Delegation in Regulation*

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Abstract

We develop a model to discuss government's incentives to delegate to bureaucrats to deal with industry. The industry consists of a polluting firm with private information about its production technology. Government requires the use of bureaucrats to implement a transfer-based regulation policy. We assume that implementation of a transfer-based policy has a bureaucratic cost as bureaucrats divert a fraction of the transfer. In this set up, we study a delegation problem, in which government decides the extent of regulatory discretion given to bureaucrats. Government faces a trade-off in its delegation decision. Specifically, bureaucrats have knowledge of the firm that government does not have, but at the same time, they have other preferences than the government (bureaucratic drift). We study government's incentives to delegate decision-making authority to bureaucrats in presence of bureaucratic cost and bureaucratic drift. We discuss whether using partial delegation, i.e., delegation followed by laws and regulations to restrict bureaucratic discretion, might help. Our findings suggest that the extent of bureaucratic discretion reduces with bureaucratic drift but changes non-monotonically with bureaucratic cost. We introduce two regulatory frameworks, which we call respectively procurement and permits, which differ in the direction of transfer between government and industry, and find that partial delegation works differently in the two frameworks. Our analyses generate a set of testable predictions regarding the optimal uses of the two regulatory settings.

JEL Codes: D02; H10; L51

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1 Introduction

Governments often delegate to bureaucrats to deal with industry (see for example, Gilardi [14]). Motivation for such delegation can arise from necessity. Given the complexity of policy making and policy administration, elected politicians have no choice but to delegate some of the responsibilities to bureaucrats. Delegation can however have contrasting effects. On one hand, the society can benefit from bureaucrats' industry-specific knowledge and expertise. On the other hand, there is a potential loss of control as non-elected officials decide policy. By studying this trade off, the extant literature on bureaucratic delegation has provided many theories to explain why delegation happens (see for example, Epstein and O'Halloran [12] and Huber and Shipan [17]). But there remain many unanswered questions regarding government's ability to design delegation rules for regulating industry. Our objective in this article is to address some of these questions.

First, the literature on bureaucratic delegation have addressed the delegation issue by focusing on the agency problem between a government and the bureaucrats, but little attention is paid on the interaction between a government and the industry. As the decision to be delegated is one of regulation, it is important to understand how delegation affects government's ability to regulate industry.

Second, a government can potentially control an industry in more than one ways (for example, privatization and regulation of commercial enterprises; implementation of public-private partnerships at various degrees, among others), and such variations can influence the extent of bureaucratic involvement and subsequently a government's capacity to regulate industry. We can therefore expect that the way a government interacts with an industry can also affect its incentive to delegate to bureaucrats. But the extant literature has not yet fully explored the relationship between the government's mode of interaction with industry and the extent of bureaucratic delegation.

Finally, bureaucratic involvement in policy administration is often necessary. Delegation of decision-making authority further extends bureaucratic intervention to policy making. Many countries have experienced varying degrees of bureaucratic corruption in policy administration (Olken and Pande [23], Banerjee et al. [7]). While acknowledging the corruption problem, we are left with an unsettling question as to what extent should society now delegate to bureaucrats the authority to decide regulation policy?

To address the above concerns, we develop a model of delegation in the context of regulating an industry. The model is built on a framework of asymmetric information. The industry consists of a single firm, whose production entails emission of pollution to the environment and who has private information about its production technology. A government can observe the pollution level and therefore can regulate the firm by introducing pollution-contingent transfer. We add to this framework three key features that capture the standard trade off that a government faces in its decision to delegate to bureaucracies the decision-making power to regulate the industry:

- First, bureaucrats have an informational advantage over the government in regulating an industry.

  The assumption is well founded in the literature.[1] There can be many reasons for which bureaucrats may possess certain informational advantages. Politicians can choose bureaucrats based on their skill and knowledge about the industry in question, while the politicians might be chosen by the society with a different objective. Further, a bureaucrat has a narrower agenda than that of a politician and can therefore find higher incentive to gather information. We introduce informational advantage by assuming that a bureaucrat can freely acquire the information about the production technology but a government cannot at any cost. Thus, if a government regulates without delegating the job to a bureaucrat, it has to share an information rent with the firm.

- Second, bureaucrats handle any transfer of resources between the firm and the government, and they divert a fraction of the transferred resources.

  We refer to this fraction as the *bureaucratic cost*. While we allow varying degrees of the bureaucratic cost in our analysis, the assumption implies that bureaucratic corruption is unavoidable in our model. The assumption makes our analysis more fitting to economies with corrupt bureaucracies. While there has been considerable debate in finding reliable estimates of the extent of corruption, most scholars agree on the prevalence of bureaucratic corruption, especially in developing economies (see for example, Svensson [25], Olken and Pande [23] and Banerjee et al. [7]).[2] In reality, bureaucratic corruption can appear in many forms. Examples include taking bribes from firms, inflated budgeting of procurement contract, selective allocation of contracts, among others (Svensson [25], Banerjee [6]). Our model of bureaucratic cost in the form of a fraction lost in any transaction, is perhaps a simple representation of a far more complex reality. Our analysis can, however, still provide important insights into the trade-off involved in the delegation problem. An interesting feature of the model is that the implication of bureaucratic cost is not limited to the case of delegation. In absence of delegation, a government can regulate an industry by introducing pollution-contingent transfer. However, bureaucratic corruption can still constrain the effectiveness of such transfer-based regulation policy as the society can only realize a fraction of the transferred resources.

[1] In the tradition of Niskanen [22], many rational choice models on bureaucratic theory assume informational advantages for the bureaucrats. See Huber and Shipan [17] and Moe [20] for reviews of this literature.

[2] Not surprisingly, we have seen a growing interest among policy makers in addressing the problem of corruption in the last decades. As of 2015 (starting from 1998), 41 countries have either ratified or acceded the OECD anti-bribery convention. Since 1996, the World Bank has supported more than 600 anticorruption programs globally (Banerjee et al. [7]).

- Third, bureaucrats are partly motivated by self-interest: when decision-making authority is delegated to a bureaucrat, she pursues an objective different from that of the government.

  Like our first assumption, this assumption has a long tradition in the literature on rational models of bureaucracy. Since Niskanen's ([21], [22]) seminal works on public bureaucracy, many formal models of bureaucracy have assumed that the bureaucrat's objective differs from that of a government (see McCubbins et al. [19], Spiller and Ferejohn [24], Epstein and O'Halloran [12], among others).[3] We introduce the difference of interests between the government and the bureaucrat, by assuming that the bureaucrat maximizes a weighted combination of the transfer between government and industry and the government's objective function. We refer to the relative weight on transfer as the *bureaucratic drift*. In our analysis, we allow varying degrees of bureaucratic drift and study its effect on government's incentive to delegate.

In a model capturing the above three features of bureaucracy, we analyze the delegation problem. We make several contributions.

First, we explain the relationship between the extent of bureaucratic discretion and bureaucratic cost and drift. It is not surprising that bureaucratic delegation may create an agency problem. The government can however align the interest of the hired bureaucrat by putting restrictions on her conduct, for example by formulating laws and regulations to go with the bureaucrat's license to deal with industry on behalf of the government. We consider a specific form of such restriction: government allows the bureaucrat to freely decide the level of transfer, but imposes bounds (both upper and lower bounds) on the pollution level. We call such restriction on bureaucratic discretion *partial delegation*. Our motivation for analyzing this specific form of partial delegation comes from both practical and analytical reasons. First, cap regulation (bounded above) and floor regulation (bounded below) are often practiced in reality (see Holmström [15], [16], Armstrong and Sappington [5]). Second, we do not allow restriction on transfer as such restrictions would be difficult to implement given that the bureaucrats themselves handle the transfers.

Partial delegation limits bureaucratic discretion. We characterize the optimal partial delegation at various levels of bureaucratic cost and bureaucratic drift. In equilibrium, three regimes with three different types of bureaucratic discretion can arise. The level of bureaucratic discretion in turn determines the regulation policy that will be in effect. In the first type of regime, the government does not delegate to bureaucrats, but regulate the industry on its own. We call this regime *no delegation*. In the second type of regime, the government delegates to bureaucrats the decision-making authority but imposes a strict bound on the pollution level. Depending on the direction of transfer between the government and the firm,

[3] Niskanen [21] analyzed bureaucrats as rational actors motivated by self interest. Similar views were also expressed in contemporary works of Tullock [26] and Down [11].

the restriction can be in form of a lower bound or an upper bound, but not both. In response, the bureaucrat implements a uniform pollution level for both types of firms. The outcome resembles a situation in which government can set a uniform pollution level and allow bureaucrats only to decide the transfer. We call this regime *partial delegation with uniformity.* Finally, in the third type of regime, the government delegates to bureaucrats the decision-making authority but imposes less stringent (compared to the second regime) bound on the pollution level. In this case, the resulting outcome is that the bureaucrat implements the government's optimal policy for only one of the two types of firms. We which call this regime *partial delegation with non-uniformity.* The three regimes represent zero, moderate and high levels of bureaucratic discretion respectively.

Our findings show that the extent of bureaucratic discretion reduces with bureaucratic drift. The government gives more discretion to a more aligned bureaucrat. An adverse effect of delegation is policy distortion. Such distortion will be less with a more aligned bureaucrat. The result is similar to what is known as *Ally Principle* in the political economy literature on delegation (Bendor et al. [8]). The ally principle holds in a number of rational choice models of delegation, though there are contrasting empirical evidence (Huber and Shipan [17]). As Huber and Shipan [17] point out, the ally principle critically depends on the assumption on exogenous sources of information asymmetry, which is also true in our model.[4]

The effect of bureaucratic cost is however not so straight forward. Bureaucratic discretion changes non-monotonically with bureaucratic cost. It is because diversion of resources by bureaucrats is unavoidable in dealing with any transfer-based regulation policy, irrespective of whether a government or a bureaucrat sets the policy. Therefore, the marginal effect of bureaucratic cost on the policies set by a bureaucrat or by a government, in turn determines government's preference over bureaucratic discretion.

We also contribute to the delegation literature by demonstrating how government's mode of interaction with an industry can have a critical effect on the government's delegation incentive. To this end, we consider two different settings in which a government can interact with the industry. The two settings are similar in terms of output production, but how bureaucratic corruption influences production differs between the two settings. In one of the settings, which we call *procurement*, the government contracts with the firm both to procure its production and regulate its pollution. In the other setting, which we call *permits*, there is no government procurement and the government contracts with the firm to give it permission to pollute. The direction of transfer differs in the two settings in the following way. In the case of procurement, the transfer goes from government to the firm in compensation for the firm's production costs. In the case of permits, the transfer goes in the opposite direction, from the firm to government in payment for the right to pollute.

[4] In models with endogenous sources of information advantage, the ally principle may fail to hold (see for example, Gailmard [13] and Bendor and Meirowitz [9]).

To illustrate the difference with an example, consider the case of building a road. In the procurement setting, the government procures the construction and compensate the producer her production cost. The producer is regulated as her choice of compensation determines the pollution level. The compensation is a transfer from the government to the producer, and therefore bureaucratic corruption affects the procurement price. In the permits setting, the producer produces on her own, and charges a toll directly to the consumers who uses the road. The government can however regulate production technology by charging a price in exchange of permitting the producer to use certain production technology to build the road. The price of the permit is a transfer from the producer to the society, and therefore bureaucratic corruption affects the permit price. It can be shown that the two settings produce the same outcome when there is no bureaucratic corruption.

In presence of bureaucratic corruption, the government needs to trade off its desire to save public funds and its desire to restrict pollution. On the other hand, for a rent-seeking bureaucrat, it is important that there is a flow of transfer through the regulatory system that she controls. The more transfers that are involved, and the more easily such transfers can be diverted, the more can such a bureaucrat get out of her position. In the procurement setting, the bureaucrat prefers high production costs and therefore restricts pollution so that transfer will be high. In the permits setting, on the other hand, the bureaucrat allows a high pollution level in order to sell more permits and thereby increase the transfer. This has implications on how government decides the optimal delegation rules. Specifically, when a government partially delegates, it sets a lower bound on the pollution level in the procurement setting and an upper bound on the pollution level in the permits setting. Consequently, the equilibrium outcome differs between the two settings. In the partial delegation regime with non-uniformity, the government can implement its preferred pollution level for only one of two types - for the cost efficient type in the procurement setting and for the cost-inefficient type in the permits setting.

We also study the government's preference over the two regulatory environments. Bureaucratic corruption affects the optimal regulation policy and the optimal delegation rule in different ways in the two settings. When a government does not delegate in equilibrium, it is constrained by the information problem. Therefore, its preference over the two settings is dominated by its concern for the information rent-sharing arrangement with the cost efficient firm. On the other hand, when a government partially delegates in equilibrium, it is constrained by the policy distortion due to bureaucratic drift. We therefore see a reversal of preference over the two regulatory environments, when a government delegates and when it does not. We illustrate the case of preference reversal with an example in the paper.

Our work relates to several strands of literature. There is a considerably large political economy literature on delegation (see Epstein and O'Halloran [12], Huber and Shipan [17], Moe [20] for comprehensive reviews of this literature). Some of ours observations are related to the findings in this literature. For example, the ally principle holds in many rational models of delegation (Huber and Shipan [17]). We differ from most of these models of delegation in how we model rent-seeking bureaucracy. Unlike political-economy models where rent-seeking is mostly linked to the bureaucrat's interest and objective, we model the effect of rent-seeking also in terms of the regulation policies offered by the regulator, who may not necessarily be a bureaucrat. There has been limited attempt to study the relationship between extent of bureaucratic rent-seeking and bureaucratic discretion, and our analysis can thus be a valuable addition to this literature. In this regard, our finding is qualitatively similar to that of Acemoglu and Verdier [1], who find that the size of bureaucracy can be large when corruption is harder to avoid.

The paper also contributes to a strand of the regulation literature that looks at how variations in the regulatory environment affect the scope and effectiveness of regulation. Of particular interest are papers (see for example, Alesina and Passarelli [4]) discussing political-economy aspects of the distinction between regulation and taxation. This literature essentially pictures a regulatory regime that affects a firm's quantities, while taxation affects the firm's prices. We add to this debate by stressing the importance of the direction of transfers in the relationship between government and industry, on top of this price-versus-quantity distinction.

Furthermore, we also relate to the discussion of the delegation problem originally analyzed by Holmström ([15], [16]), with recent contributions by Alonso and Matouschek [2] and Amador and Bagwell [3]. We extend this research to regulation with asymmetric information. In so doing, we limit ourselves to a case of two types of the privately informed firm. The implication is that the informed bureaucrat has a finite action set to consider. Our notion of partial delegation has features similar to interval delegation studied in the delegation literature. While interval delegation refers to a bounded choice set in the form of an interval in a unidimensional policy space, our description of partial delegation differ in two ways. First, we deal with a two-dimensional policy space, in which a regulator can choose both pollution level and transfer. Second, we consider an interval restriction on the choice of pollution but not on the choice of transfer. The extant literature is mostly concerned with the optimality of interval delegation, we differ in our approach by looking at how variation in the regulatory framework could affect the optimal partial delegation rules.

Finally, our basic model of government facing a polluting firm with private information about its technology essentially follows the regulation framework developed in Boyer and Laffont [10] and Laffont [18].

The paper is organized as follows. In the next section, we present our basic model. In Sections 3 and 4, we discuss delegation to the bureaucrat, both complete and partial, in the cases of procurement and permits, respectively. In Section 5, we compare the two settings, while Section 6 concludes. A number of proofs of our results are relegated to an Appendix.

2 The model

2.1 The environment

The society consists of a consumer C and a producer P.[5] P produces a good that gives a positive consumption utility, measured by G, to C. P incurs cost to produce the good. We assume that the cost function is private information of P. P can reduce its production cost by employing a resource. We assume that the use of this resource is costly to C. We can interpret this cost as the benefit that C can receive from alternate uses of it. We refer to this resource as pollution and we focus on the problem of how C can optimally control the level of pollution.

Production technology

P's cost of production is $\theta(K-d)$, where $K>0$ is a constant, $d\in[0,K]$ is the pollution level chosen by P, and θ is a cost characteristic which is private information. For a given pollution level d, θ measures P's cost efficiency in production, a higher θ implying a higher cost or lower efficiency. We assume that θ can take two values $\{\underline{\theta},\overline{\theta}\}$, with $0<\underline{\theta}<\overline{\theta}<K$, and $\nu\in(0,1)$ is the probability that $\theta=\underline{\theta}$. Define $\triangle\theta:=\overline{\theta}-\underline{\theta}$. C is adversely affected by pollution, and his disutility is given by $\frac{d^2}{2}$. The social value of production is therefore

$$V(\theta,d)=G-\theta(K-d)-\frac{1}{2}d^2,$$

where the gross value of production G satisfies

$$G\geq\frac{K^2}{2}, \tag{1}$$

ensuring that the social value of production is non-negative even at maximum pollution, *i.e.*, that $V(\theta,K)\geq 0$. Note that the socially efficient pollution level is θ for a given θ.

Controlling pollution

We assume that P's choice of the pollution level d is observable and verifiable. We consider two different structures in which C can affect P's choice of pollution level.

In the first structure, which we refer to as *Procurement*, C makes a transfer to P to compensate his production costs. The transfer is a function of the observed pollution level. In order to make the transfer, C has to raise public funds. In return, P provides the good to C, and C can consume the good at no additional cost.

[5]This means that we disregard consumer heterogeneity.

In the second structure, which we refer to as *Permits*, P produces the good and then sells it to C in the market. C has to pay a price to purchase the good. C can, however, charge a permit fee to compensate the disutility from pollution. The fee is a function of the observed pollution level.

Throughout, we consider the *perfect Bayesian Nash equilibrium* as the solution concept of the game.

2.2 The procurement framework

In the procurement framework, C implements a contract $\alpha = (t, d) \in A = \mathbb{R}_+ \times [0, K]$ that determines a transfer t from C to P and a pollution level d. In other words, P gets paid t in order to keep pollution down at d. Given a contract $\alpha = (t, d)$, the payoff of P is

$$U_P^R(\theta, t, d) = t - \theta(K - d). \tag{2}$$

We will consider pairs of contracts $(\underline{\alpha}, \overline{\alpha}) = \left((\underline{t}, \underline{d}), (\overline{t}, \overline{d})\right) \in A^2$, for the two types $\underline{\theta}$ and $\overline{\theta}$, that satisfy *incentive-compatibility* constraints:

$$\overline{t} - \overline{\theta}\left(K - \overline{d}\right) \geq \underline{t} - \overline{\theta}\left(K - \underline{d}\right), \tag{ICH-R}$$

$$\underline{t} - \underline{\theta}\left(K - \underline{d}\right) \geq \overline{t} - \underline{\theta}\left(K - \overline{d}\right). \tag{ICL-R}$$

We also assume that the producer's participation is voluntary so that contracts must be individually rational. A pair of contracts $(\underline{\alpha}, \overline{\alpha})$ satisfy the *individual-rationality* constraints if:

$$\overline{t} - \overline{\theta}\left(K - \overline{d}\right) \geq 0\ , \tag{IRH-R}$$

$$\underline{t} - \underline{\theta}\left(K - \underline{d}\right) \geq 0\ . \tag{IRL-R}$$

Bureaucratic cost of procurement

We assume that implementing a regulatory policy with transfer has a bureaucratic cost. For every 1 unit of fund raised, P receives only a fraction $(1 - \lambda)$ of it, where $\lambda \in (0, 1)$, and the remaining fraction λ is consumed by the bureaucracy.[6] Therefore, in order to make a utility transfer of t to P, C has to raise public funds of $\frac{t}{1-\lambda}$ (out of which $\frac{\lambda t}{1-\lambda}$ is consumed in bureaucracy). The payoff of C from a contract α is given by

$$U_C^R(\alpha) \quad = \quad G - \frac{1}{2}d^2 - \frac{t}{1-\lambda}\ . \tag{3}$$

[6]Public transfer often involves other forms of distortionary cost, such as distortion caused by taxation. We disregard such costs and focus on the bureaucratic cost.

Delegation

C can delegate the regulatory decision to an outside regulator, a bureaucrat B. We assume that B is informed about P's cost. B can therefore implement a type-contingent regulatory policy.

In our basic model, if C delegates, B has authority to choose regulatory policy according to her own preferences. We assume that B has vested interest in that fraction of the transfer that is consumed in bureaucracy. Specifically, B's payoff is a weighted average of that fraction and the consumer's payoff:

$$\begin{aligned} U_B^R(\theta,\alpha) &= \beta\frac{\lambda t}{1-\lambda} + (1-\beta)\,U_C^R(\alpha) \\ &= (1-\beta)\left[\left(G-\frac{1}{2}d^2\right)-\left(1-\frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)t\right] \end{aligned} \tag{4}$$

where $\beta \in (0,1)$ measures the extent of the bureaucrat's rent-seeking motivation. We impose the restriction

$$\beta < \frac{1}{1+\lambda} \tag{5}$$

to ensure that the bureaucrat does not choose an infinitely high transfer.

Timeline

The game proceeds as follows.

- Stage 1. C decides whether to delegate decision making authority to an outside bureaucrat B. If he does not delegate, then the authority remains with C.
- Stage 2. P learns his type θ, which can be either $\underline{\theta}$ with probability ν or $\overline{\theta}$ with probability $1-\nu$. B also learns P's type at zero cost.
- Stage 3. The player with decision making authority determines the regulatory policy.
- Stage 4. Production takes place. C consumes the good. Payoffs are realized. The game ends.

2.3 The permits framework

In the permits framework, the contract $\alpha \in A$ that C implements now determines a transfer t from P to C and a pollution level d. In other words, P pays t to C in order to be allowed to pollute d. Thus, unlike the procurement framework, here C does not provide P with a transfer to compensate the production cost. Instead, P sells the good to C after production at a price p; as P knows his type during production, this price can effectively vary across types. For given price p and permit contract $\alpha = (t,d)$, the payoff of P is

$$U_P^T(\theta,\alpha) = p(\theta) - \theta(K-d) - t. \tag{6}$$

Again, we consider pairs of contracts $(\underline{\alpha}, \overline{\alpha})$ satisfying *incentive-compatibility* constraints,

$$-\overline{\theta}\left(K-\overline{d}\right) - \overline{t} \geq -\overline{\theta}\left(K-\underline{d}\right) - \underline{t}, \tag{ICH-T}$$

$$-\underline{\theta}\left(K-\underline{d}\right) - \underline{t} \geq -\underline{\theta}\left(K-\overline{d}\right) - \overline{t}, \tag{ICL-T}$$

and *individual-rationality* constraints:

$$p\left(\overline{\theta}\right) - \overline{\theta}\left(K-\overline{d}\right) - \overline{t} \geq 0\ , \tag{IRH-T}$$

$$p\left(\underline{\theta}\right) - \underline{\theta}\left(K-\underline{d}\right) - \underline{t} \geq 0\ . \tag{IRL-T}$$

Bureaucratic cost of permits

Also permit fees have bureaucratic cost. In particular, for 1 unit of fee transferred from P, C receives a fraction $1-\lambda$ of it, and the remaining fraction λ is consumed by the bureaucracy. The payoff of C is therefore

$$U_C^T(\alpha) \quad = \quad G + (1-\lambda)\,t - \frac{1}{2}d^2 - p\ . \tag{7}$$

Delegation

Again, C can delegate the decision making authority to a bureaucrat B, who is informed about P's cost efficiency and can implement a type-contingent transfer policy. However, B has a vested interest in the transfer. For a given type θ, transfer t and pollution level d, her payoff is

$$\begin{aligned} U_B^T(\theta,\alpha) &= \beta\lambda t + (1-\beta)\,U_C^T(\alpha) \\ &= (1-\beta)\left[G + \left(1+\lambda\frac{2\beta-1}{1-\beta}\right)t - \frac{1}{2}d^2 - p(\theta)\right] \end{aligned} \tag{8}$$

where again $\beta < \frac{1}{1+\lambda}$.

Timeline

The timing of the game is parallel to the one in the case of procurement.

- Stage 1. C decides whether to delegate decision making authority to an outside bureaucrat B. If he does not delegate, the decision making power remains with C.
- Stage 2. P learns his type θ, which can either be $\underline{\theta}$ with probability ν or $\overline{\theta}$ with probability $1-\nu$. B also learns P's type at zero cost.

- Stage 3. The player with decision making authority determines the permit contracts.
- Stage 4. P produces and sets a market price p. C decides whether or not to purchase the good at price p. Payoffs are realized. The game ends.

2.4 Discussion of the model

It is important to note that the two frameworks, procurement and permits, differ in the direction of transfer. In the procurement framework, the transfer goes from C to P, whereas under permits, the transfer goes the other way round. In both these structures, C would ideally prefer to implement a type-contingent transfer rule. C is however, informationally constrained, and we therefore deal with an adverse-selection problem in both scenarios.

At the base of our model lies a simple incentive-regulation problem. Consumers get positive utility from consumption of a good. A producer can produce the good for consumers, but production has a negative social externality, such as cost of pollution, or opportunity cost of use of certain inputs that consumers value. Consumers have a dual objective $-$ they prefer production to take place and they like to keep down the negative externality. The procurement framework combines the regulation problem with a procurement problem. The permits framework assumes away the procurement problem and focuses on the regulation problem. In the permits framework, consumers acquire the good from the market without any procurement. The second framework thus resembles a simple taxation problem in which consumers charge a tax to regulate the negative social externality of production.

3 Procurement: Analysis

We write all decision variables in the procurement framework with a superscript R. We use different subscripts, depending on the context. We solve the game by backward induction. As no strategic decision is made at stage 4, we start at stage 3.

Consider first the regulatory contract that C chooses if he has perfect information about θ. The contract for type θ solves the following problem:

$$\max_{\alpha} G - \frac{1}{2}d^2 - \frac{t}{1-\lambda} \tag{9}$$
$$\text{subject to (IRH-R) and (IRL-R).}$$

We denote the solution with subscript CI. Clearly, P's participation constraint is binding, so we write $t = \theta\,(K - d)$. Replacing t in (9), we find from the first-order condition that the optimal contract $\alpha^R_{CI}(\theta) = \left(t^R_{CI}(\theta), d^R_{CI}(\theta)\right)$ is given by

$$\begin{aligned} d^R_{CI}(\theta) &= \min\left\{\frac{\theta}{1-\lambda}, K\right\}, \\ t^R_{CI}(\theta) &= \theta\left[K - d^R_{CI}(\theta)\right]. \end{aligned} \tag{10}$$

Note that, when the pollution is at the maximum, then there is also no transfer: $\alpha^R_{CI}(\theta) = (0, K)$; in this case, essentially, government lets the producer go unregulated, with no transfer, and it happens when $\lambda \in \left[1 - \frac{\theta}{K}, 1\right)$. The kink in the optimal choice of pollution level stems from the linearity in pollution technology.

Inserting for the optimal contract in (9), we find C's payoff as

$$V^R(\theta, \lambda) := \begin{cases} G - \frac{\theta}{1-\lambda}K + \frac{\theta^2}{2(1-\lambda)^2} & \text{if } \frac{\theta}{1-\lambda} < K; \\ G - \frac{K^2}{2} & \text{if } \frac{\theta}{1-\lambda} \geq K. \end{cases} \tag{11}$$

Note how the condition in (1) ensures that this payoff is always non-negative.

3.1 Regulation by consumer

With no delegation at stage 1, the uninformed consumer offers an incentive-compatible pair of contracts $(\underline{\alpha}, \overline{\alpha})$ to P at stage 3. The contract pair solves the following problem:

$$\max_{\underline{\alpha}, \overline{\alpha}} \nu \left[G - \frac{1}{2}\underline{d}^2 - \frac{\underline{t}}{1-\lambda}\right] + (1-\nu)\left[G - \frac{1}{2}\overline{d}^2 - \frac{\overline{t}}{1-\lambda}\right] \tag{12}$$

subject to (IRH-R), (IRL-R), (ICH-R), and (ICL-R).

We denote the solution with subscript CN. The following Lemma describes the contract pair.

Lemma 1. *Assume that C does not delegate the decision making authority. The contract pair $\left(\alpha^R_{CN}(\underline{\theta}), \alpha^R_{CN}(\overline{\theta})\right) = \left(\left(t^R_{CN}(\underline{\theta}), d^R_{CN}(\underline{\theta})\right), \left(t^R_{CN}(\overline{\theta}), d^R_{CN}(\overline{\theta})\right)\right)$ that C offers to P is given by*

$$\begin{aligned} d^R_{CN}(\underline{\theta}) &= \min\left\{\frac{\underline{\theta}}{1-\lambda}, K\right\}, \\ d^R_{CN}(\overline{\theta}) &= \min\left\{\frac{1}{1-\lambda}\left(\overline{\theta} + \frac{\nu}{1-\nu}\triangle\theta\right), K\right\}, \\ t^R_{CN}(\underline{\theta}) &= \underline{\theta}\left(K - d^R_{CN}(\underline{\theta})\right) + \triangle\theta\left(K - d^R_{CN}(\overline{\theta})\right), \\ t^R_{CN}(\overline{\theta}) &= \overline{\theta}\left(K - d^R_{CN}(\overline{\theta})\right). \end{aligned} \tag{13}$$

Proof. In the Appendix. □

The pollution level is socially efficient for the low-cost type of firm. However, in order to reduce the information rent of the low-cost type, the consumer distorts the pollution level set for the high-cost type and allows it to pollute more. With an increase in the bureaucratic cost, this distortion rises.

3.2 Regulation by bureaucrat

With delegation at stage 1, the informed B offers a type-contingent contract at stage 3. The contract for type θ solves the following problem:

$$\max_{\alpha} (1-\beta)\left[\left(G-\frac{1}{2}d^2\right)-\left(1-\frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)t\right], \tag{14}$$
$$\text{subject to} \quad t-\theta\left(K-d\right)\geq 0.$$

We denote the solution with subscript BI. The following Lemma describes the contract.

Lemma 2. *Assume that C delegates the decision making authority to a bureaucrat. The contract $\alpha_{BI}^{R}(\theta)=\left(t_{BI}^{R}(\theta), d_{BI}^{R}(\theta)\right)$ that the bureaucrat offers to P of type $\theta\in\left\{\underline{\theta},\overline{\theta}\right\}$ is given by*

$$\begin{aligned} d_{BI}^{R}(\theta) &= \min\left\{\left(1-\frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)\theta, K\right\} \\ t_{BI}^{R}(\theta) &= \theta\left(K-d_{BI}^{R}(\theta)\right). \end{aligned} \tag{15}$$

Proof. In the Appendix. □

The bureaucrat's choice of pollution level is always below the consumer's choice because of her vested interest in transfer. In order to increase the level of transfer, she sets the production cost at a higher level, and makes the producer to under pollute.

Example. Consider the following parameter values: $G=50$, $K=10$, $\lambda=0.25$, $\beta=0.65$, $\nu=0.5$, $\overline{\theta}=4$, and $\underline{\theta}=2$. Figure 1 plots the contract choices by an informed consumer, an uninformed consumer and the bureaucrat, respectively, in (d,t) space. The straight lines represent P's individual rationality constraints (the steeper one corresponds to the high-cost type $\overline{\theta}$), and P's payoff increases in the top-right direction. The dashed curves are the consumer's indifference curves, with payoff increasing in the bottom-left direction. The points A and B are the consumer's first-best choices for types $\underline{\theta}$ and $\overline{\theta}$, respectively. An uninformed consumer's choice of contracts for types $\underline{\theta}$ and $\overline{\theta}$ are given by the points C and D, respectively. The distance between the dotted line containing C and the solid line containing A measures the information rent. The type-$\underline{\theta}$ producer is indifferent between C and D. The dot-dashed curves are the bureaucrat's indifference curves, and points E and F are B's choice of contracts for types $\underline{\theta}$ and $\overline{\theta}$, respectively.

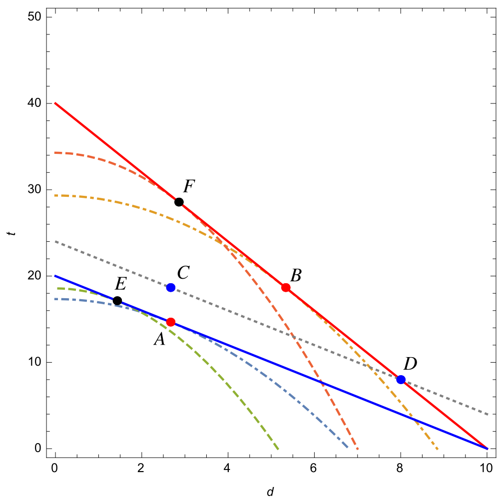

Figure 1: Optimal procurement contracts

3.3 The decision to delegate

The consumer faces a trade-off in delegation. There are two types of loss that the consumer incurs if he does not delegate. First, the consumer has to share an information rent with the low-cost firm. Second, there will be distortion at the pollution level chosen for the high-cost firm. On the other hand, by delegating to an informed bureaucrat, the consumer can save the information rent, but there will be distortion at the pollution level chosen for firms of both types, as the objective of the bureaucrat is not aligned with that of the consumer. Comparing C's payoff under the two regimes, we can derive the condition under which the consumer prefers to delegate decision making authority to the bureaucrat. Precisely, he delegates decision making authority if the following condition holds:

$$\triangle D^R := \quad E_\theta U_C^R \left(\alpha_{BI}^R (\theta)\right) - E_\theta U_C^R \left(\alpha_{CN}^R (\theta)\right) \quad > 0,$$

where, for an arbitrary function $f(\cdot)$ of θ, we let $E_\theta f(\theta) := \nu f(\underline{\theta}) + (1-\nu) f\left(\overline{\theta}\right)$.

The following proposition describes how the two parameters β and λ affect the consumer's preference for delegation.

Proposition 1. *(i) The consumer delegates if his expected benefit from delegation, $\triangle D^R$, is positive.*

(ii)$\triangle D^R$ *decreases with respect to the bureaucrat's rent seeking motivation β and moves non-monotonically with respect to the bureaucratic cost λ.*

Proof. In the Appendix. □

The effect of β on $\triangle D^R$ is straightforward. β has no impact on the consumer's payoff from no delegation. On the other hand, the consumer's payoff from delegation decreases continuously with respect to β. This is because the bureaucrat decreases the permissible pollution level d_{BI}^{R} with β in order to increase the level of compensatory transfer, and a decrease in d_{BI}^{R} adversely affects the consumer's payoff from delegation.

The non-monotonic effect of λ on $\triangle D^{R}$ is driven by the following facts. First, there is a direct negative effect of λ on the consumer's payoff. For any fixed values of transfer t and pollution level d, C's payoff reduces as the bureaucratic cost increases. Secondly, the effect of λ on the optimal pollution level set by the bureaucrat, $d_{BI}^{R}(\theta)$, changes non-monotonically with respect to β. It is decreasing (increasing) in λ when β is more (less) than 1/2, *i.e.*, when the bureaucrat puts relatively high (low) weight on her private interest in transfer than on the consumer's payoff. Thirdly, the consumer saves an information rent (shared otherwise with the low-cost firm) from delegation. One unit of information rent effectively costs the consumer public funds of amount $1+\lambda$. Thus the saving from delegation is increasing in λ. The rent, however, approaches zero when the optimal pollution level for the high-cost firm $d_{CN}^{R}\left(\overline{\theta}\right)$ approaches K. In fact, it can be shown that, if $d_{CN}^{R}\left(\overline{\theta}\right)$ is sufficiently close to K (which is more likely for higher values of ν) and β is more than 1/2, then the consumer's benefit from delegation decreases with the bureaucratic cost λ. Hence, we can conclude that, when the firm is more likely to be low-cost and bureaucrats have a high rent-seeking motivation, the consumer's payoff from delegation decreases with respect to the bureaucratic cost.

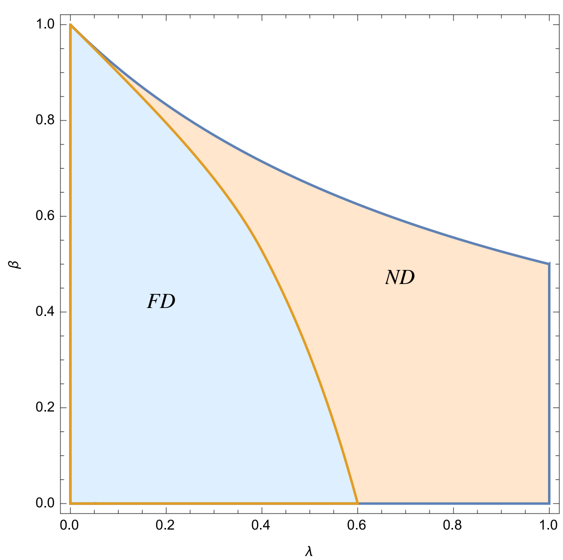

Figure 2. Equilibrium delegation

Example continued. Figure 2 plots the equilibrium delegation region in (λ, β) space. In particular, the FD area represents parameter values for which the benefit from delegation is positive so that the consumer delegates in equilibrium.

3.4 Partial delegation

The consumer can improve his payoff from delegation by restricting the bureaucrat's choice set. We consider a specific type of restriction that the consumer may impose and study the optimal restriction in that category. Such delegation with a restricted choice set we call *partial delegation*. This notion resembles interval delegation, which has been studied by, *e.g.*, Alonso and Matouschek (2008) and Amador and Bagwell (2013). Since the task to be delegated is one of regulation, we have on the one hand a multi-dimensional action space and on the other hand a two-type information issue. Here, we do not consider optimal interval regulation and limit our attention to partial delegation.

As the bureaucrat has an interest in the transfer, her preferred pollution level is always below that of the consumer. The consumer can therefore improve his payoff by imposing a lower bound on the bureaucrat's choice of pollution level. As the consumer is informationally constrained, he cannot, however, impose type-dependent bounds. Before we study the optimal bounds (from the consumer's perspective), we first look at how a bounded choice set affects the bureaucrat's choice of regulatory contracts.

Specifically, we impose a restriction that the bureaucrat choose regulatory contracts $\alpha(\theta) = (t(\theta), d(\theta)), \theta \in \{\underline{\theta}, \overline{\theta}\}$ under the constraint that $d(\theta) \in [d_1, d_2] \subseteq [0, K]$; it is this constraint that we call *partial delegation*. Since the bureaucrat is informed, her contract for type θ solves the following problem:

$$
\begin{aligned}
&\max_{\alpha} (1-\beta)\left[\left(G - \frac{1}{2}d^2\right) - \left(1 - \frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)t\right], \qquad (16)\\
&\text{subject to } \; t - \theta(K-d) \geq 0, \;\text{ and }\; d \in [d_1, d_2].
\end{aligned}
$$

We denote the solution with a superscript PR and a subscript BI. The following Lemma describes the bureaucrat's choice of contracts.

Lemma 3. *Assume that C delegates the decision making authority with the restriction that $d \in [d_1, d_2] \subseteq [0, K]$. The bureaucrat's regulation contract for type $\theta \in \{\underline{\theta}, \overline{\theta}\}$ is given by $\alpha_{BI}^{PR}(\theta, d_1, d_2) = \left(t_{BI}^{PR}(\theta, d_1, d_2), d_{BI}^{PR}(\theta, d_1, d_2)\right)$, where*

$$
\begin{aligned}
d_{BI}^{PR}(\theta, d_1, d_2) &= \begin{cases} d_1 & \text{if } d_1 \geq \left(1 - \frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)\theta \\ \left(1 - \frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)\theta & \text{if } d_1 < \left(1 - \frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)\theta < d_2 \\ d_2 & \text{if } \left(1 - \frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)\theta \geq d_2 \end{cases}\\
t_{BI}^{PR}(\theta, d_1, d_2) &= \theta\left(K - d_{BI}^{PR}(\theta, d_1, d_2)\right).
\end{aligned}
$$

Proof. In the Appendix. □

The solution under partial delegation coincides with the one under complete delegation if the latter lies in the bounded interval $[d_1, d_2]$; otherwise, the optimal solution lies at the boundaries. The consumer can therefore affect the bureaucrat's optimal choices by manipulating d_1 and d_2. Below we study the consumer's choice of d_1 and d_2.

3.4.1 Optimal partial delegation

Before we describe the consumer's choice of bounds, the following observations are worth noting. First, the upper bound d_2 has no effect. This is because the bureaucrat's choice of pollution levels are always below those of the consumer. C would be adversely affected if he were to choose some $d_2 < d_{BI}^R\left(\overline{\theta}\right)$. But for any $d_2 \geq d_{BI}^R\left(\overline{\theta}\right)$, the bureaucrat's choices are unaffected by d_2. Disregarding the consumer's indifference, we simply assume that he picks $d_2 = d_{CI}^R\left(\overline{\theta}\right)$, which is his first-best choice of pollution level for the high-cost firm.

Secondly, regarding the consumer's choice of a lower bound, two possibilities arise. The first possibility is for the consumer to choose his first-best pollution level for the low-cost firm, *i.e.*, $d_1 = d_{CI}^R\left(\underline{\theta}\right)$. This way, the consumer implements the first-best contract for the low-cost firm by delegation, since now this will also be the choice of the bureaucrat for this type of firm. But there is still a distortion at the contract offered to the high-cost firm − the bureaucrat sets the pollution level at her own preferred choice, $d_{BI}^R\left(\overline{\theta}\right) < d_{CN}^R\left(\overline{\theta}\right)$.

The second possibility is for the consumer to set d_1 at a level that is higher than $d_{BI}^R\left(\overline{\theta}\right)$, the bureaucrat's choice of pollution level for the high-cost firm under full delegation. In this case, the bureaucrat chooses $d\left(\underline{\theta}\right) = d\left(\overline{\theta}\right) = d_1$. By setting $d_1 > d_{BI}^R\left(\overline{\theta}\right)$, the consumer reduces the distortion at the contract offered to the high-cost firm. But in order to do so, he brings distortion to the contract offered to the low-cost firm.

The consumer's choice between the alternatives is driven by the difference between $d_{BI}^R\left(\overline{\theta}\right)$ and $d_{CI}^R\left(\overline{\theta}\right)$. If $d_{BI}^R\left(\overline{\theta}\right)$ is sufficiently large (so that the difference is small), then the consumer prefers the first possibility over the second one.

With respect to the second possibility, consider a hypothetical situation in which the consumer has full information about firm type and chooses contracts with a restriction of a uniform level of pollution for both types; in other words, the transfer may differ across types, but the pollution level must be the same for both types. It can easily be shown that the consumer's choice of pollution level in this hypothetical situation is given by

$$\min\left\{\frac{E_\theta \theta}{1-\lambda}, K\right\}, \tag{17}$$

which is equal to $d_{CI}^R\left(E_\theta \theta\right)$, where $d_{CI}^R\left(\cdot\right)$ is given in (10). Note that $d_{CI}^R\left(E_\theta \theta\right) \in \left[d_{CI}^R\left(\underline{\theta}\right), d_{CI}^R\left(\overline{\theta}\right)\right]$.

We denote the consumer's choice of the lower and upper bounds by d_1^R and d_2^R, respectively. The following proposition characterizes these bounds.

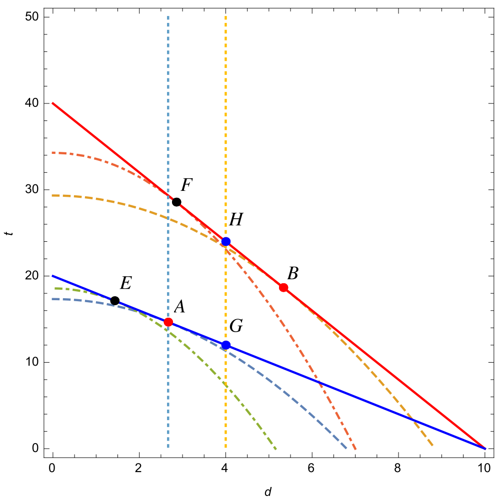

Figure 3: The regulation contracts under partial delegation

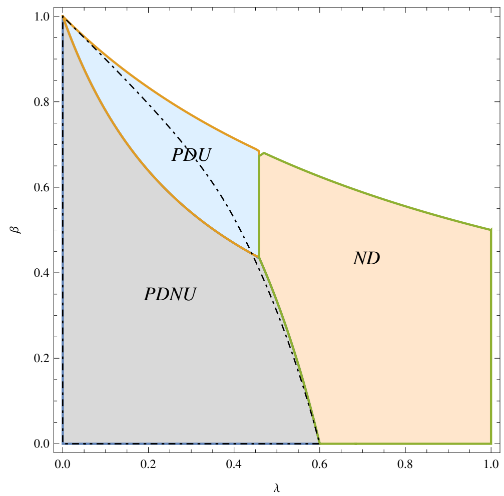

Figure 4: Equilibrium delegation under partial delegation

Proposition 2. *Under procurement, the consumer's optimal partial delegation is given by the interval* $\left[d_1^R, d_2^R\right] \subseteq [0, K]$. *There exists a critical value* $d^* \in \left[d_{CI}^R\left(\underline{\theta}\right), d_{CI}^R\left(E_\theta\theta\right)\right]$ *such that,*

1. If $d_{BI}^R\left(\overline{\theta}\right) > d^*$, then $\left[d_1^R, d_2^R\right] = \left[d_{CI}^R\left(\underline{\theta}\right), d_{CI}^R\left(\overline{\theta}\right)\right]$, and the bureaucrat's contracts are given by $d\left(\underline{\theta}\right) = d_{CI}^R\left(\underline{\theta}\right)$, $d\left(\overline{\theta}\right) = d_{BI}^R\left(\overline{\theta}\right)$, and $t\left(\theta\right) = \theta\left(K - d\left(\theta\right)\right)$, $\theta \in \left\{\underline{\theta}, \overline{\theta}\right\}$.

2. If $d_{BI}^R\left(\overline{\theta}\right) < d^*$, then $\left[d_1^R, d_2^R\right] = \left[d_{CI}^R\left(E_\theta\theta\right), d_{CI}^R\left(\overline{\theta}\right)\right]$, and the bureaucrat's contracts are given by $d\left(\underline{\theta}\right) = d\left(\overline{\theta}\right) = d_{CI}^R\left(E_\theta\theta\right)$, and $t\left(\theta\right) = \theta\left(K - d\left(\theta\right)\right)$, $\theta \in \left\{\underline{\theta}, \overline{\theta}\right\}$.

Proof. In the Appendix. □

Clearly the consumer's payoff under optimal partial delegation is always weakly higher than his payoff under full delegation, since, under partial delegation, he can always choose full delegation if he so prefers. Thus, the range of parameter values at which partial delegation happens in equilibrium is broader, compared to the range of parameter values at which complete delegation happens.

We denote the consumer's benefit from partial delegation, over and above that of complete delegation, by $\triangle PD^R$. C partially delegates the decision making authority if his benefit from partial delegation is more than his benefit from no delegation, *i.e.*, if

$$\triangle PD^R := \quad E_\theta U_C^R\left(\alpha_{BI}^{PR}\left(\theta, d_1^R, d_2^R\right)\right) - E_\theta U_C^R\left(\alpha_{CN}^R\left(\theta\right)\right) \quad > 0.$$

We have:

Proposition 3. *(i) In equilibrium, the consumer employs partial delegation if* $\triangle PD^R$ *is positive.*

(ii) The range of parameter values at which partial delegation happens in equilibrium is broader, compared to the range of parameter values at which full delegation happens in equilibrium.

Example continued. In Figure 3 (which is comparable to Figure 1), points A and B are the consumer's first-best contracts, whereas points E and F are the bureaucrat' contracts under complete delegation. In our example, $d_{CI}^{R}(\underline{\theta}) = 2.67$, and $d_{CI}^{R}(E_{\theta}\theta) = 4$. With partial delegation, the consumer can implement contracts A and F by setting d_1 at 2.67, or he can implement contracts G and H by setting d_1 at 4. In the example, the consumer's expected payoff turns out to be higher at the pair $\{G, H\}$, implying the optimal $d_1 = 4$. Figure 4 (which is comparable to Figure 2) plots the equilibrium delegation region in (λ, β) space under optimal partial delegation. The PDU area represents parameter values for which C can implement his first best choice of contracts under the restriction of a uniform pollution level. The PDNU area represents parameter values for which C can implement his first-best choice of contract for the low-cost firm, but B chooses her preferred contract for the high-cost firm. The dot-dashed curve shows the parameter values of (λ, β) at which C is indifferent between delegation and no delegation in the full-delegation case. Note that the scope of delegation increases with optimal partial delegation.

3.5 Main findings on procurement

The main findings from our analysis of the procurement framework are as follows.

- An informationally constrained consumer can benefit from delegating decision making authority to an informed bureaucrat if the bureaucrat's rent seeking motivation is relatively low. The benefit, however, changes in a non-monotonic way with bureaucratic costs. Even when full delegation of decision making authority is not beneficial, the consumer might improve his payoff from delegation by suitably restricting the bureaucrat's choice set.
- Through such partial delegation,
  - either the consumer implements his first-best choice of contract for the low-cost firm (but cannot implement the first-best choice of contract for the high-cost firm);
  - or the consumer implements his first-best choice of contracts under the restriction of a uniform pollution level.

4 Permits: Analysis

We write all decision variables in the permits framework with a superscript T. We use different subscripts depending on the context. We again solve the game by backward induction.

The consumer's utility from consuming the good is fixed at G. At stage 4, the producer therefore sets the price at G, and the consumer accepts this price. Thus, $p(\theta) = G$.

Consider first the regulatory contract that the consumer chooses if he has perfect information about θ. The contract for type θ solves the following problem:

$$\max_{\alpha} G - (1-\lambda) t - \frac{1}{2} d^2 - G, \tag{18}$$
$$\text{subject to (IRH-T) and (IRL-T).}$$

We denote the solution with subscript CI. Again, P's participation constraint is clearly binding, so we write $t = G - \theta(K - d)$. Replacing t in (18), we find from the first-order condition that the optimal contract $\alpha_{CI}^T(\theta) = \left(t_{CI}^T(\theta), d_{CI}^T(\theta)\right)$ is given by

$$\begin{aligned} d_{CI}^T(\theta) &= (1-\lambda)\theta, \\ t_{CI}^T(\theta) &= G - \theta\left(K - d_{CI}^T(\theta)\right). \end{aligned} \tag{19}$$

Inserting for the optimal contract in (18) gives the consumer's payoff as

$$V^T(\theta, \lambda) := (1-\lambda)\left(G - \theta K + \frac{1}{2}(1-\lambda)\theta^2\right). \tag{20}$$

Note that the condition in (1) does not, in general, ensure a non-negative payoff to the consumer in the case of permits. However, we do have $V^T(\theta, \lambda) \geq 0$ for all λ at the θ values that we discuss in our Example: $\overline{\theta} = 4$, and $\underline{\theta} = 2$.

4.1 Regulation by consumer

With no delegation at stage 1, the uninformed consumer offers an incentive-compatible pair of contracts $(\underline{\alpha}, \overline{\alpha})$ to P at stage 3. The contract pair solves:

$$\max_{\underline{\alpha}, \overline{\alpha}} \nu \left[(1-\lambda)\underline{t} - \frac{1}{2}\underline{d}^2\right] + (1-\nu)\left[(1-\lambda)\overline{t} - \frac{1}{2}\overline{d}^2\right], \tag{21}$$
$$\text{subject to (IRH-T), (IRL-T), (ICH-T), and (ICL-T).}$$

We denote the solution with subscript CN. The following Lemma describes this contract pair.

Lemma 4. *Assume that C does not delegate the decision making authority. The contract pair $\left(\alpha_{CN}^T(\underline{\theta}), \alpha_{CN}^T(\overline{\theta})\right) = \left(\left(t_{CN}^T(\underline{\theta}), d_{CN}^T(\underline{\theta})\right), \left(t_{CN}^T(\overline{\theta}), d_{CN}^T(\overline{\theta})\right)\right)$ that C offers to P is* *given by*

$$\begin{aligned} d_{CN}^{T}\left(\underline{\theta}\right) &= (1-\lambda)\,\underline{\theta}, \\ d_{CN}^{T}\left(\overline{\theta}\right) &= \min\left\{(1-\lambda)\left(\overline{\theta}+\frac{\nu}{1-\nu}\triangle\theta\right), K\right\}, \\ t_{CN}^{T}\left(\underline{\theta}\right) &= G-\overline{\theta}\left(K-d_{CN}^{T}\left(\underline{\theta}\right)\right)-\triangle\theta\left(K-d_{CN}^{T}\left(\overline{\theta}\right)\right), \\ t_{CN}^{T}\left(\overline{\theta}\right) &= G-\overline{\theta}\left(K-d_{CN}^{T}\left(\overline{\theta}\right)\right). \end{aligned} \tag{22}$$

Proof. The proof resembles that of Lemma 1 and therefore is omitted. □

Unlike the procurement framework, the pollution level is below the socially efficient level for the low-cost firm. The transfer compensates for the social cost of pollution. But since a fraction of it is lost due to bureaucratic costs, the consumer allows less pollution than what is first-best. The pollution level can, however, be either below or above the socially efficient level for the high-cost firm: in order to reduce the information rent of the low-cost type, the consumer increases the transfer to be paid by the high-cost type and allows it to pollute more.

4.2 Regulation by bureaucrat

With delegation at stage 1, the informed bureaucrat offers a type-contingent contract at stage 3. The contract for type θ solves the following problem:

$$\begin{aligned} &\max_{(t,d)}(1-\beta)\left[\left(1+\lambda\frac{2\beta-1}{1-\beta}\right)t-\frac{1}{2}d^{2}\right], \\ &\text{subject to}\ \ G-\theta\,(K-d)-t\geq 0. \end{aligned} \tag{23}$$

We denote the solution with subscript BI. The following Lemma describes this contract.

Lemma 5. *Assume that C delegates the decision making authority to a bureaucrat. The contract $\alpha_{BI}^{T}(\theta)=\left(t_{BI}^{T}(\theta), d_{BI}^{T}(\theta)\right)$ that the bureaucrat offers to P of type $\theta\in\left\{\underline{\theta},\overline{\theta}\right\}$ is given by*

$$\begin{aligned} d_{BI}^{T}(\theta) &= \begin{cases} \left(1+\lambda\frac{2\beta-1}{1-\beta}\right)\theta, & \textit{if } \left(1+\lambda\frac{2\beta-1}{1-\beta}\right)\theta<K \\ K, & \textit{if } \left(1+\lambda\frac{2\beta-1}{1-\beta}\right)\theta\geq K \end{cases} \\ t_{BI}^{T}(\theta) &= G-\theta\left(K-d_{BI}^{T}(\theta)\right). \end{aligned}$$

Proof. In the Appendix. □

The bureaucrat's choice of pollution level is always above that of the consumer because of her interest in transfer. In order to increase the transfer, she allows the producer to over pollute.

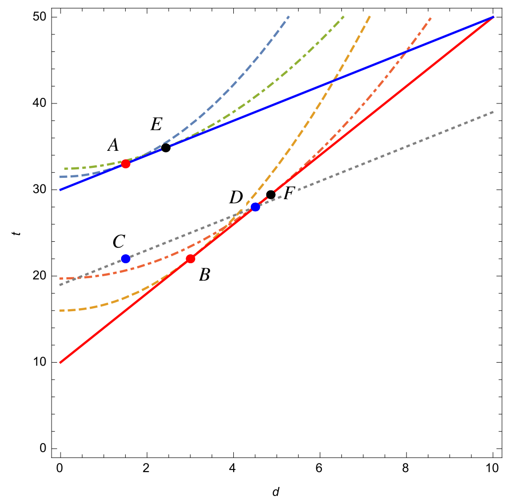

Figure 5: Optimal permits

Example continued. Figure 5 plots contracts in (d, t) space. The straight lines represent P's individual rationality constraints; the steeper one corresponds to the high-cost type $\overline{\theta}$. Unlike the procurement framework, here P's payoff is increasing in the bottom-right direction. The dotted curves are the consumer's indifference curves, with payoff increasing in the top-left direction. The points A and B are an informed consumer's choices for types $\underline{\theta}$ and $\overline{\theta}$, respectively. An uninformed consumer's choice of contracts for types $\underline{\theta}$ and $\overline{\theta}$ are given by the points C and D, respectively. The distance between the dashed line containing C and the straight line containing A measures the information rent. The low-cost type $\underline{\theta}$ is indifferent between C and D. The dashed curves represent the bureaucrat's indifference curves, with payoff increasing in the top-left direction. The points E and F are B's choice of contracts for types $\underline{\theta}$ and $\overline{\theta}$, respectively.

4.3 The decision to delegate

Comparing the consumer's payoff under the two regimes, we can derive the condition under which the consumer prefers to delegate decision making authority to the bureaucrat:

$$\triangle D^T := \quad E_\theta U_C^T \left(\alpha_{BI}^T (\theta)\right) - E_\theta U_C^T \left(\alpha_{CN}^T (\theta)\right) \quad \geq 0.$$

The following proposition describes how the two parameters β and λ affect the consumer's preference for delegation.

Proposition 4. *(i) The consumer delegates if his expected benefit from delegation, $\triangle D^T$, is positive.*

(ii) $\triangle D^T$ decreases with respect to the bureaucrat's rent seeking motivation β and moves

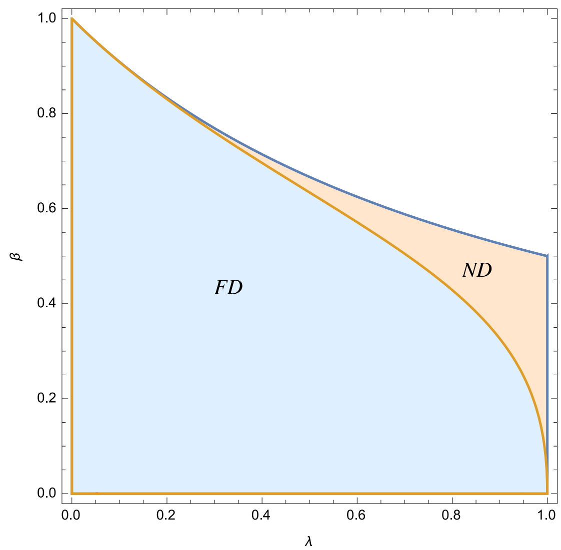

Figure 6: Equilibrium delegation

non-monotonically with respect to the bureaucratic cost λ*.*

Proof. Similar to the proof of Proposition 1, and so skipped. $\square$

The comparative-statics effects of λ and β on $\triangle D^T$ are quite similar to their effects on $\triangle D^R$, which we have discussed in Section 3.3.

Example continued. Figure 6 plots the equilibrium delegation region in (λ, β) space. In particular, the FD region represents parameter values for which the consumer prefers delegation.

4.4 Partial delegation

Like the procurement framework, the consumer can improve his payoff by restricting the choice of the bureaucrat. To see this, we again introduce partial delegation, *i.e.*, we impose a restriction that the bureaucrat choose regulatory contracts $\alpha(\theta), \theta \in \{\underline{\theta}, \overline{\theta}\}$ under the constraint that $d(\theta) \in [d_1, d_2] \subseteq [0, K]$. As the bureaucrat is informed, her contract for type θ solves the following problem:

$$\max_{(t,d)} (1-\beta)\left[\left(1+\lambda\frac{2\beta-1}{1-\beta}\right)t - \frac{1}{2}d^2\right], \tag{24}$$
$$\text{subject to } \; G - \theta(K-d) - t \geq 0, \; \text{ and } \; d \in [d_1, d_2].$$

We denote the solution with a superscript PT and a subscript BI. The following Lemma describes the bureaucrat's choice of contracts.

Lemma 6. *Assume that C delegates the decision-making authority with the restriction that $d \in [d_1, d_2] \subseteq [0, K]$. The bureaucrat's regulation contract for type $\theta \in \{\underline{\theta}, \overline{\theta}\}$ is given by $\alpha_{BI}^{PT}(\theta, d_1, d_2) = \left(t_{BI}^{PT}(\theta, d_1, d_2), d_{BI}^{PT}(\theta, d_1, d_2)\right)$, where*

$$
\begin{aligned}
d_{BI}^{PT}(\theta, d_1, d_2) &= \begin{cases} d_1 & \text{if } d_1 \geq \left(1 + \lambda \frac{2\beta - 1}{1 - \beta}\right)\theta \\ \left(1 + \lambda \frac{2\beta - 1}{1 - \beta}\right)\theta & \text{if } d_1 < \left(1 + \lambda \frac{2\beta - 1}{1 - \beta}\right)\theta < d_2 \\ d_2 & \text{if } \left(1 + \lambda \frac{2\beta - 1}{1 - \beta}\right)\theta \geq d_2 \end{cases} \\
t_{BI}^{PT}(\theta, d_1, d_2) &= G - \theta\left(K - d_{BI}^{PT}(\theta, d_1, d_2)\right).
\end{aligned}
$$

Proof. In the Appendix. □

The solution under partial delegation again coincides with the one under complete delegation if the latter lies in the bounded interval $[d_1, d_2]$; otherwise, the solution lies at the boundary. Below we study the consumer's choice of d_1 and d_2.

4.4.1 Optimal partial delegation

Unlike the procurement framework, the lower bound d_1 has no effect. This is because the bureaucrat's choice of pollution levels are always above those of the consumer. C would be adversely affected if he were to choose some $d_1 > d_{BI}^{T}(\underline{\theta})$. But for any $d_1 \leq d_{BI}^{T}(\underline{\theta})$, the bureaucrat's choices are unaffected by d_1. We therefore simply assume that the consumer picks $d_1 = d_{CI}^{T}(\underline{\theta})$, which is his first-best choice of pollution level for the low-cost firm.

Secondly, regarding the consumer's choice of an upper bound, two different possibilities arise. The first one is for the consumer to choose his first-best pollution level for the high-cost firm: $d_2 = d_{CI}^{T}(\overline{\theta})$. This way, the consumer implements his first-best contract for the high-cost firm by delegation. But, there is still a distortion at the contract offered to the low-cost firm $-$ the bureaucrat sets the pollution level at her own preferred choice $d_{BI}^{T}(\underline{\theta}) > d_{CI}^{T}(\underline{\theta})$.

The second possibility is for the consumer to set d_2 at a level that is lower than $d_{BI}^{T}(\underline{\theta})$, the bureaucrat's choice of pollution level for the low-cost firm under full delegation. In this case, the bureaucrat sets $d(\underline{\theta}) = d(\overline{\theta}) = d_2$. By setting $d_2 < d_{BI}^{T}(\underline{\theta})$, the consumer reduces the distortion at the contract offered to the low-cost firm. But in order to do so, he brings distortion to the contract offered to the high-cost firm.

The consumer's choice between the alternatives is driven by the difference between $d_{BI}^{T}(\underline{\theta})$ and $d_{CI}^{T}(\underline{\theta})$. If $d_{BI}^{T}(\underline{\theta})$ is sufficiently small (so that the difference is small), then the consumer prefers the first possibility over the second one. With respect to the second possibility, consider a hypothetical situation in which the consumer has full information about firm type and chooses contracts with a restriction of a uniform level of pollution for both types; in other words, the transfer may differ across types, but the pollution level must be the same for both types. Let us denote the consumer's choice of pollution level in this hypothetical situation by $d^T_{CI}(E_\theta\theta)$. It can easily be shown that the consumer's choice of pollution level in this hypothetical situation is given by

$$\min\{(1-\lambda)\,E_\theta\theta, K\},$$

which is equal to $d^T_{CI}(E_\theta\theta)$, where $d^T_{CI}(\cdot)$ is given in (19). Note that $d^T_{CI}(E_\theta\theta) \in \left[d^T_{CI}(\underline{\theta}), d^T_{CI}(\overline{\theta})\right]$. We denote the consumer's choice of the lower and upper bounds by d^T_1 and d^T_2, respectively. The following proposition characterizes these bounds.

Proposition 5. *Under permits, the consumer's optimal partial delegation is given by the interval* $\left[d^T_1, d^T_2\right] \subseteq [0, K]$. *There exists a critical value* $d^{**} \in \left[d^T_{CI}(E_\theta\theta), d^T_{CI}(\overline{\theta})\right]$ *such that,*

1. If $d^T_{BI}(\underline{\theta}) < d^{**}$, then $\left[d^T_1, d^T_2\right] = \left[d^T_{CI}(\underline{\theta}), d^T_{CI}(\overline{\theta})\right]$, and the bureaucrat's contracts are given by $d(\underline{\theta}) = d^T_{BI}(\underline{\theta})$, $d(\overline{\theta}) = d^T_{CI}(\overline{\theta})$, and $t(\theta) = G - \theta\left(K - d^{PT}_{BI}(\theta)\right), \theta \in \left\{\underline{\theta}, \overline{\theta}\right\}$.
2. If $d^R_{BI}(\overline{\theta}) \geq d^{**}$, then $\left[d^T_1, d^T_2\right] = \left[d^T_{CI}(\underline{\theta}), d^T_{CI}(E_\theta(\theta))\right]$, and the bureaucrat's contracts are given by $d(\underline{\theta}) = d(\overline{\theta}) = d^T_{CI}(E_\theta\theta)$, and $t(\theta) = G - \theta\left(K - d^{PT}_{BI}(\theta)\right), \theta \in \left\{\underline{\theta}, \overline{\theta}\right\}$.

Proof. Similar to the proof of Proposition 2, and so skipped. □

Clearly, the consumer's payoff under optimal partial delegation is always weakly higher than his payoff under full delegation, since, under partial delegation, he can always choose full delegation if he so prefers. Thus, the range of parameter values at which partial delegation happens in equilibrium is broader, compared to the range of parameter values at which complete delegation happens.

We denote the consumer's benefit from partial delegation, over and above that of complete delegation, by $\triangle PD^T$. C partially delegates the decision making authority if his benefit from partial delegation is more than his benefit from no delegation, *i.e.*, if

$$\triangle PD^T := \quad E_\theta U^T_C\left(\alpha^{PT}_{BI}(\theta)\right) - E_\theta U^T_C\left(\alpha^T_{CN}(\theta)\right) \quad \geq 0.$$

We have:

Proposition 6. *(i) In equilibrium, the consumer employs partial delegation if* $\triangle PD^T$ *is positive.*

(ii) The range of parameter values at which partial delegation happens in equilibrium is broader, compared to the range of parameter values at which full delegation happens in equilibrium.

Proof. The proof directly follows from the preceding discussion, and is so skipped. □

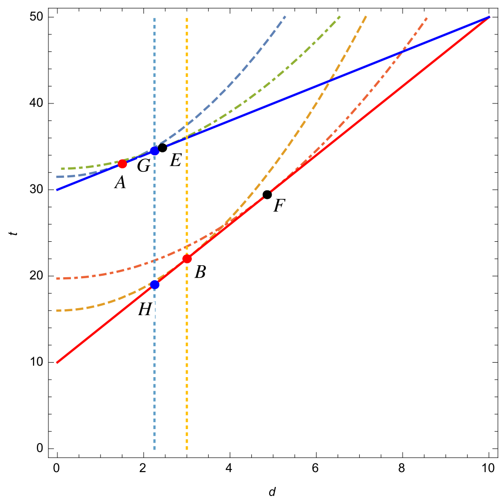

Figure 7: The permits under partial delegation

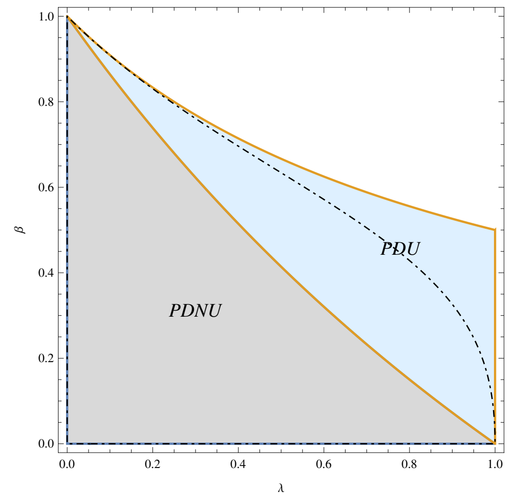

Figure 8: Equilibrium delegation under partial delegation

Example continued. In Figure 7 (which is based on Figure 5), the points A and B represent the consumer's preferred contracts, whereas the points E and F are the contracts offered by the bureaucrat under full delegation. In case of partial delegation, the consumer can either implement the contracts at points A and F by setting d_2 at the pollution level of B, or can implement the contracts at points G and H by setting d_2 at the pollution level of G. The choice depends on which combination gives him higher payoff. Figure 8 (which is comparable to Figure 6) plots the equilibrium delegation region in (λ, β) space under optimal partial delegation. The PDU area represents parameter values for which C can implement his first best choice of contracts under the restriction of a uniform pollution level. The PDNU area represents parameter values for which C can implement his first-best choice of contract for the high-cost firm, but B chooses her preferred contract for the low-cost firm. The dot-dashed curve shows the parameter values of (λ, β) at which C is indifferent between delegation and no delegation in the full-delegation case. Note that the scope of delegation increases with optimal partial delegation. In fact, in this example for all parameter values of (λ, β), the consumer's payoff from optimal partial delegation is higher than his payoff from no delegation.

4.5 Summary of the main findings

The main findings from our analysis of the permits framework are as follows.

- Like the procurement framework, an informationally constrained consumer can benefit from delegation if the bureaucrat's rent-seeking motivation is relatively low. The benefit changes in a non-monotonic way with bureaucratic costs. Even when full delegation is not beneficial, the consumer can improve his payoff from delegation by suitably restricting the bureaucrat's choice set.

- Unlike the procurement framework, through such partial delegation,
  - either the consumer implements his preferred contract for the high-cost firm but cannot implement the preferred contract for the low-cost firm);
  - or the consumer implements his preferred contract under the restriction of a uniform pollution level.

5 Comparison of procurement and permits

We so far assumed that the two frameworks, procurement and permits, were exogenously given. We now ask what C's preferred framework would be, if he could choose it.

5.1 Complete information

In absence of the information problem, the bureaucratic cost λ has different effects on C's payoff in the two frameworks. Recall that C's payoff at the optimal contracts under full information in the two frameworks procurement and permits are given by $V^R(\theta,\lambda)$ and $V^T(\theta,\lambda)$, respectively; see equations (11) and (20). Note that $V^R(\theta,0) = V^T(\theta,0)$. Furthermore, $V^R(\theta,1) = G - \frac{K^2}{2}$ and $V^T(\theta,1) = 0$. While $V^R(\theta,\lambda)$ is always positive under the condition in (1), a necessary and sufficient condition for $V^T(\theta,\lambda)$ to be positive for all λ is $\theta \leq \frac{G}{K}$. To keep the *ex-ante* difference between the two frameworks at the minimum possible level, we hereafter impose two assumptions in our analysis.

$$G = \frac{K^2}{2} \text{ and } \theta \leq \frac{G}{K} = \frac{K}{2} \tag{25}$$

The two assumptions together imply that under full information, C receives identical payoff at $\lambda = 1$ in the two frameworks and his payoff is positive at any λ in both frameworks.

A direct inspection of C's payoffs, (11) and (20), shows that for any given θ, $V^R(\theta,\lambda)$ and $V^T(\theta,\lambda)$ are decreasing in λ. Furthermore, the decrease in $V^T(\theta,\lambda)$ is steeper than that in $V^R(\theta,\lambda)$ at $\lambda = 0$ by the condition in (1). Therefore, at any given θ, C prefers procurement over permit whenever the bureaucratic cost λ is below a threshold level (at $\theta = \frac{K}{2}$, the slopes are identical at $\lambda = 0$ and the threshold can be zero). In our model with two types, the above observation implies that, for any given probability distribution over the two types, C prefers procurement over permit *ex ante* if λ is low.

Lemma 7. *Assume (25) holds for both types $\underline{\theta}$ and $\overline{\theta}$. For any given probability ν of the low cost type $\underline{\theta}$, there exists a threshold $\overline{\lambda}(\nu)$ such that, for any λ below $\overline{\lambda}(\nu)$, C prefers procurement over permit.*

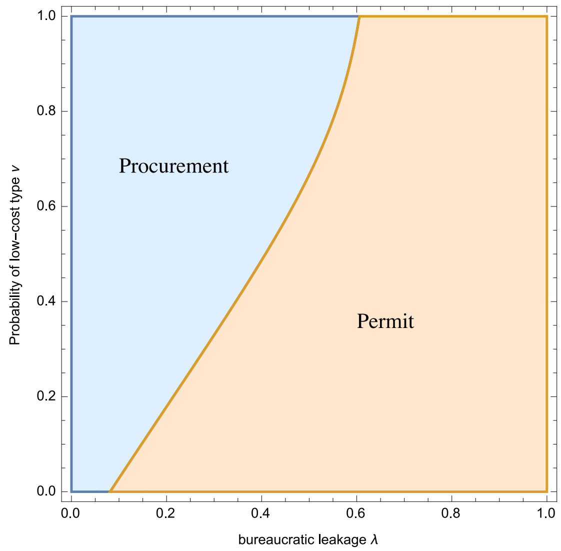

Figure 9: Procurement versus permits in (λ, ν) space under full information with $\underline{\theta} = 2, \overline{\theta} = 4$

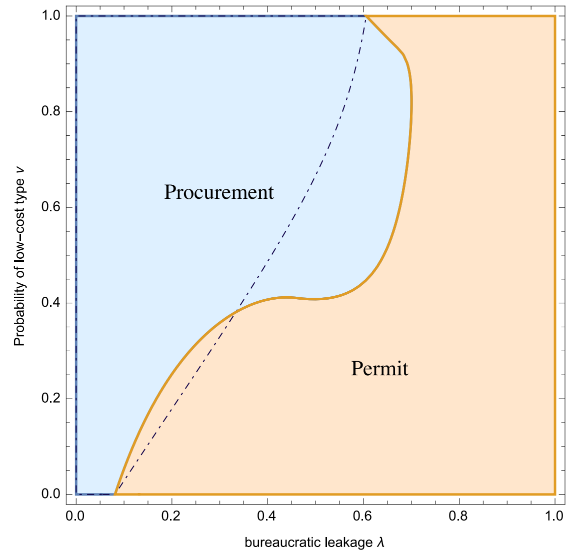

Figure 10: Procurement versus permits in (λ, ν) space under incomplete information and no delegation

Example continued. The parameter values $\underline{\theta} = 2$ and $\overline{\theta} = 4$ in our example satisfy the condition in (25). Figure 9 shows C's preference over procurement and permit in (λ, ν) space.

5.2 Incomplete information and no delegation

First consider the possibility that C does not delegate. In the procurement framework, C's expected payoff at the optimal incentive-compatible contracts $\left(\alpha^R_{CN}\left(\underline{\theta}\right), \alpha^R_{CN}\left(\overline{\theta}\right)\right)$ is given by

$$\nu V^R\left(\underline{\theta}, \lambda\right) + (1-\nu) V^R\left(\overline{\theta}, \lambda\right) - \left[\nu \frac{IR^R}{1-\lambda} + (1-\nu)\left(d^R_{CN}\left(\overline{\theta}\right) - d^R_{CI}\left(\overline{\theta}\right)\right)^2\right], \qquad (26)$$

where $IR^R := \triangle\theta\left(K - d^R_{CN}\left(\overline{\theta}\right)\right)$ is the information rent shared with the low-cost producer.

Similarly, in the permits framework, C's expected payoff at the optimal incentive-compatible contracts $\left(\alpha^T_{CN}\left(\underline{\theta}\right), \alpha^T_{CN}\left(\overline{\theta}\right)\right)$ is given by

$$\nu V^T\left(\underline{\theta}, \lambda\right) + (1-\nu) V^T\left(\overline{\theta}, \lambda\right) - \left[\nu (1-\lambda) IR^T + (1-\nu)\left(d^T_{CN}\left(\overline{\theta}\right) - d^T_{CI}\left(\overline{\theta}\right)\right)^2\right], \qquad (27)$$

where $IR^T = \triangle\theta\left(K - d^T_{CN}\left(\overline{\theta}\right)\right)$ is the information rent shared with the low cost producer.

We let $\triangle_{CN}$ denote the difference in C's payoff between the two frameworks, procurement and permit, with incomplete information and no delegation. Subtracting (27) from (26), we can write $\triangle_{CN}$ as follows:

$$\triangle_{CN} = \triangle_{CI} - \left\{ \nu \triangle_{IR} + (1-\nu) \left[\left(\overline{\delta}_{CN}^{R} \right)^2 - \left(\overline{\delta}_{CN}^{T} \right)^2 \right] \right\} \tag{28}$$

where

$$\begin{aligned}
\triangle_{CI} &= \nu \left(V^R(\underline{\theta}, \lambda) - V^T(\underline{\theta}, \lambda) \right) + (1-\nu) \left(V^R(\overline{\theta}, \lambda) - V^T(\overline{\theta}, \lambda) \right), \\
\triangle_{IR} &= \frac{IR^R}{1-\lambda} - (1-\lambda) IR^T, \\
\overline{\delta}_{CN}^{R} &= d_{CN}^{R}(\overline{\theta}) - d_{CI}^{R}(\overline{\theta}), \text{ and} \\
\overline{\delta}_{CN}^{T} &= d_{CN}^{T}(\overline{\theta}) - d_{CI}^{T}(\overline{\theta}).
\end{aligned}$$

$\triangle_{CI}$ is the difference in C's payoff between the two frameworks in full information, $\triangle_{IR}$ is the difference in the effect of information rent-sharing on C between the two frameworks, and $\overline{\delta}_{CN}^{R}$ and $\overline{\delta}_{CN}^{T}$ measure the distortion in the pollution level chosen for the high-cost firm in the procurement framework and the permits framework, respectively.

Before we compare $\triangle_{CN}$ with $\triangle_{CI}$, the following observations are worth noting. First, the difference between $\triangle_{CN}$ and $\triangle_{CI}$ will disappear at $\nu = 0$ and at $\nu = 1$, when there is no uncertainty. Second, even though the information rent in procurement is lower than the information rent in permit, *i.e.*, $IR^R \leq IR^T$, the differential impact $\triangle_{IR}$ can take either sign, depending on value of λ. This is because, in the procurement framework, C has to raise additional public funds, to cover the bureaucratic cost, in order to pay the information rent to P. On the other hand, in the permits framework, the low-cost firm keeps the information rent with it and C can realize only a fraction of the loss due to the bureaucratic cost.

In general, the difference between $\triangle_{CN}$ and $\triangle_{CI}$ can take either sign, implying that C can have a preference reversal between procurement and permit because of incomplete information. We can track the difference closely when v takes values close to 0 or 1. In particular, when v is sufficiently close to 1 (when a low cost firm is more likely), C chooses the maximum possible pollution level K for the high-cost firm (*i.e.*, $d_{CN}^{R}(\overline{\theta}) = d_{CN}^{T}(\overline{\theta}) = K$), which results in zero information rent in both frameworks. Therefore, for v sufficiently close to 1, the comparison between $\triangle_{CN}$ and $\triangle_{CI}$ is driven by the sign of $\left(\overline{\delta}_{CN}^{R} \right)^2 - \left(\overline{\delta}_{CN}^{T} \right)^2$, which is negative when $d_{CN}^{R}(\overline{\theta}) = d_{CN}^{T}(\overline{\theta}) = K$. Thus, at ν sufficiently close to 1, we have $\triangle_{CN} > \triangle_{CI}$. This implies that C will prefer procurement more in the incomplete-information case than in the full-information case when ν is sufficiently close to 1.

On the other hand, when ν approaches zero (when a high-cost firm is more likely), the distortion in the pollution level set for the high-cost firm reduces to zero in both frameworks. Thus, for ν sufficiently close to 0, the comparison between $\triangle_{CN}$ and $\triangle_{CI}$ is driven by $\triangle_{IR}$, which can take either sign depending on the value of λ. In the example below, we illustrate a situation in which $\triangle_{IR} > 0$ at $\nu = 0$ and $\lambda = \overline{\lambda}(0)$. Thus, in this example, C will prefer permit more in the incomplete information case than in the full information case when υ is sufficiently close to zero.

The following proposition documents the above observation.

Proposition 7. *Assume (25) holds for both types $\underline{\theta}$ and $\overline{\theta}$.*
1. When the probability of a low cost firm ν is close to 1, the prevalence of C preferring procurement to permits is larger in the incomplete information case than in the full information case.
2. When the probability of a low cost firm ν is close to 0, the prevalence of C preferring permit to procurement is larger in the incomplete information case than in the full information case if $\triangle_{IR}$, computed at $\nu = 0$ and $\lambda = \overline{\lambda}(0)$, is positive.

Example continued. Figure 10 shows C's preference over procurement and permit in (λ, ν) space in the incomplete-information case. The dot-dashed curve shows the parameter values of (λ, ν) at which C is indifferent between procurement and permit under full information, *i.e.*, when $\triangle_{CI} = 0$.

5.3 Incomplete information and optimal partial delegation

Next, we consider the situation in which C partially delegates with optimal restrictions on the bureaucrat's choice of bounds. Let $\triangle_{BI}$ denote the difference in C's payoff between the two frameworks, procurement and permits, under optimal partial delegation. We can write $\triangle_{BI}$ as follows:

$$\triangle_{BI}^{P} \quad = \quad \triangle_{CI} - \left[\nu\left(\underline{\delta}_{BI}^{PR}\right)^2 + (1-\nu)\left(\overline{\delta}_{BI}^{PR}\right)^2\right] + \left[\nu\left(\underline{\delta}_{BI}^{PT}\right)^2 + (1-\nu)\left(\overline{\delta}_{BI}^{PT}\right)^2\right] \qquad (29)$$

where

$$\begin{aligned}
\underline{\delta}_{BI}^{PR} &= d_{BI}^{PR}\left(\underline{\theta}\right) - d_{CI}^{R}\left(\underline{\theta}\right), \\
\underline{\delta}_{BI}^{PT} &= d_{BI}^{PT}\left(\underline{\theta}\right) - d_{CI}^{T}\left(\underline{\theta}\right), \\
\overline{\delta}_{BI}^{PR} &= d_{BI}^{PR}\left(\overline{\theta}\right) - d_{CI}^{R}\left(\overline{\theta}\right), \text{ and} \\
\overline{\delta}_{BI}^{PT} &= d_{BI}^{PT}\left(\overline{\theta}\right) - d_{CI}^{T}\left(\overline{\theta}\right).
\end{aligned}$$

$\underline{\delta}_{BI}^{PR}$ and $\underline{\delta}_{BI}^{PT}$ measure the distortion in the pollution level chosen for a low-cost firm under optimal partial delegation in the procurement framework and the permits framework, respectively. Similarly, $\overline{\delta}_{BI}^{PR}$ and $\overline{\delta}_{BI}^{PT}$ measure the distortion in the pollution level chosen for a high-cost firm under optimal partial delegation in the procurement framework and the permits framework, respectively.

Before we compare $\triangle^{P}_{BI}$ with $\triangle_{CI}$, the following observations are worth noting. First, in the procurement framework, C chooses partial uniform delegation if a low-cost firm is more likely (ν is sufficiently close to 0) and in the permits framework, C chooses partial uniform delegation if a high-cost firm is more likely (ν is sufficiently close to 1). Secondly, in the procurement framework, partial uniform delegation leads to

$$d^{PR}_{BI}\left(\underline{\theta}\right) = d^{PR}_{BI}\left(\overline{\theta}\right) = \nu d^{R}_{CI}\left(\underline{\theta}\right) + (1-\nu)\, d^{R}_{CI}\left(\overline{\theta}\right),$$

while in the permits framework, partial uniform delegation leads to

$$d^{PT}_{BI}\left(\underline{\theta}\right) = d^{PT}_{BI}\left(\overline{\theta}\right) = \nu d^{T}_{CI}\left(\underline{\theta}\right) + (1-\nu)\, d^{T}_{CI}\left(\overline{\theta}\right).$$

Finally, if C does not choose partial uniform delegation, then we have $\underline{\delta}^{PR}_{BI} = 0$ and $\overline{\delta}^{PT}_{BI} = 0$, *i.e.*, C implements the full-information contract for the low-cost firm in the procurement framework and for the high-cost firm in the permit framework. In general, the difference between $\triangle^{P}_{BI}$ and $\triangle_{CI}$ can take either sign. We investigate the sign when ν takes values close to 0 or 1.

When ν is sufficiently close to 1 (when a low-cost firm is more likely), C chooses the partial uniform delegation in the permit framework but not in the procurement framework. In this case, we can rewrite (29) as

$$\begin{aligned} \triangle^{P}_{BI} &= \triangle_{CI} - (1-\nu)\left(d^{R}_{BI}\left(\overline{\theta}\right) - d^{R}_{CI}\left(\overline{\theta}\right)\right)^{2} + \nu(1-\nu)\left(d^{T}_{CI}\left(\overline{\theta}\right) - d^{T}_{CI}\left(\underline{\theta}\right)\right)^{2} \\ &= \triangle_{CI} - (1-\nu)\left[\frac{\left(\lambda\beta\overline{\theta}\right)^{2}}{(1-\lambda)^{2}(1-\beta)^{2}} - \nu(1-\lambda)^{2}(\Delta\theta)^{2}\right]. \end{aligned} \tag{30}$$

After simplifying (30), we find that a necessary and sufficient condition for $\triangle^{P}_{BI} - \triangle_{CI} < 0$ is that

$$\frac{\overline{\lambda}(1)\,\beta}{\left(1-\overline{\lambda}(1)\right)^{2}(1-\beta)} > \frac{\triangle\theta}{\overline{\theta}}. \tag{31}$$

This condition is more likely to hold if $\overline{\lambda}(1)$ and β are large. On the other hand, when ν is sufficiently close to 0 (when a high-cost firm is more likely), C chooses the partial uniform delegation in the procurement framework but not in the permits framework. In this case, we can rewrite (29) as

$$\begin{aligned} \triangle^{P}_{BI} &= \triangle_{CI} - \nu(1-\nu)\left(d^{R}_{CI}\left(\overline{\theta}\right) - d^{R}_{CI}\left(\underline{\theta}\right)\right)^{2} + \nu\left(d^{T}_{BI}\left(\underline{\theta}\right) - d^{T}_{CI}\left(\underline{\theta}\right)\right)^{2} \\ &= \triangle_{CI} - \nu\left[\frac{(1-\nu)(\triangle\theta)^{2}}{(1-\lambda)^{2}} - \frac{\left(\lambda\beta\underline{\theta}\right)^{2}}{(1-\beta)^{2}}\right]. \end{aligned} \tag{32}$$

After simplifying (32), we find that a necessary and sufficient condition for $\triangle^{P}_{BI} - \triangle_{CI} < 0$

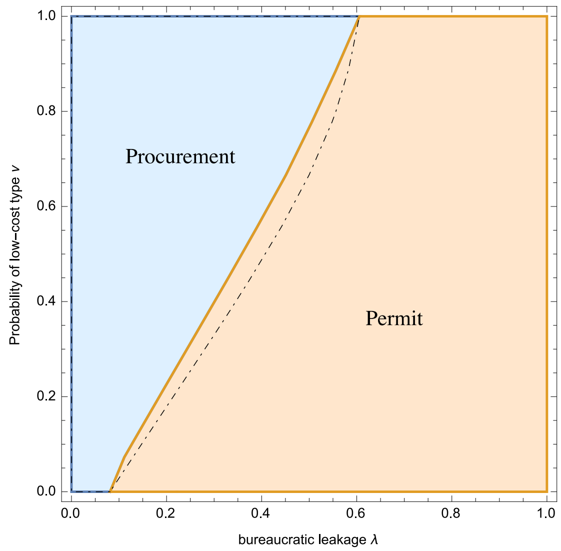

Figure 11a: Procurement versus permits in (λ, ν) space (with $\beta = 0.4$) under incomplete information and with optimal partial delegation

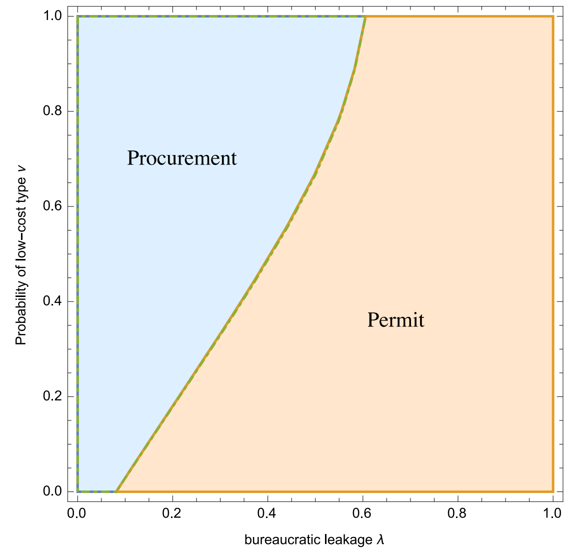

Figure 11b: Procurement versus permits in (λ, ν) space (with $\beta = 0.1$) under incomplete information and with optimal partial delegation

is that

$$\frac{\overline{\lambda}(0)\left(1-\overline{\lambda}(0)\right)\beta}{(1-\beta)} < \frac{\triangle\theta}{\underline{\theta}}. \tag{33}$$

This condition is more likely to hold if $\overline{\lambda}(0)$ is either large or small and β is small. In the example, we illustrate a situation when both conditions (31) and (33) are satisfied for the values of $\overline{\lambda}(0)$ and $\overline{\lambda}(1)$. In the following proposition, we document the above findings.

Proposition 8. *Assume (25) holds for both types $\underline{\theta}$ and $\overline{\theta}$.*

1. When the probability of a low-cost firm ν is close to 1, the prevalence of C preferring permits to procurement in the partial-delegation case than in the full information case if (31) holds.

2. When the probability of a low-cost firm ν is close to 0, the prevalence of C preferring permits to procurement in the partial-delegation case than in the full information case if (33) holds.

Example continued. Figure 11a (assumed $\beta = 0.4$) and 11b (assumed $\beta = 0.1$) show C's preference over procurement and permit in (λ, ν) space in the optimal partial delegation case. The dot-dashed curve shows the parameter values of (λ, ν) at which C is indifferent between procurement and permit under full information, *i.e.*, when $\triangle_{CI} = 0$.

6 Concluding remarks

We develop a simple model to study government's incentives to delegate regulatory authority to a rent-seeking bureaucrat. The bureaucrat has knowledge of a firm's production technology that government does not have. But the bureaucrat's interest may not be aligned with that of government. Government thus faces a trade-off in its delegation decision. Our analysis shows that certain forms of partial delegation, *i.e.*, delegation followed by laws and regulations to instruct the bureaucrat, have a potential to improve government's benefit from delegation.

In addition, our findings shows that the relative merit of partial delegation may be influenced by how government makes transaction with the industry. We introduce two settings, which we call procurement and permits respectively and which differ in the direction of transfers between government and industry, and we find that partial delegation works differently in the two settings. Further, the government's relative preference over the two frameworks is affected by its decision on partial delegation.

Appendix

The Appendix contains the proofs omitted in the text.

Proof of Lemma 1

Proof. Note that C's expected payoff is weakly decreasing in transfers and that P's payoff is increasing in transfers. C would therefore prefer to reduce transfer as much as possible subject to P's participation constraint. It can be shown that the participation constraint for the high-cost firm and the incentive-compatibility constraint for the low-cost firm will be binding at the optimum. The low-cost firm can always pretend to be the high-cost firm and gets a payoff of $\overline{t} - \underline{\theta}\left(K - \overline{d}\right)$. In order to make him choose $(\underline{t}, \underline{d})$, C therefore shares an information rent of $IR\left(\overline{d}\right) = \triangle\theta\left(K - \overline{d}\right)$. Therefore, $\overline{t} = \overline{\theta}\left(K - \overline{d}\right)$, and $\underline{t} = \underline{\theta}\left(K - \underline{d}\right) + IR\left(\overline{d}\right)$. Replacing $\overline{t}$ and $\underline{t}$ in (12) and using the fact that (IRH-R) and (ICL-R) together imply (IRL-R), we can rewrite the optimization problem as follows:

$$
\begin{aligned}
&\max_{\underline{\alpha},\overline{\alpha}} \nu\left[V\left(\underline{\theta},\underline{d}\right) - \frac{\lambda}{1-\lambda}\underline{\theta}\left(K-\underline{d}\right)\right] \\
&\quad + (1-\nu)\left[V\left(\overline{\theta},\overline{d}\right) - \frac{\lambda}{1-\lambda}\overline{\theta}\left(K-\overline{d}\right)\right] - \frac{\nu}{1-\lambda}IR\left(\overline{d}\right), \\
&\text{subject to } (ICH-R).
\end{aligned}
\tag{6.1}
$$

From the first-order conditions of the unconstrained problem, we see that the pollution levels are given by $d_{CN}^{R}\left(\underline{\theta}\right) = \min\left\{\frac{\underline{\theta}}{1-\nu}, K\right\}$ and $d_{CN}^{R}\left(\overline{\theta}\right) = \min\left\{\left(\frac{1}{1-\lambda}\right)\left(\overline{\theta} + \frac{\nu}{1-\nu}\Delta\theta\right), K\right\}$.[7] The transfers are given by $t_{CN}^{R}\left(\overline{\theta}\right) = \overline{\theta}\left(K - d_{CN}^{R}\left(\overline{\theta}\right)\right)$ and $t_{CN}^{R}\left(\underline{\theta}\right) = \underline{\theta}\left(K - d_{CN}^{R}\left(\underline{\theta}\right)\right) + \triangle\theta\left(K - d_{CN}^{R}\left(\overline{\theta}\right)\right)$. □

Proof of Lemma 2

Proof. Under condition (5), the bureaucrat's objective function is decreasing in t. Consequently, P's participation constraint will be binding, and we can write $t = \theta(K - d)$. Replacing t in (14), we see that the optimal level of pollution is a solution of the following optimization problem:

$$
\max_{\alpha}(1-\beta)\left(V(\theta, d) + \frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\theta(K-d)\right) \tag{6.2}
$$

From the first order condition, it is easy to see that the optimal pollution level is the minimum of $\left(1 - \frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)\theta$ and K. □

Proof of Proposition 1

[7] Note that $d_{CN}\left(\overline{\theta}\right) \geq d_{CN}\left(\underline{\theta}\right)$, which ensures that ICH-R is satisfied at the unconstrained solution.

Proof. Define

$$\begin{aligned}
G_1(d,\lambda) &= \nu\left[V(\underline{\theta},d)-\frac{\lambda}{1-\lambda}\underline{\theta}(K-d)\right], \\
G_2(d,\lambda) &= (1-\nu)\left[V(\overline{\theta},d)-\frac{\lambda}{1-\lambda}\overline{\theta}(K-d)\right], \text{ and} \\
G_3(d,\lambda) &= (1-\nu)\left[V(\overline{\theta},d)-\frac{\lambda}{1-\lambda}\overline{\theta}(K-d)\right]-\frac{\nu}{1-\lambda}IR(d).
\end{aligned}$$

Note that

$$\triangle D^R = G_1\left(d^R_{BI}(\underline{\theta}),\lambda\right)+G_2\left(d^R_{BI}(\overline{\theta}),\lambda\right)-G_1\left(d^R_{CN}(\underline{\theta}),\lambda\right)-G_3\left(d^R_{CN}(\overline{\theta}),\lambda\right).$$

First we look at the comparative-statics effect of β. It is easy to see that $\frac{dG_1\left(d^R_{CN}(\underline{\theta}),\lambda\right)}{d\beta}=\frac{dG_3\left(d^R_{CN}(\overline{\theta}),\lambda\right)}{d\beta}=0$. Moreover, we have

$$\frac{dG_1\left(d^R_{BI}(\underline{\theta}),\lambda\right)}{d\beta}=\frac{\partial G_1\left(d^R_{BI}(\underline{\theta}),\lambda\right)}{\partial d^R_{BI}(\underline{\theta})}\cdot\frac{dd^R_{BI}(\underline{\theta})}{d\beta}=\nu\left(\frac{\underline{\theta}}{1-\lambda}-d^R_{BI}(\underline{\theta})\right)\frac{dd^R_{BI}(\underline{\theta})}{d\beta},$$

and,

$$\frac{dG_2\left(d^R_{BI}(\overline{\theta}),\lambda\right)}{d\beta}=\frac{\partial G_2\left(d^R_{BI}(\overline{\theta}),\lambda\right)}{\partial d^R_{BI}(\overline{\theta})}\cdot\frac{dd^R_{BI}(\overline{\theta})}{d\beta}=(1-\nu)\left(\frac{\overline{\theta}}{1-\lambda}-d^R_{BI}(\overline{\theta})\right)\frac{dd^R_{BI}(\underline{\theta})}{d\beta}.$$

Note that $d^R_{BI}(\theta)\leq\frac{\theta}{1-\lambda}$ for $\theta\in\left\{\underline{\theta},\overline{\theta}\right\}$, and $\frac{dd^R_{BI}(\theta)}{d\beta}=-\frac{\lambda\theta}{(1-\lambda)(1-\beta)^2}\leq 0$ for $\theta\in\left\{\underline{\theta},\overline{\theta}\right\}$. Hence, $\frac{d\triangle D^R}{d\beta}\leq 0$.

Next, we consider the effect of λ. As $d^R_{CN}(\underline{\theta})$ maximizes $G_1(d,\lambda)$, applying the envelope theorem, we find that $\frac{dG_1\left(d^R_{CN}(\underline{\theta}),\lambda\right)}{d\lambda}=\frac{\partial G_1\left(d^R_{CN}(\underline{\theta}),\lambda\right)}{\partial\lambda}=-\nu\underline{\theta}\left(K-d^R_{CN}(\underline{\theta})\right)$. Similarly, applying the envelope theorem, we get that $\frac{dG_3\left(d^R_{CN}(\overline{\theta}),\lambda\right)}{d\lambda}=\frac{\partial G_3\left(d^R_{CN}(\overline{\theta}),\lambda\right)}{\partial\lambda}=-(1-\nu)\underline{\theta}\left(K-d^R_{CN}(\overline{\theta})\right)-\nu\triangle\theta\left(K-d^R_{CN}(\overline{\theta})\right)$. Moreover, we have

$$\begin{aligned}
\frac{dG_1\left(d^R_{BI}(\underline{\theta}),\lambda\right)}{d\lambda} &= \frac{\partial G_1\left(d^R_{BI}(\underline{\theta}),\lambda\right)}{\partial d^R_{BI}(\underline{\theta})}\cdot\frac{dd^R_{BI}(\underline{\theta})}{d\lambda}+\frac{\partial G_1\left(d^R_{BI}(\underline{\theta}),\lambda\right)}{\partial\lambda} \\
&= \nu\left(\frac{\underline{\theta}}{1-\lambda}-d^R_{BI}(\underline{\theta})\right)\frac{dd^R_{BI}(\underline{\theta})}{d\lambda}-\nu\underline{\theta}\left(K-d^R_{BI}(\underline{\theta})\right),
\end{aligned}$$

and

$$\begin{aligned}\frac{dG_2\left(d^R_{BI}\left(\overline{\theta}\right),\lambda\right)}{d\lambda} &= \frac{\partial G_2\left(d^R_{BI}\left(\overline{\theta}\right),\lambda\right)}{\partial d^R_{BI}\left(\overline{\theta}\right)}\cdot\frac{dd^R_{BI}\left(\overline{\theta}\right)}{d\lambda}+\frac{\partial G_2\left(d^R_{BI}\left(\overline{\theta}\right),\lambda\right)}{\partial\lambda}\\ &= (1-\nu)\left(\frac{\overline{\theta}}{1-\lambda}-d^R_{BI}\left(\overline{\theta}\right)\right)\frac{dd^R_{BI}\left(\overline{\theta}\right)}{d\lambda}-(1-\nu)\,\underline{\theta}\left(K-d^R_{BI}\left(\overline{\theta}\right)\right).\end{aligned}$$

Thus,

$$\begin{aligned}\frac{d\triangle D^R}{d\lambda} &= \left[\nu\left(\frac{\underline{\theta}}{1-\lambda}-d^R_{BI}\left(\underline{\theta}\right)\right)\frac{dd^R_{BI}\left(\underline{\theta}\right)}{d\lambda}\right]+\left[(1-\nu)\left(\frac{\overline{\theta}}{1-\lambda}-d^R_{BI}\left(\overline{\theta}\right)\right)\frac{dd^R_{BI}\left(\overline{\theta}\right)}{d\lambda}\right] \\ &+ \left[\nu\underline{\theta}\left(d^R_{BI}\left(\underline{\theta}\right)-d^R_{CN}\left(\underline{\theta}\right)\right)\right]+\left[(1-\nu)\,\underline{\theta}\left(d^R_{BI}\left(\overline{\theta}\right)-d^R_{CN}\left(\overline{\theta}\right)\right)\right]+\left[\nu\triangle\theta\left(K-d^R_{CN}\left(\overline{\theta}\right)\right)\right].\end{aligned} \tag{6.3}$$

Note that $\frac{dd^R_{BI}(\theta)}{d\lambda}\gtrless 0$ if $\beta\lesseqgtr\frac{1}{2}$ for $\theta\in\left\{\underline{\theta},\overline{\theta}\right\}$. Hence, the first and the second terms in (6.3) is negative (positive) if β is more (less) than 1/2, the third and the fourth terms are always negative, and the fifth term is always positive. Together, the sign of $\frac{d\triangle D^R}{d\lambda}$ can be positive or negative depending on the magnitude of each of these terms. It can be easily shown, though, that if $\beta>\frac{1}{2}$ (so that the first and the second terms are negative) and $d^R_{CN}\left(\overline{\theta}\right)$ is close to K (which makes the fifth term negligible), then $\frac{d\triangle D^R}{d\lambda}$ takes negative values, implying that the differential benefit from delegation decreases with the bureaucratic cost. □

Proof of Lemma 3

Proof. Replacing t by $\theta(K-d)$ in (16), and using the first order condition of the optimization problem, we can see that the solution is given by $d^{PR}_{BI}(\theta,d_1,d_2)=\min\left\{\max\left\{d_1,\left(1-\frac{\lambda}{1-\lambda}\frac{2\beta-1}{1-\beta}\right)\theta\right\},d_2\right\}$ and $t^{PR}_{BI}(\theta,d_1,d_2)=\theta\left(K-d^{PR}_{BI}(\theta,d_1,d_2)\right)$. □

Proof of Proposition 2

Proof. TO BE ADDED. □

Proof of Lemma 5

Proof. The bureaucrat's objective function is increasing in t and P's payoff is decreasing in t. Consequently, P's participation constraint will be binding. We can therefore write $t=G-\theta(K-d)$. Replacing t in (23), we see that the optimal level of pollution solves

$$\max_{\alpha}(1-\beta)\left(V(\theta,d)-\lambda\frac{2\beta-1}{1-\beta}\theta(K-d)-G\left(1-\lambda\frac{2\beta-1}{1-\beta}\right)\right) \tag{6.4}$$

From the first-order condition, it is easy to see that the optimal pollution level is the minimum of $\left(1+\lambda\frac{2\beta-1}{1-\beta}\right)\theta$ and K. Thus the optimal contract is given by $d^T_{BI}(\theta)=\min\left\{\left(1+\lambda\frac{2\beta-1}{1-\beta}\right)\theta,K\right\}$ and $t^T_{BI}(\theta)=G-\theta\left(K-d^T_{BI}(\theta)\right)$. □

Proof of Lemma 6

Proof. The bureaucrat's objective function is increasing in t, and P's payoff is decreasing in t. Consequently, P's participation constraint will be binding. We can therefore write $t = G - \theta(K - d)$. Replacing t in (24), and using the first-order condition, we find that the solution is given by $d_{BI}^{PT}(\theta, d_1, d_2) = \min\left\{\max\left\{d_1, \left(1 + \lambda\frac{2\beta-1}{1-\beta}\right)\theta\right\}, d_2\right\}$ and $t_{BI}^{PT}(\theta, d_1, d_2) = G - \theta\left(K - d_{BI}^{PR}(\theta, d_1, d_2)\right)$. □

Proof of Lemma 7

Proof. TO BE ADDED. □

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