupt and there is cut-money culture, the equilibrium is free of corruption when $[1 - \rho(1 - b)] \leq \frac{\delta D'(e^{GC})}{p(e^{GC})}$ and $\alpha \geq \hat{\alpha}(\lambda)$. The question is, does this apparently paradoxical result hold true even when SP does not have much of concern for welfare? In the remaining part of this section, we focus on this interesting scenario.

Assumption 3. $[1 - \rho(1 - b)] \leq \frac{\delta D'(e^{GC})}{p(e^{GC})}$

Note that under Assumption 3, we have $e^{GC} < e^{PC}$ (Proposition 2), and no corruption occurs in the equilibrium in absence of cut-money culture (Proposition 4). The presence of cut-money culture adds some twist if the disagreement quota under cut-money culture leaves room for petty corruption, which occurs when corrupt SP does not care much about welfare ($\alpha < \hat{\alpha}(\lambda)$). In the latter case, the disagreement quota $e^{CMNG} = e^{CM} (< e^{PC})$. If SP sets $e = e^{CM}$, he does not get any bribe directly from M but receives $\lambda b x(e^{CM}) p(q^{CM}) (> 0)$ as bribe via I with probability $\rho (> 0)$, as his share of proceeds of petty corruption. Alternatively, if SP sets $e > e^{CM}$, he can get some bribe directly from M and increase welfare, but that would reduce proceeds of petty corruption and hence, reduce his indirect bribe income.[16]. Therefore, when $\alpha < \hat{\alpha}(\lambda)$, SP faces a trade-off between his direct and indirect bribe incomes, unlike as in the former case or in absence of cut-money culture.

[16]See the proof of Lemma 13 for details.

Lemma 13. *Suppose that (i) Assumption 1, Assumption 2 and Assumption 3 hold true, (ii) $\theta_{SP} = \theta_I = 1$ and $\rho > 0$, and (iii) $\lambda > 0$. In the equilibrium SP sets extraction quota $e = e^{CMBC}$, which is as follows.*

(a) When $\gamma \geq \kappa\lambda\rho b$ or $\alpha > \bar{\alpha}$, $e^{CMBC} = e^{PC}$

(b) When $\gamma < \kappa\lambda\rho b$ and $\alpha < \bar{\alpha}$, $e^{CMBC} < e^{PC}$

where (i) e^{PC} is as in Lemma 9, (ii) $\bar{\alpha} \in (0,1)$ and $\bar{\alpha} < \hat{\alpha}(\lambda)$, and (iii) $\kappa = \left. \frac{-\frac{d[x(e)p(q(e))]}{de}}{\frac{d\,E\pi(q(e))}{de}} \right|_{e=e^{PC}} > 0$.

Proof: See Appendix

Lemma 13 states that under cut-money culture and in the presence of grand corruption such that $\alpha < \hat{\alpha}(\lambda)$, SP's optimal choice of extraction quota is lower than the *no petty corruption enforcing* quota, or e^{PC}, if the SP's concern for welfare and bargaining power over the direct bribe schedule are sufficiently low. On the contrary, if either the SP's concern for welfare or his bargaining power is sufficiently high, then it is optimal for the planner to set the *no petty corruption enforcing* quota e^{PC}. The mechanism behind this result is as follows. When $\alpha < \hat{\alpha}(\lambda)$, the disagreement quota is given by $e^{CMNG} = e^{CM} < e^{PC}$. Under the possibilities of grand and petty corruption, a reduction in quota from e^{PC} not only reduces welfare (since the total extraction becomes higher than e^{PC}), but also results in a reduction in direct bribe that the SP receives from M. The corresponding fall in the SP's payoff is more than compensated by the increase in his indirect bribe proceeds from over-extraction, if the corrupt SP's payoff function is sufficiently skewed toward bribe maximization and his bargaining power over the direct bribe schedule is sufficiently low. In this case, the SP finds it optimal to trade off the direct bribe from M in favour of higher indirect bribe through over-extraction and, thus, sets the quota $e^{CMBC} < e^{PC}$. Consequently, there is over-extraction in equilibrium, or $x(e^{CMBC}) > 0$, and thus, petty corruption occurs. Further, if $\alpha < \hat{\alpha}(\lambda)$ and $e^{CMBC} > e^{CM}$, grand corruption also occurs in the equilibrium. It can be checked that $e^{CM} < e^{CMBC} < e^{PC}$ holds true, if $\kappa_{CM}\lambda\rho b < \gamma < \kappa\lambda\rho b$, i.e., if SP's bargaining power is moderate, and $\alpha < \bar{\alpha} < \hat{\alpha}(\lambda)$, i.e., SP's concern for welfare is sufficiently low. While a low value of α implies that the SP prioritizes his personal gains through bribe - direct and/or indirect- over welfare maximization, a moderate bargaining power over the direct bribe schedule ensures that the total bribe received by the planner consists of both direct and indirect components. Here, the planner's bargaining power is sufficient to secure him a positive direct bribe from the monopolist, however, it is not enough for the SP to completely sacrifice the indirect bribe from over-extraction. Hence, by setting a quota in between e^{CM} and e^{PC}, the SP ensures that the welfare loss from over-extraction via petty corruption, and legalised extraction beyond the social optimum via grand corruption is offset by personal gains from both sources of bribes – direct and indirect.

Proposition 8. *Suppose that Assumption 1, Assumption 2 and Assumption 3 hold true, and both the policy maker and the inspector are corrupt. Cut-money culture infuses corruption, either petty corruption or both petty and grand corruption, in the equilibrium, whenever the policy maker's welfare concern and his bargaining power over bribe schedule are not sufficiently high.*

Proof: See Appendix.

Note that petty corruption can never occur in absence of cut-money culture (Proposition 3). Thus, evidence of petty corruption would suggest that the policy maker is corrupt and there is cut-money culture. It also suggest that total extraction of the resource is more, welfare is less and environmental damage is higher than those at the first-best level.

On the other hand, evidence of both grand and petty corruption would suggest that (a) there is cut-money culture, (b) the extraction quota set by the policy maker e^{CMBC} is in the interval (e^{CM}, e^{PC}), (c) total extraction $(q(e^{CMBC}))$ is greater than q^{PC} $(> q^{FB})$ but lower than that in case only petty corruption occurs in the equilibrium under regulation $(q(e^{CMNG})$. As a consequence, when both grand and petty corruption occurs, welfare is lower (higher) and environmental damage is higher (lower) than the first-best level (than that in case only petty corruption occurs). Clearly, all out corruption (grand as well as petty corruption) may result in better environmental and welfare outcomes compared to those in the scenario wherein only petty corruption occurs but no grand corruption takes place in the equilibrium. It is interesting to note that any corruption control mechanism that is effective to refrain corrupt policy makers from engaging in grand corruption, but leaves room for petty corruption and cut money culture, welfare and environmental outcomes are likely to be worse than those in the scenario in which corrupt policy makers can engage in grand corruption as well. This seems to provide some justification for legalizing grand corruption, as is the case for lobbying in many developed countries including the USA, Germany, Canada and Australia.

Our analysis also suggest that, if there is a corruption control mechanism that effectively eliminates possibilities of grand corruption as well as of cut-money culture, petty corruption would never occur in the equilibrium. However, the threat of petty corruption distorts the equilibrium extraction amount upward from q^{FB} to q^{PC}. On the other hand, whenever Assumption 3 holds true, if there is no possibility of petty corruption, the equilibrium extraction quota under grand corruption gets distorted upward to q^{GC} ($< q^{PC}$). Therefore, under Assumption 3, targetting petty corruption would result in higher welfare and lower environmental damage compared to targetting grand corruption and cut-money culture.

Now, to complete the analysis, suppose that Assumption 3 does not hold true, i.e., we have $[1 - \rho(1 - b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$. In this case, SP's optimal choice of quota in absence of cut-money culture is $e^{GC} (> e^{PC})$ and only grand corruption occurs in the equilibrium (Proposition 2). Since for any quota $e \geq e^{PC}$, it is not optimal for M to engage in over extraction, for all $e \geq e^{PC}$, it is optimal for SP to set $e = e^{GC}$ regardless of whether there is cut-money culture or not. However, SP may set quota $e = e^{CMBC} \in (e^{CM}, e^{PC})$ and receive bribe both directly from M and indirectly via I in the presence of cut-money culture. It may be optimal for SP to set $e = e^{GC}$ compared to $e^{CMBC} \in (e^{CM}, e^{PC})$ even when $\gamma < \kappa\lambda\rho b$ and $\alpha < \bar{\alpha}$. The reason is as follows. In this case, we have $e^{GC} > e^{PC}$. Therefore, if SP sets $e = e^{GC}$, (a) he gets a higher direct bribe income compared to setting $e = e^{CMBC}$, but (b) he cannot not expect to get any indirect bribe income unlike as in case $e = e^{CMBC}$. However, the loss of expected indirect bribe income is likely to be over compensated by the gain in direct bribe income, since the firm's expected revenue per unit of over-extracted resource is less than the price of the legally extracted resource and SP's share in bribe paid to I is strictly less than one ($\lambda < 1$). It follows that, when Assumption 3 does not hold true, elimination of possibilities of grand corruption and cut-money culture would result in superior welfare and environmental outcomes compared to targetting petty corruption.

Therefore, targetting petty corruption would result in higher (lower) welfare and lower (higher) environmental damage than targetting grand corruption and cut-money culture, if proportionate reduction in expected effective price of over extracted resource under petty corruption is less than the discounted net marginal environmental damage to price ratio under grand corruption.

5 Conclusion

Considering a sequential move game in the context of natural resource extraction under quota regulation, we have examined how corruption at different levels of bureaucratic hierarchy affects the equilibrium extraction quota, illegal mining, environmental degradation and welfare. We have considered alternative scenarios of corruption possibilities: (a) only grand corruption, which distorts the quota policy, (b) only petty corruption, which weakens enforcement of the regulation, (c) both grand and petty corruption without cut-money culture, and (d) cut money culture, wherein policy enforcers share their bribe income with corrupt policy maker. Our analysis offers several novel insights to understand the implications of different types of corrupt practices on formulation of the extraction quota regulation and its enforcement, and on the equilibrium environmental damage and social welfare.

First, while any type of corruption distorts the equilibrium extraction quota upward from its social welfare maximizing level, resulting in higher environmental damage and lower social welfare, grand corruption results in lower (greater) distortion in quota compared to petty corruption, if the reduction in the firms' expected effective price under petty corruption is less (more) than the 'discounted net marginal environmental damage' to price ratio under grand corruption. This is true, when there is possibility of only one type of corruption, either grand or petty – not both, and there is no cut-money culture.

Second, in absence of cut-money culture, petty corruption can never occur in the equilibrium, regardless of whether the policy maker is honest or corrupt. Nevertheless, mere existence of the possibility of petty corruption, distorts the equilibrium extraction quota upward unless the policy maker is corrupt and he sufficiently discounts the net marginal environmental damage due to extraction. In the later case, only grand corruption occurs and the corrupt policy maker sets a very high extraction quota in exchange of direct bribe payment from the firm, which results in more environmental damage and lower welfare than those in the earlier case. In contrast, if the 'discounted net marginal environmental damage' to price ratio under grand corruption is greater than the reduction in the firms' expected effective price under petty corruption, the threat of petty corruption leaves no room for grand corruption and the equilibrium is free of corruption, in absence of cut-money culture, despite the fact that both the policy maker and the enforcer are corrupt. In the corruption free equilibrium, the upward distortion in extraction quota remains at the minimum possible level, which coincides with the 'no petty corruption enforcing quota' and illegal extraction does not occur, which results in lower environmental damage and higher welfare compared to those in the scenario wherein grand corruption occurs in the equilibrium.

Third, interestingly, the presence of cut-money culture infuses corruption, either petty corruption or both petty and grand corruption, in the equilibrium, whenever corrupt policy maker's welfare concern and his bargaining power over bribe schedule are not sufficiently high, provided that the reduction in the firms' expected effective price under petty corruption is less than the 'discounted net marginal environmental damage' to price ratio under grand corruption. Otherwise, if the reduction in the firms' expected effective price under petty corruption is more than the 'discounted net marginal environmental damage' to price ratio under grand corruption, either only grand corruption or both grand and petty corruption occurs in the equilibrium under cut-money culture.

Our analysis also offers important insights in designing appropriate corruption control mechanisms, in case the policy maker and policy enforcer(s) are responsive to external incentives. We demonstrate that evidence of petty corruption implies that the policy maker is corrupt and cut-money culture prevails in the society. A corruption control mechanism that effectively refrains policy makers from accepting any bribe, neither directly from firms nor indirectly via policy enforcers, petty corruption can never occur in the equilibrium, since in that case the equilibrium quota policy erodes incentives for illegal extraction. However, if the corruption control mechanism that is effective to refrain corrupt policy makers from engaging in grand corruption, but leaves room for petty corruption and cut money culture, welfare and environmental outcomes are likely to be worse than those in case corrupt policy makers can engage in grand corruption as well, under certain conditions. This seems to provide some justification for legalizing grand corruption, as is the case for lobbying aimed to influence government policies in many developed countries.

Moreover, if the reduction in the firms' expected effective price under petty corruption is less than the 'discounted net marginal environmental damage' to price ratio under grand corruption, the threat of petty corruption distorts the equilibrium extraction by a larger extent than that under grand corruption alone. In such cases, targetting petty corruption would result in higher welfare and lower environmental damage compared to targetting grand corruption and cut-money culture. In the alternative scenario, in which the reduction in the firms' expected effective price under petty corruption is more than the 'discounted net marginal environmental damage' to price ratio under grand corruption, refraining policy makers to engage in any form of corruption would result in higher welfare and lower environmental damage compared to targetting petty corruption.

Note that existing literature on environmental damage estimation is far from conclusive and suggests alternative methodologies and estimates, implying that there is sufficient room for subjective judgements.[17]. Our analysis highlights that, given the choice, a corrupt policy maker would always prefer underestimation of environmental damage due to extraction of natural resources.[18]

We have considered monopoly in the market for natural resources, market is not sensitive to illegal extraction of the resource, and the policy maker's type becomes common knowledge before other agents makes any decision. It seems to be interesting to extend the analysis by relaxing these assumptions. It would also be interesting to consider repeated interactions among agents in the model. However, these are beyond the scope of the present paper and remain open for future research.

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[17] See, for example, Sourokou et al. (2024); Pirmana et al. (2021); Menegaki and Damigos (2020); Metcalf and Stock (2017); Nordhaus (2014)

[18] For instance, in a recent study, Mervine et al. (2025) find that biomass carbon emission from land use changes due to nickel mining might be 4 to 500 times higher than the values provided by the Nickel Institute.

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Appendix

A Proofs

Proof of Lemma 1(a): From Equation 2, $W(q) = qp(q) - C(q) - D(q)$. Thus $\frac{dW}{dq} = qp'(q)+p(q)-C'(q)-D'(q)$, and from Assumption 1, $\frac{d}{dq}\left(\frac{dW}{dq}\right) = qp''(q)+2p'(q)-C''(q)-D''(q) < 0$. Now, note that (i) from Assumption 1, $\left.\frac{dW}{dq}\right|_{q=0} = p(0) - C'(0) - D'(0) > 0$, and (ii) from Assumption 1 and Equation 1, $\left.\frac{dW}{dq}\right|_{q=q^*} = -D'(q^*) < 0$. So, by intermediate value theorem, there exists a unique $q = q^{FB} \in (0, q^*)$ such that $q^{FB} = \underset{q(\geq)0}{Argmax} W(q)$. Thus, $0 < q^{FB} < q^*$.

To see why $\pi(q^{FB}) < \pi(q^*)$, observe that (i) from Assumption 1, $\pi(q)$ is concave in q, (ii) from Equation 1, $\pi(q)$ is maximized at $q = q^*$ and consequently, $\left.\frac{d\pi}{dq}\right|_{q<q^*} > 0$, and (iii)$q^{FB} < q^*$. □

Proof of Lemma 1(b): Note that we have the following. (1) From Lemma 1(a), $q^{FB} < q^*$. (2) $W(q)$ is strictly concave in q (by Assumption 1) where the maximum is at $q = q^{FB}$. (3) $D'(q) > 0$ and $D''(q) > 0$ (by Assumption 1). Thus, $W(q^{FB}) > W(q^*)$ and $D(q^{FB}) < D(q^*)$. □

Proof of Lemma 2: In the presence of regulation and no scope for corruption, given Equation 1, M finds it optimal to set $q(e)$ as follows

$$q(e) = \begin{cases} e, \text{ if } e < q^* \\ q^*, \text{ if } e \geq q^* \end{cases}$$

SP's problem under no scope of corruption is given by $\underset{e(\geq)0}{Max}\ W(e)$, and we know from Equation 2 that $q^{FB} = \underset{q(\geq 0)}{Argmax} W(q)$. Thus, in equilibrium, the SP sets $e = q^{FB}$ as the extraction quota. Further, observe that $e = q^{FB} < q^*$ (From Lemma 1(a)), hence, $q(e) = q^{FB}$. □

Proof of Lemma 4: First, note that from Lemma 3, $q^{GC} = e^{GC}$. Next, since $e^{GC} = \underset{e\in(q^{FB},q^*]}{Argmax} O_1(e|\rho = 0)$, $e = e^{GC}$ is the solution to the first order condition $\frac{\partial O_1(\rho = 0)}{\partial e} = \alpha W'(e) + (1-\alpha)\gamma\pi'(e) = 0$. Thus, from implicit function theorem, we get the following:

(a)

$$\frac{\partial q^{GC}}{\partial \alpha} = \frac{\partial e^{GC}}{\partial \alpha} = -\frac{1}{\frac{\partial^2 O_1(\rho=0)}{\partial e^2}\Big|_{e=e^{GC}}} \frac{\partial^2 O_1(\rho=0)}{\partial \alpha \partial e}\Bigg|_{e=e^{GC}} = -\frac{W'(e^{GC}) - \gamma \pi'(e^{GC})}{\frac{\partial^2 O_1(\rho=0)}{\partial e^2}\Big|_{e=e^{GC}}} < 0,$$

since (i) $\frac{\partial^2 O_1(\rho=0)}{\partial e^2} < 0$ from Assumption 1, (ii) $W'(e^{GC}) < 0$ as $W(q)$ is concave in q and $e^{GC} > q^{FB} = \underset{q\geq 0}{Argmax} W(q)$, and (iii) $\pi'(e^{GC}) > 0$ as $\pi(q)$ is concave in q and $e^{GC} < q^* = \underset{q\geq 0}{Argmax}\, \pi(q)$.

(b)

$$\frac{\partial q^{GC}}{\partial \gamma} = \frac{\partial e^{GC}}{\partial \gamma} = -\frac{1}{\frac{\partial^2 O_1(\rho=0)}{\partial e^2}\Big|_{e=e^{GC}}} \frac{\partial^2 O_1(\rho=0)}{\partial \gamma \partial e}\Bigg|_{e=e^{GC}} = -\frac{(1-\alpha)\pi'(e^{GC})}{\frac{\partial^2 O_1(\rho=0)}{\partial e^2}\Big|_{e=e^{GC}}} > 0,$$

since (i) $\frac{\partial^2 O_1(\rho=0)}{\partial e^2} < 0$ from Assumption 1, and (ii) $\pi'(e^{GC}) > 0$ at as $\pi(q)$ is concave in q and $e^{GC} < q^* = \underset{q\geq 0}{Argmax}\, \pi(q)$.

□

Proof of Lemma 5: Note that we have the following. (1) $q^{FB} < q^{GC} < q^*$, by Lemma 3. (2) $W(q)$ is strictly concave in q (by Assumption 1) and is maximum at $q = q^{FB}$. (3) $D'(q) > 0$ and $D''(q) > 0$, by Assumption 1. Therefore, $W(q^{FB}) > W(q^{GC}) > W(q^*)$ and $D(q^{FB}) < D(q^{GC}) < D(q^*)$. □

Proof of Lemma 6(a): If M sets $x = 0$, its expected profit $E\pi(x = 0|e = q^{FB}) = q^{FB} p(q^{FB}) - C(q^{FB})$. Alternatively, if M sets some $x > 0$, its expected profit $E\pi(x > 0|e = q^{FB}) = (q^{FB} + \rho(1-b)x)p(q^{FB} + x) - C(q^{FB} + x)$. Thus

$$\begin{aligned}
& E\pi(x > 0|e = q^{FB}) - E\pi(x = 0|e = q^{FB}) > 0 \\
\Rightarrow\ & q^{FB}[p(q^{FB} + x) - p(q^{FB})] - [C(q^{FB} + x) - C(q^{FB})] + \rho(1-b)xp(q^{FB} + x) > 0 \\
\Rightarrow\ & q^{FB} \tfrac{p(q^{FB}+x) - p(q^{FB})}{x} - \tfrac{C(q^{FB}+x) - C(q^{FB})}{x} + \rho(1-b)p(q^{FB} + x) > 0
\end{aligned}$$

Now,

$$\begin{aligned}
& q^{FB} \underset{x\to 0}{limit} \tfrac{p(q^{FB}+x) - p(q^{FB})}{x} - \underset{x\to 0}{limit} \tfrac{C(q^{FB}+x) - C(q^{FB})}{x} + \rho(1-b) \underset{x\to 0}{limit}\, p(q^{FB} + x) > 0 \\
\Rightarrow\ & q^{FB} p'(q^{FB}) - C'(q^{FB}) + \rho(1-b)p(q^{FB}) > 0,
\end{aligned}$$

which is true by Assumption 2, since $q^{FB} p'(q^{FB}) - C'(q^{FB}) + \rho(1-b)p(q^{FB}) > 0 \Leftrightarrow 1 - \rho(1-b) < \frac{p(q^{FB}) - C'(q^{FB})}{p(q^{FB})} - \frac{1}{\epsilon^d|_{q=q^{FB}}}$. Therefore, $\underset{x\geq 0}{Argmax} E\pi(x|e = q^{FB}) > 0$

Next, suppose that, given the quota $e = q^{FB}$, M extracts $q = q^{FB} - y$ amount, where $y \in [0, q^{FB}]$. That is, M under-extracts the resource by amount y. Then, M's profit is $E\pi(q^{FB} - y|e = q^{FB}) = \pi(q^{FB} - y) = p(q^{FB} - y)(q^{FB} - y) - C(q^{FB} - y)$ $\forall y \in [0, q^{FB}]$, since M does not over-extract any amount. Note that $\frac{\partial E\pi(q^{FB} - y|e = q^{FB})}{\partial y} =$

$-[p'(q^{FB}-y)(q^{FB}-y)+p(q^{FB}-y)-C'(q^{FB}-y)] < 0 \; \forall y \in [0, q^{FB}]$, by Lemma 1, Assumption 1 and equation 3. It follows that $[\underset{y\in[0,q^{FB}]}{Argmax} E\pi(q^{FB}-y|e=q^{FB})] = 0$.

Now, since $E\pi(q^{FB}-y|e=q^{FB})|_{y=0} = E\pi(x|e=q^{FB})|_{x=0} = q^{FB}p(q^{FB}) - C(q^{FB})$, $\underset{x\geq 0}{Argmax} E\pi(x|e=q^{FB}) > 0$ and $[\underset{y\in[0,q^{FB}]}{Argmax} E\pi(q^{FB}-y|e=q^{FB})] = 0$, It is optimal for M to over-extract the resource when SP sets quota $e = q^{FB}$. □

Proof of Lemma 6(b): From equation 10, $E\pi(x|e) = (e+\rho(1-b)x)p(e+x) - C(e+x) \, \forall x \geq 0$. Thus, $\frac{\partial E\pi(x|e)}{\partial x} = (e+\rho(1-b)x)p'(e+x) + \rho(1-b)p(e+x) - C'(e+x)$, and $\frac{\partial}{\partial e}[\frac{\partial E\pi(x|e)}{\partial x}] = (e+\rho(1-b)x)p''(e+x) + p' + \rho(1-b)p'(e+x) - C''(e+x) < 0 \, \forall x \geq 0$ (by Assumption 1). That is, $\frac{\partial E\pi(x|e)}{\partial x}$ is strictly decreasing in e, for all $x \geq 0$.

Now, (a) from Lemma 6(a), we can write $\frac{\partial E\pi(x|e=q^{FB})}{\partial x}|_{x=0} > 0$ and (b) $\frac{\partial E\pi(x|e=q^*)}{\partial x} < 0 \, \forall x \geq 0$, since $\frac{\partial E\pi(x|e=q^*)}{\partial x} = (q^*+\rho(1-b)x)p'(q^*+x) + \rho(1-b)p(q^*+x) - C'(q^*+x) \leq q^*p'(q^*) + \rho(1-b)p(q^*) - C'(q^*) < q^*p'(q^*) + p(q^*) - C'(q^*) = 0$ (by Assumption 1 and equation 3). So, by intermediate value theorem, there exists a unique $e = e^{PC} \in (q^{FB}, q^*)$, such that $\frac{\partial E\pi(x|e=e^{PC})}{\partial x}|_{x=0} = 0$, and (a) for all $e < e^{PC}$. $\frac{\partial E\pi(x|e)}{\partial x}|_{x=0} > 0 \Rightarrow x(e) > 0$ and (b) for all $e > e^{PC}$, $\frac{\partial E\pi(x|e)}{\partial x}|_{x=0} < 0 \Rightarrow x(e) = 0$. Finally, it is easy to observe that e^{PC} is given by $\frac{\partial E\pi(x|e=e^{PC})}{\partial x}|_{x=0} = 0 \Leftrightarrow e^{PC}p'(e^{PC}) + \rho(1-b)p(e^{PC}) - C'(e^{PC}) = 0$. . □

Proof of Lemma 7: Note that q^* is M's optimal choice of extraction in absence of regulation: $q^* = \underset{q\geq 0}{Argmax}\, \pi(q) = \underset{q\geq 0}{Argmax}\, qp(q) - C(q)$. Also, if M's level of extraction q is such that $q \leq e$, i.e., if M does not over-extract, it complies with the quota regulation and thus it can sell its entire produce in the market without incurring any additional cost, regardless of whether I is honest or corrupt. Therefore, if $e \leq q^*$, M does not have any incentive to under-extract (i.e., $q < e$ is not optimal for M). Alternatively, if $e > q^*$, it is optimal for M to under-extract by $(e - q^*)$ amount, since (i) $\pi(q)$ is strictly concave in q (by Assumption 1) and is maximum at $q = q^*$, and (ii) under-extraction does not invite any additional cost/penalty.

Now, from Lemma 6(b), we have $x(e) \begin{cases} > 0, \; \forall e < e^{PC} \\ = 0, \; \forall e \geq e^{PC} \end{cases}$, where $e^{PC} \in (q^{FB}, q^*)$. Therefore, when there is possibility petty corruption only, M's optimal level of extraction q^{PC} is as follows. $q^{PC} = \begin{cases} e + x(e), \; if\, e \in (0, e^{PC}) \\ e, \; if\, e \in [e^{PC}, q^*) \\ q^*, \; if\, e \geq q^* \end{cases}$.

□

Proof of Lemma 8: From Lemma 6, whenever $e < e^{PC}$, $x(e) > 0$. Next, since $x(e) = \underset{x\geq 0}{Argmax} E\pi(x|e)$, $x = x(e)(> 0)$ is the solution of the first order condition $\frac{\partial E\pi(x|e)}{\partial x} = (e+\rho(1-b)x)p'(e+x) + \rho(1-b)p(e+x) - C'(e+x) = 0$. Therefore, by implicit function theorem, we get the following.

(a) $\frac{\partial x(e)}{\partial \rho} = -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \frac{\partial^2 E\pi(x|e)}{\partial \rho \partial x} = -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \big((1-b)xp'(e+x) + (1-b)p'(e+x)\big) < 0$, since $\frac{\partial^2 E\pi(x|e)}{\partial x^2} < 0$ and $\big((1-b)xp'(e+x) + (1-b)p'(e+x)\big) < 0$ for all $\rho, b \in (0,1)$, by Assumption 1.

(b)

$$
\begin{aligned}
\frac{\partial x(e)}{\partial b} &= -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \frac{\partial^2 E\pi(x|e)}{\partial b \partial x} \\
&= -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} (-\rho x p'(e+x) - \rho p(e+x)) \\
&= -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \frac{ep'(e+x) - C'(e+x)}{1-b} \\
&< 0, \text{ by Assumption 1,}
\end{aligned}
$$

where the third equality holds because $\frac{\partial E\pi(x|e)}{\partial x} = 0 \Rightarrow -\rho x p'(e+x) - \rho p(e+x) = \frac{ep'(e+x) - C'(e+x)}{1-b}$

(c)

$$
\begin{aligned}
\frac{\partial x(e)}{\partial e} &= -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \frac{\partial^2 E\pi(x|e)}{\partial e \partial x} \\
&= -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \Big(\big(e + \rho(1-b)x\big)p''(e+x) + p'(e+x) + \rho(1-b)p'(e+x) - C''(e+x)\Big) \\
&< 0, \text{ by Assumption 1,}
\end{aligned}
$$

Next,

$$
\begin{aligned}
\frac{\partial\big(e + x(e)\big)}{\partial e} &= 1 + \frac{\partial x(e)}{\partial e} \\
&= 1 - \frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \frac{\partial^2 E\pi(x|e)}{\partial e \partial x} \\
&= -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \Big(- \frac{\partial^2 E\pi(x|e)}{\partial x^2} + \frac{\partial^2 E\pi(x|e)}{\partial e \partial x}\Big) \\
&= -\frac{1}{\frac{\partial^2 E\pi(x|e)}{\partial x^2}} \big(1 - \rho(1-b)\big)p'(e+x) \\
&< 0, \text{ by Assumption 1,}
\end{aligned}
$$

□

Proof of Lemma 9(a): First, note that $W(q) = qp(q) - C(q) - D(q)$ is concave in q and has a unique maximum at $q = q^{FB}$, which is given by equation 4. We have $0 < q^{FB} < e^{PC} < q^*$, from Lemma 1(a) and Lemma 6(b). It follows that $W(q^{FB}) > W(e^{PC}) > W(q^*)$.

Also, from Lemma 7, $q^{PC} = \begin{cases} e + x(e),\ if\ e \in (0, e^{PC}) \\ = e,\ if e \in [e^{PC}, q^*) \\ = q^*,\ if\ e \geq q^* \end{cases}$; where $x(e) = \underset{x \geq 0}{Argmax}\ E\pi(x|e)$ and q^* is M's optimal quantity of extraction in absence of any regulation, which is given by equation 3.

Therefore, $e^{PC} = \underset{e \geq e^{PC}}{Argmax} W(q(e))$.

Next, from Lemma 8(b), we have $\frac{\partial(e+x(e))}{\partial e} < 0 \, \forall e < e^{PC}$. It follows that, if SP sets quota $e = e^{PC} - \Delta < e^{PC}$, where $\Delta \in (0, e^{PC})$, it is optimal for M to over extract by more than Δ amount and, thus, M's optimal extraction amount $q^{PC} > e^{PC}$. And, we know, for all $q > e^{PC}$, $W(q) < W(e^{PC})$. Clearly, it is never optimal for SP to set quota $e < e^{PC}$. Therefore, overall, we have $e^{PC} = \underset{e>0}{Argmax} W(q(e))$. □

Proof of Lemma 9(b): Follows directly from Lemma 9(a) and Lemma 7 □

Proof of Lemma 9(c): Since $x(e) = \underset{x \geq 0}{Argmax}\, E\pi(x|e = e^{PC}) = 0$, by Lemma 9(b), there will not be any over extraction in the equilibrium. Further, since petty corruption can take place only if M over extracts, there is no scope for petty corruption in the equilibrium. □

Proof of Lemma 10. Note that we have the following. (1) $q^{FB} < q^{PC} < q^*$, by Lemma 1(a), Lemma 6(b) and Lemma 7. (2) $W(q)$ is strictly concave in q (by Assumption 1) and is maximum at $q = q^{FB}$. (3) $D'(q) > 0$ and $D''(q) > 0$, by Assumption 1. Therefore, $W(q^{FB}) > W(q^{PC}) > W(q^*)$ and $D(q^{FB}) < D(q^{PC}) < D(q^*)$. □

Proof of Proposition 1: Follows directly from Lemma 2, Lemma 3 and Lemma 9. □

Proof of Proposition 2: Note that in the presence of petty corruption possibilities the optimal quota set by honest SP, $e = e^{PC}$, is such that M does not have any incentive to over-extract the resource: $\frac{\partial E\pi(x|e=e^{PC})}{\partial x}|_{x=0} = 0 \Leftrightarrow e^{PC}p'(e^{PC}) + \rho(1-b)p(e^{PC}) - C'(e^{PC}) = 0$. On the other hand, the equilibrium quota under grand corruption e^{GC} is given by equation (9): $e^{GC}p'(e^{GC}) + p(e^{GC}) - C'(e^{GC}) = \delta D'(e^{GC})$, where $\delta = \frac{\alpha}{\alpha+(1-\alpha)\gamma} \in (0, 1)$ is the factor by which net environmental damage is discounted under grand corruption. Therefore, we have the following, since $\frac{\partial E\pi(x|e)}{\partial x}$ is strictly decreasing in e, for all $x \geq 0$ (see proof of Lemma 6(b)).

$$e^{GC} > (=) < e^{PC} \Leftrightarrow \frac{\partial E\pi(x|e = e^{GC})}{\partial x}|_{x=0} < (=) > 0$$
$$\Leftrightarrow 1 - \rho(1-b) > (=) < \frac{\delta D'(e^{GC})}{p(e^{GC})}$$

Now, since $q^{PC} = e^{PC}$ and $q^{GC} = e^{GC}$ from Lemma 9(b) and Lemma 3(a), respectively, i.e., in the equilibrium M extracts at the level of quota regardless of the type of corruption, grand or petty, we have the following.

$$q^{GC} > (=) < q^{PC} \Leftrightarrow 1 - \rho(1-b) > (=) < \frac{\delta D'(q^{GC})}{p(q^{GC})}$$

Next, since a higher amount of extraction results in a higher net environmental damage (Assumption 1), whenever $e^{GC} > (<) e^{PC}$, we have $q^{GC} > (<) q^{PC}$, and thus $D(e^{GC}) > (<) D(e^{PC})$.

Finally, since $e^{GC}, e^{PC} \in (q^{FB}, q^*)$ (by Lemma 3(a) and Lemma 9(a)) and welfare function is strictly concave in extraction level and has a unique maximum at $q = q^{FB}$, $W(e^{GC}) < (>) W(e^{PC})$ holds true whenever $e^{GC} > (<) e^{PC}$. □

Proof of Lemma 11: We have $\theta_{SP} = \theta_I = 1$, $\rho > 0$ and $\lambda > 0$. That is, both grand and petty corruption are possible and there is no cut-money culture, in case there is disagreement over bribe schedule between SP and M in the present scenario, SP does not receive any bribe and thus, from equation 6, $O_1 = \alpha W(q(e))$. It follows that, when there is disagreement over bribe schedule between SP and M, the present scenario is equivalent to the scenario considered in section 2.2 and thus Lemma 6, Lemma 7, Lemma 8, Lemma 9 and Lemma 10 hold true. Clearly, in the case of disagreement over bribe schedule, SP's optimal choice of extraction quota is $e^{NG}|_{\substack{\rho>0 \\ \lambda=0}} = e^{PC}$, which is as in Lemma 9.

Next, since Lemma 6 and Lemma 7 holds true, we can write

$$E\pi(x|e \geq e^{PC}) = \begin{cases} ep(e) - C(e)\, \forall\, e \in [e^{PC}, q^*] \\ q^*p(q^*) - C(q^*)\, \forall\, e \geq q^* \end{cases} \quad \text{and}$$
$$E\pi(x|e < e^{PC}) = [e + \rho(1-b)x(e)]p(e + x(e)) - C(e + x(e)),$$

where q^* is the equilibrium extraction in absence of any regulation, which is given by equation 3, and $x(e)$ is the optimal amount of over-extraction for any given quota e, which is as in Lemma 6. Thus, we can write the following.

(a) When $e < e^{PC}$, $\frac{dE\pi(x|e)}{de} = \underbrace{\frac{\partial E\pi(x|e)}{\partial e}}_{(+),\forall e<e^*} + \underbrace{\frac{\partial E\pi(x|e)}{\partial x}}_{=0} \underbrace{\frac{\partial x(e)}{\partial e}}_{(-),\forall e<e^{PC},\, by\, Lemma\, 8} > 0$, since $e^{PC} < q^*$, $x(e) = \underset{x}{Argmax} E\pi(x|e)$ and $\frac{\partial^2 E\pi(x|e)}{\partial x^2} < 0$.
Clearly, $E\pi(x|e < e^{PC}) < E\pi(x|e = e^{PC})$.

(b) When $e \geq e^{PC}$, $x(e) = 0$ and $\frac{dE\pi}{de} \begin{cases} > 0,\ \forall e \in [e^{PC}, q^*) \\ < 0\, \forall e > q^* \\ = 0\, if\ e = q^* \end{cases}$.

Therefore, in the present scenario, M will not agree to pay any bribe to SP corresponding to any $e < e^{PC}$ and the bribe schedule $S(e)$, which is the outcome of the bargaining between SP and M, is given by $S(e) = \begin{cases} \gamma[\pi(q^*) - E\pi(x|e = e^{PC})],\ if\ e \geq q^* \\ \gamma[\pi(e) - E\pi(x|e = e^{PC})],\ if\ e \in [e^{PC}, q^*] \\ 0,\ if e \in [0, e^{PC}] \end{cases}$.

Now, since $\theta_{SP} = 1$ and $\lambda = 0$, $EB_{SP} = S(e)$ and we have the following from equation 6.

$$O_1 = \alpha W(q(e)) + (1-\alpha)EB_{SP}, \text{ where } \alpha \in (0,1)$$
$$= \begin{cases} \alpha W(e + x(e)),\ if\ e \in [0, e^{PC}] \\ \alpha W(e) + (1-\alpha)\gamma[\pi(e) - \pi(e^{PC})],\ e \in [e^{PC}, q^*] \\ \alpha W(q^*) + (1-\alpha)\gamma[\pi(q^*) - \pi(e^{PC})],\ if e \geq q^* \end{cases},$$

since $x(e^{PC}) = 0$ and Lemma 7 holds true even when ($\theta_{SP} = \theta_I = 1$, $\rho > 0$ and $\lambda = 0$), we can write $q(e) = \begin{cases} e + x(e),\ if\ e \in (0, e^{PC}] \\ e,\ if\ e \in [e^{PC}, q^*] \\ q^*,\ if\ e \geq q^* \end{cases}$. It is straightforward to observe that

(a) $e^{PC} = \underset{e \in [0, e^{PC}]}{Argmax}\, \alpha W(e)$.

(b) $\underset{e \in [e^{PC}, q^*]}{Argmax}\, \alpha W(e) + (1-\alpha)\gamma[\pi(e) - \pi(e^{PC})] = \begin{cases} e^{PC},\ if e^{GC} \underset{(=)}{<} e^{PC} \\ e^{GC},\ if e^{GC} > e^{PC} \end{cases}$, since $[\underset{e}{Argmax}\, \alpha W(e) + (1-\alpha)\gamma[\pi(e) - \pi(e^{PC})]] \equiv [\underset{e}{Argmax}\, \alpha W(e) + (1-\alpha)\gamma[\pi(e) - \pi(e^{FB})]] = e^{GC} < q^*$.

(c) $\alpha W(q^*) + (1-\alpha)\gamma[\pi(q^*) - \pi(e^{PC})]$ in independent of e for all $e \geq q^*$.

Clearly, $[\underset{e \geq 0}{Argmax}\, O_1] = e^{BC} = \begin{cases} e^{PC},\ if e^{GC} < e^{PC} \\ e^{GC},\ if e^{GC} \geq e^{PC} \end{cases}$. Since $e^{PC} < q^*$, $e^{GC} < q^*$ and $x(e) = 0\, \forall e \geq e^{PC}$, we have $q^{BC} = e^{BC} + x(e^{BC}) = e^{BC}$. Finally, from Proposition 2, (i) $e^{GC} \underset{(=)}{<} e^{PC}$ if $[1 - \rho(1-b)] \underset{(=)}{<} \frac{\delta D'(e^{GC})}{p(e^{GC})}$ and (ii) $e^{GC} > e^{PC}$ if $[1 - \rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$.

□

Proof of Proposition 3: Follows directly from Lemma 11, Proposition 2 and Lemma 9. □

Proof of Proposition 4: Follows directly from Lemma 11, Proposition 2 and Lemma 9. □

Proof of Proposition 5: Follows directly from Lemma 11, Proposition 2 and Lemma 9. □

Proof of Proposition 6: Note that we have the following.

1. From Proposition 2, (a) $e^{PC} < e^{GC}$, if $[1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$, and (b) $e^{PC} > (=) e^{GC}$, if $[1 - \rho(1-b)] < (=) \frac{\delta D'(e^{GC})}{p(e^{GC})}$.

2. $q^{FB} < e^{PC}, e^{GC} < q^*$, from Lemma 3(a) and Lemma 6(b).

3. From Lemma 11, (a) $e^{BC} = e^{GC}$, if $[1 - \rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$, and (b) $e^{BC} = e^{PC}$, if $[1 - \rho(1-b)] < (=) \frac{\delta D'(e^{GC})}{p(e^{GC})}$.

From (1), (2) and (3), it follows that (a) $q^{FB} < e^{PC} < e^{GC} = e^{BC} < q^*$, if $[1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$; and (b) $q^{FB} < e^{GC} < (=) e^{PC} = e^{BC} < q^*$, if $[1 - \rho(1-b)] < (=) \frac{\delta D'(e^{GC})}{p(e^{GC})}$.

Next, from Lemma 6, we know (i) $q = e + x(e)$, where $x(e)$ is the M's optimal amount of over extraction for any given quota $e(\geq 0)$, (ii) $x(e) = 0 \forall e \geq e^{PC}$, and (iii) when there is no possibility of petty corruption, $x(e) = 0$. Therefore, $q^{PC} = q(e^{PC}) = e^{PC}$ and $q^{GC} = q(e^{GC}) = e^{GC}$. Therefore, it is easy to observe that (a) $q^{FB} < q^{PC} = e^{PC} < q^{GC} = e^{GC} = e^{BC} = q^{BC} < q^*$, if $[1-\rho(1-b)] > \frac{\delta D'(e^{GC})}{p(e^{GC})}$; and (b) $q^{FB} < q^{GC} = e^{GC} < (=)q^{PC} = e^{PC} = e^{BC} = q^{BC} < q^*$, if $[1-\rho(1-b)] < (=)\frac{\delta D'(e^{GC})}{p(e^{GC})}$.

Finally, by Assumption 1, $D'(q) > 0 \forall q \geq 0$ and $W(q)$ is strictly concave in q. Further, we have $W(q)$ is maximum at q^{FB}, q^* maximizes $\pi(q)$ in absence of any regulation, and $q^{FB} < q^*$ by Lemma 1. Thus, (1) Proposition 6(a(ii)) implies Proposition 6(a(iii)) and Proposition 6(a(iv)), and (2) Proposition 6(b(ii)) implies Proposition 6(b(iii)) and Proposition 6(b(iv)). □

Proof of Lemma 12: Note that, since $\theta_I = 1$, $\rho \in (0,1)$ and Assumption 1 and Assumption 2 hold true, for any given e, M's optimal choice of over-extraction $x(e)$ is as in Lemma 6 and M's optimal choice of total extraction $q = q^{PC}$ is as in Lemma 7. Further, since $\theta_{SP} = 1$, cut-money culture exists ($\lambda \in (0,1)$) and grand corruption cannot occur, expected bribe income of SP is $EB_{SP} = \lambda\rho b x(e) p(q(e))$, where $q(e) = e + x(e)$ and $b \in (0,1)$. Therefore, from equation 6, we can write SP's objective function $O_1(\cdot)$ as follows.

$$O_1(e) = \begin{cases} \alpha W(q(e)) + (1-\alpha)\lambda\rho b x(e) p(q(e)),\ if\ e \in [0, e^{PC}] \\ \alpha W(e),\ if\ e \in [e^{PC}, q^*] \\ \alpha W(q^*),\ if\ e \geq q^* \end{cases} \tag{12}$$

Fisrt, note that $O_1(e^{PC}) > O_1(e|e > e^{PC})$. This is because, (a) $W''(q) < 0$ and $e^{PC} > q^{FB} = \underset{e>0}{Argmax} W(e)$ (by Lemma 6) imply that $e^{PC} = \underset{e\in[e^{PC},q^*]}{Argmax}\ \alpha W(e)$, and (b) $\alpha W(q^*)$ is independent of e $\forall e \geq q^*$.

Next, from equation 12, we get the following, since $x(e^{PC}) = 0$ (by Lemma 6), $x'(e^{PC}) < -1$ (by Lemma 8 and $W'(e^{PC}) < 0$.

$$\frac{dO_1(e|e \leq e^{PC})}{de} = \alpha(1+x'(e))W'(q(e)) + (1-\alpha)\lambda\rho b[x'(e)p(q(e)) + x(e)(1+x'(e))p'(q(e))]$$

$$\Rightarrow \frac{dO_1(e|e \leq e^{PC})}{de}|_{e=e^{PC}} = \alpha\underbrace{(1+x'(e^{PC}))W'(e^{PC})}_{(+)ve} + (1-\alpha)\lambda\underbrace{\rho b p(e^{PC})x'(e^{PC})}_{(-)ve}$$

Clearly, (a) if $\alpha = 0$, $\frac{dO_1(e|e \leq e^{PC})}{de}|_{e=e^{PC}} < 0$, (b) if $\alpha = 1$, $\frac{dO_1(e|e \leq e^{PC})}{de}|_{e=e^{PC}} > 0$, and (c) $\frac{dO_1(e|e \leq e^{PC})}{de}|_{e=e^{PC}}$ is strictly monotone in $\alpha \in [0,1]$. It implies that there exists a $\alpha = \hat{\alpha}(\lambda) \in (0,1)$ such that $\frac{dO_1(e|e \leq e^{PC})}{de}|_{e=e^{PC}} \begin{cases} < 0 \text{ if } \alpha < \hat{\alpha}(\lambda) \\ > (=)0 \text{ if } \alpha > (=)\hat{\alpha}(\lambda) \end{cases}$; where $\hat{\alpha}(\lambda) = \frac{-\lambda\rho b p(e^{PC})x'(e^{PC})}{-\lambda\rho b p(e^{PC})x'(e^{PC}) + (1+x'(e^{PC}))W'(e^{PC})}$. It is easy to check that $\hat{\alpha}(\lambda) \in (0,1)$ and $\frac{d\hat{\alpha}(\lambda)}{d\lambda} > 0$, for all $\lambda, \rho, b \in (0,1)$. It follows that $\underset{e\in[0,e^{PC}]}{Argmax}\, O_1(e) = \begin{cases} e^{CM} \text{ if } \alpha < \hat{\alpha}(\lambda) \\ e^{PC} \text{ if } \alpha \geq \hat{\alpha}(\lambda) \end{cases}$, where $e^{CM} < e^{PC}$. Now, since $O_1(e^{PC}) > O_1(e|e > e^{PC})$, we get the following.

$$\underset{e \geq 0}{Argmax}\, O_1(e) = \begin{cases} e^{CM} \text{ if } \alpha < \hat{\alpha}(\lambda) \\ e^{PC} \text{ if } \alpha \geq \hat{\alpha}(\lambda) \end{cases}, \text{ where } e^{CM} < e^{PC}. \qquad \square$$

Proof of Proposition 7: (a) Note that, given quota e, M's expected profit $E\pi(x|e)$ when it over-extracts $x(\geq 0)$ amount of the resource is given by $E\pi(x|e) = (e + \rho x)p(e + x) - C(e + x) - \rho bxp(e + x)$, as in equation 10, regardless of whether there is cut-money culture or not, since the bribe rate, b, and the prior probability of I being corrupt, ρ, are exogeneously determined and fixed (by construction). Now, by Lemma 6, $x(e) = \underset{x \geq 0}{Argmax}\, E\pi(x|e) \begin{cases} > 0, \forall e < e^{PC} \\ = 0, \forall e \geq e^{PC} \end{cases}$. In the present scenario ($\theta_{SP} = \theta_I = 1$, $\rho > 0$, $\lambda > 0$, and there is no grand corruption), when $\alpha < \hat{\alpha}(\lambda)$, SP's optimal choice of quota is given by $e = \begin{cases} e^{CM} \in (0, e^{PC}), \text{ if } \alpha < \hat{\alpha}(\lambda) \\ e^{PC}, \text{ if } \alpha \geq \hat{\alpha}(\lambda) \end{cases}$, by Lemma 12.

(b) It is evident from Lemma 6 and Lemma 12 that, in the present scenario, the equilibrium over-extraction $x(e) = \begin{cases} x(e^{CM}) > 0, \text{ if } \alpha < \hat{\alpha}(\lambda) \\ x(e^{PC}) = 0, \text{ if } \alpha \geq \hat{\alpha}(\lambda) \end{cases}$.

(c) Given extraction quota e, equilibrium total extraction is $q(e) = e + x(e)$, where $x(e)$ is as in Lemma 6. Now, (i) by Lemma 8, $\frac{\partial q(e)}{\partial e} = \frac{\partial (e+x(e))}{\partial e} < 0$, and (ii) by Lemma 12, $e = \begin{cases} e^{CM} < e^{PC}, \text{ if } \alpha < \hat{\alpha}(\lambda) \\ e^{PC}, \text{ if } \alpha \geq \hat{\alpha}(\lambda) \end{cases}$. Therefore, the equilibrium total extraction under cut-money culture $q = \begin{cases} q(e^{CM}) = e^{CM} + x(e^{CM}) > q(e^{PC}), \text{ if } \alpha < \hat{\alpha}(\lambda) \\ q(e^{PC}) = e^{PC}, \text{ if } \alpha \geq \hat{\alpha}(\lambda) \end{cases}$. Under petty corruption without cut-money culture, the equilibrium total extraction is $q^{PC} = e^{PC}$, by Lemma 9.

Second, Since environmental damage $D(q(e))$ is increasing in $q(e)$, by Assumption 1, $D(q(e^{CM})) > D(q(e^{PC}))$.

Third, note that $x(e) > 0$ for all $e < e^{PC}$ by Lemma 6.

$$\begin{aligned} E\pi(x|e) = E\pi(e + x(e)) &= (e + \rho x(e))p(e + x(e)) - C(e + x(e)) - \rho bx(e)p(e + x(e)) \\ &= (e + \rho(1 - b)x(e))p(e + x(e)) - C(e + x(e)) \end{aligned}$$

.

Therefore, for all $e < e^{PC}$, we can write the following.

$$\begin{aligned}
\frac{dE\pi(x|e)}{de} &= \frac{\partial E\pi(x|e)}{\partial x}\frac{dx(e)}{de} + \frac{\partial E\pi(x|e)}{\partial e} \\
&= 0 + \frac{\partial E\pi(x|e)}{\partial e}, \text{ since } \frac{\partial E\pi(x|e)}{\partial x} = 0 \,\text{at}\, x = x(e) \\
&= p(q) + (e + \rho(1-b)x(e))p'(q) - C'(q), \text{where}\, q = e + x(e) \\
&= (1 - \rho(1-b))p(q), \text{ since } \frac{\partial E\pi(x|e)}{\partial x} = 0 \Rightarrow (e + \rho(1-b)x(e))p' - C' = -\rho(1-b)p(q) \\
&> 0
\end{aligned}$$

Now, $e^{CM} < e^{PC}$ and $\frac{dE\pi(x|e)}{de} > 0$ together imply that $E\pi(q^{CM}) < E\pi(q^{PC})$.

Finally, note that $W(q)$ is strictly concave in q (by Assumption 1) and W(q) is maximum at $q = q^{FB}$ (by equation 4). We also have $q^{FB} < q^{PC}$ (by Lemma 9) and $q^{PC} < q(e^CM)$ (as shown above). Therefore, $W(q(e^CM)) < W(q^{PC})$. □

Proof of Lemma 13: In the present scenario $\theta_{SP} = \theta_I = 1$, $\rho > 0$ and $\lambda \in (0,1)$. It is easy to observe that Lemma 6, Lemma 7 and Lemma 8 hold true in the present scenario as well. From the discussion in Section 4.1, it follows that in the event of disagreement over bribe schedule SP's optimal choice of extraction quota is e^{CMNG}, which is given by Lemma 12. It is easy to observe that $e^{CMNG} < q^*$, where q^* is M's optimal regulation in absence of any regulation (given by equation 3). Further, from the proof of Lemma 11, we know $\frac{dE\pi(q(e))}{de} \begin{cases} > 0,\, \forall e < q^* \\ < 0\, \forall e > q^* \\ = 0\, if\; e = q^* \end{cases}$, where $q(e) = e + x(e)$. Therefore, in the present scenario, M will not agree to pay any bribe to SP corresponding to any $e < e^{CMNG}$. We can write the bribe schedule $S(e)$, which is the outcome of the bargaining between SP and M, as follows. $S(e) = \begin{cases} \gamma[E\pi(x|e) - E\pi(x|e = e^{CMNG})],\, if\; e \in [e^{CMNG}, q^*] \\ \gamma[\pi(q^*) - E\pi(x|e = e^{CMNG})],\, if\; e \geq q^* \\ 0,\, if e \in [0, e^{CMNG}] \end{cases}$ Note that $E\pi(q(e)) = E\pi(x|e)$.

Now, SP's total expected bribe income (EB_{SP}) is the sum of (a) direct bribe income, i.e.,'bribe paid directly by M to SP, given by $S(e)$, and (b) indirect bribe income, i.e.,'expected bribe income of SP, which is SP's share of proceed of petty corruption', given by $\lambda\rho bx(e)p(q(e))$. Therefore, $EB_{SP} = S(e) + \lambda\rho bx(e)p(q(e))$. Also, note that $x(e|e \geq e^{PC}) = 0$ (by Lemma 6). Therefore, in the present scenario SP's objective function, O_1, can be expressed as follows.

$$\begin{aligned}
O_1 &= \alpha W(q(e)) + (1-\alpha)EB_{SP}, \\
&= \begin{cases} \alpha W(q(e)) + (1-\alpha)\lambda\rho bx(e)p(q(e)), \text{ if } e \leq e^{CMNG} \\ \alpha W(q(e)) + (1-\alpha)[\gamma(E\pi(x|e) - E\pi(x|e = e^{CMNG})) + \lambda\rho bx(e)p(q(e))], \text{ if } e \in [e^{CMNG}, e^{PC}] \\ \alpha W(e) + (1-\alpha)[\gamma(E\pi(x|e) - E\pi(x|e = e^{CMNG}))], \text{ if } e \in [e^{PC}, q^*] \\ \alpha W(q^*) + (1-\alpha)[\gamma(\pi(q^*) - E\pi(x|e = e^{CMNG}))], \text{ if } e \geq q^* \end{cases},
\end{aligned} \tag{13}$$

where a higher value of the parameter $\alpha \in (0,1)$ indicates that the corrupt SP's welfare concern is greater.

It is straightforward to observe the following.

(a) For all $e \geq e^{PC}$, O_1 is maximum at $e = e^{PC}$, by Lemma 11 and Assumption 3. The reason is as follows.

(i) $\underset{e \in [e^{PC}, q^*]}{Argmax}\ \alpha W(e) + (1-\alpha)[\gamma(E\pi(x|e) - E\pi(x|e = e^{CMNG}))] = e^{BC}$, where e^{PC}, by Assumption 3, Proposition 2 and Lemma 11, since $\underset{e}{Argmax}\ W(e) + (1 - \alpha)\gamma[E\pi(x|e) - E\pi(x|e = e^{CMNG})] \equiv \underset{e}{Argmax}\ W(e) + (1-\alpha)\gamma E\pi(x|e)$, since $E\pi(x|e = e^{CMNG})]$ is independent of e.

(ii) For all $e \geq q^*$, $O_1 = \alpha W(q^*) + (1-\alpha)[\gamma(\pi(q^*) - E\pi(x|e = e^{CMNG}))]$, whcih is a constant.

(iii) From (i) and (ii) it follows that $O_1|_{e=e^{PC}} > O_1|_{e=q^*}$.

(b) For all $e \leq e^{CMNG}$, there cannot be any grand corruption, while petty corruption occurs except when $e = e^{CMNG} = e^{PC}$. Thus, $\underset{e \leq e^{CMNG}}{Argmax}\ O_1 = e^{CMNG}$, since e^{CMNG} is the optimal quota choice of SP under cut-money culture when grand corruption cannot occur, by Lemma 12.

(c) Suppose that $e \in [e^{CMNG}, e^{PC}]$. Then, if $e^{CMNG} = e^{PC}$, then $e = e^{PC}$, which is independent of e. Let $e^{CMNG} = e^{CM}$. We know that $e^{CM} < e^{PC}$, by Lemma 12. Now, when $e \in [e^{CM}, e^{PC}]$, we have the following.

(i) $W'(q(e))\frac{dq(e)}{de} = W'(q(e))(1 + x'(e)) > 0$, since $1 + x'(e) < 0$ (by Lemma 8) and $q(e) = e + x(e) > q^{FB}\ \forall e \in [0, e^{PC}]$, $W'(q^{FB}) = 0$ and $W''(\cdot) < 0$ (by Assumption 1).

(ii)

$$\begin{aligned}
\frac{dE\pi(\cdot)}{de} &= \frac{d}{de}\big[(e + \rho(1-b)x(e))p(e + x(e)) - C(e + x(e))\big] \\
&= \frac{\partial E\pi}{\partial x}\Big|_{x=x(e)}\frac{dx(e)}{de} + \frac{dE\pi}{de}, \text{ since } x = x(e) \text{ is } M\text{'s optimal choice, given } e. \\
&= \frac{dE\pi}{de}, \text{ since } \frac{\partial E\pi}{\partial x}\Big|_{x=x(e)} = 0 \\
&= p(\cdot) + (e + \rho(1-b)x(e))p'(\cdot) - C'(\cdot) \\
&= (1 - \rho(1-b))p(\cdot), \text{ since we have} \\
&\qquad \frac{\partial E\pi}{\partial x}\Big|_{x=x(e)} = \rho(1-b)p(\cdot) + (e + \rho(1-b)x(e))p'(\cdot) - C'(\cdot) = 0 \\
&> 0.
\end{aligned}$$

(iii)

$$\begin{aligned}\frac{d\big(x(e)p(e+x(e))\big)}{de}] &= x'(e)p(\cdot)+xp'(\cdot)(1+x'(e)) \\ &= x'(e)\frac{C'(\cdot)-ep'(\cdot)}{\rho(1-b)}+x(e)p'(\cdot), \text{since } \frac{\partial E\pi}{\partial x}\Big|_{x=x(e)}=0 \\ &< 0, \text{ since Assumption 1 holds true, } x(e)\geq 0, \\ &\qquad \text{and } x'(e)<0 \text{ by Lemma 8.}\end{aligned}$$

Now, $\frac{dO_1}{de} = \underbrace{\alpha W'(q(e))\frac{dq(e)}{de}}_{(+)ve} + (1-\alpha)\big[\gamma \underbrace{\frac{dE\pi(\cdot)}{de}}_{(+)ve} + \underbrace{\lambda\rho b \frac{d\big(x(e)p(e+x(e))\big)}{de}}_{(-)ve}\big]$. Therefore, we can state the following, where $\kappa = \frac{-\frac{d[x(e)p(q(e))]}{de}}{\frac{d\,E\pi(q(e))}{de}}\Big|_{e=e^{PC}} > 0$.

- If $\gamma \geq \kappa\lambda\rho b$, $\frac{dO_1}{de}\big|_{e=e^{PC}} > 0 \Rightarrow e^{PC} = \underset{e\in[e^{CM},e^{PC}]}{Argmax}\ O_1$.
- If $\gamma < \kappa\lambda\rho b$, $\lim_{\alpha\to 0}\frac{dO_1}{de}\big|_{e=e^{PC}} < 0$ and $\lim_{\alpha\to 1}\frac{dO_1}{de}\big|_{e=e^{PC}} > 0$. Since O_1 is strictly monotone in α, $\exists$ an $\bar{\alpha}\in(0,1)$ such that $\frac{dO_1}{de}\big|_{e=e^{PC}} \begin{cases} = 0, \text{ if } \alpha=\bar{\alpha} \\ > 0, \text{ if } \alpha>\bar{\alpha} \\ < 0, \text{ if } \alpha<\bar{\alpha}\end{cases}$, if $\gamma < \kappa\lambda\rho b$. It follows that $\underset{e\in[e^{CM},e^{PC}]}{Argmax}\ O_1 \begin{cases} = e^{PC} \text{ if } \gamma<\kappa\lambda\rho b \text{ and } \alpha>\bar{\alpha} \\ < e^{PC} \text{ if } \gamma<\kappa\lambda\rho b \text{ and } \alpha<\bar{\alpha}\end{cases}$

Thus, for all $e\in[e^{CM},e^{PC}]$, $\underset{e\in[e^{CM},e^{PC}]}{Argmax}\ O_1 \begin{cases} = e^{PC} \text{ if } \gamma\geq\kappa\lambda\rho b \text{ or } \alpha>\bar{\alpha} \\ < e^{PC} \text{ if } \gamma<\kappa\lambda\rho b \text{ and } \alpha<\bar{\alpha}\end{cases}$.

From (a), (b) and (c), we get $e^{CMBC} = \underset{e\in(0,1)}{Argmax}\ O_1 \begin{cases} = e^{PC} \text{ if } \gamma\geq\kappa\lambda\rho b \text{ or } \alpha>\bar{\alpha} \\ < e^{PC} \text{ if } \gamma<\kappa\lambda\rho b \text{ and } \alpha<\bar{\alpha}\end{cases}$.

Next, to see that $\bar{\alpha} < \hat{\alpha}(\lambda)$, observe the following.

(i) When there is a disagreement over the bribe schedule (between SP and M) and grand corruption doesn't occur under cut money culture, then from the proof of Lemma 12, at $\alpha = \hat{\alpha}(\lambda)$,

$$\frac{dO_1}{de}\Big|_{e=e^{PC}} = \hat{\alpha}(\lambda)W'(e^{PC})\frac{dq(e)}{de}\Big|_{e=e^{PC}} + (1-\hat{\alpha}(\lambda))\lambda\rho b\frac{d(x(e)p(e+x(e))}{de}\Big|_{e=e^{PC}} = 0$$

.

(ii) In the present scenario i.e. when there is agreement over the bribe schedule (between SP and M), and possibilities of grand corruption arise under cut money culture, at $\alpha = \bar{\alpha}$,

$$\frac{dO_1}{de}\Big|_{e=e^{PC}} = \bar{\alpha}W'(e^{PC})\frac{dq(e)}{de}\Big|_{e=e^{PC}} + (1-\bar{\alpha})[\gamma\frac{dE\pi(.)}{de}\Big|_{e=e^{PC}} + \lambda\rho b\frac{d(x(e)p(e+x(e))}{de}\Big|_{e=e^{PC}}] = 0$$

Thus, from (i) and (ii), we have

$$\hat{\alpha}(\lambda)W'(e^{PC})\frac{dq(e)}{de}\bigg|_{e=e^{PC}} + (1-\hat{\alpha}(\lambda))\lambda\rho b\frac{d(x(e)p(e+x(e))}{de}\bigg|_{e=e^{PC}}$$
$$= \bar{\alpha}W'(e^{PC})\frac{dq(e)}{de}\bigg|_{e=e^{PC}} + (1-\bar{\alpha})[\gamma\frac{dE\pi(.)}{de}\bigg|_{e=e^{PC}} + \lambda\rho b\frac{d(x(e)p(e+x(e))}{de}\bigg|_{e=e^{PC}}],$$

or

$$(\bar{\alpha}-\hat{\alpha}(\lambda))\underbrace{[W'(e^{PC})\frac{dq(e)}{de}\bigg|_{e=e^{PC}} - \lambda\rho b\frac{d(x(e)p(e+x(e)))}{de}]}_{+ve} = \underbrace{-(1-\bar{\alpha})\gamma\frac{dE\pi(.)}{de}\bigg|_{e=e^{PC}}}_{-ve}$$

Since $[W'(e^{PC})\frac{dq(e)}{de}\Big|_{e=e^{PC}} - \lambda\rho b\frac{d(x(e)p(e+x(e)))}{de}] > 0$, and $-(1-\bar{\alpha})\gamma\frac{dE\pi(.)}{de}\Big|_{e=e^{PC}} < 0$, we must have $\bar{\alpha}-\hat{\alpha}(\lambda) < 0$, or $\bar{\alpha} < \hat{\alpha}(\lambda)$.

□

Proof of Proposition 8: Follows directly from Lemma 13, Proposition 4, and the fact that $e^{CM} < e^{CMBC} < e^{PC}$ if $\kappa_{CM}\lambda\rho b < \gamma < \kappa\lambda\rho b$, and $\alpha < \bar{\alpha} < \hat{\alpha}(\lambda)$, where $\kappa_{CM} = -\frac{\frac{d(x(e)p(e+x(e)))}{de}}{\frac{dE\pi(\cdot)}{de}}\Big|_{e=e^{CM}}$.

□