Contracts and Induced Institutional Change*

Bård Harstad Torben Mideksa

University of Oslo

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Abstract

While traditional contract theory takes the institutional environment as exogenously given, this paper analyzes how the agents' incentives to (de)centralize authority change when contracts are anticipated. In our model, induced institutional change will always harm the principal, and, under specified conditions, the outcome can be the reverse of what the principal seeks. The theory's applications span from industrial organization, when collusion influences mergers, to environmental conservation agreements, when tropical countries strategically decide on whether to (de)centralize forest management. These decisions may change when conservation agreements are anticipated; the consequence can be increased deforestation overall, despite the principal's payments for conservation.

Keywords: Contracts in the presence of externalities, decentralization, centralization, mergers, Cournot competition, induced institutional change, conservation, climate change, REDD, PES

JEL codes: D86, H23, H87, Q58.

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1 Introduction

The literature on contracts traditionally studies how a principal should optimally contract with agents, taking as given the institutional environment, such as the number of agents one can contract with (Bolton and Dewatripont, 2005). But in several situations, ranging from industrial organization to payments for environmental services, institutions may be endogenous, as when firms or districts can merge and centralize authority, or alternatively split and decentralize. The motivation for such institutional change can be influenced by the anticipation of contracts. The induced institutional changes are clearly important for the principal, but can they also harm the principal and undo the effects of the contracts themselves?

To shed light on these possibilities, this paper studies a simple setting with many agents, each taking an action. We allow for externalities between the agents that can be negative or positive, and that may work directly on the utility levels, or indirectly through a common market price, as with Cournot competition (so that the externalities are *pecuniary*). In these settings, a subset of the agents may have an incentive to merge and centralize authority, because they will then internalize the externalities on each other (e.g., to get market power). Alternatively, a subset of the agents may prefer decentralization because they want to influence the actions taken by the agents *outside* of this subset.[1] When the agents also anticipate that a principal will offer contracts or payment schedules in return for particular actions, then the incentives to (de)centralize may change. If the incentives do change, we show that the induced institutional change will always harm the principal. Furthermore, we describe when the effects of the induced institutional change might indeed undo the effects of the contracts themselves. In these cases, the principal would clearly have been better off if she could have committed to abstain from offering contracts or payment schedules.

In the following, we will explain the theory's relevance for both industrial organization and environmental policy such as conservation programs. To start with the former, it is well known that firms may prefer to merge to gain market power. On the other hand, if a set of firms merges to cut production, firms outside of the merger might decide to raise *their* production levels. When both effects are taken into account, a merger is profitable only when it includes most of the n firms in the market. This result, by Salant et al. (1983), has later been extended in various directions (Gaudet and Salant, 1991; Kamien and Zang, 1990; Perry and Porter, 1985). The condition derived by Salant et al. (1983: 191) is a special case of the condition we present below for the simplest benchmark case in which there is no principal or

[1] Of these two effects, the first, i.e., the benefit from centralizing authority in the presence of externalities, has been recognized at least since the famous decentralization theorem of Oates (1972). However, the second effect was first detected in the literature on mergers in industrial organization, discussed below.

contracts (Proposition 0).

But these conditions can be influenced by the presence of a principal or third party, such as a common supplier. If the principal prefers lower quantities or a higher market price, she may offer payment schedules as a function of the quantities that the firms produce (see McAfee and Schwartz (1994), or Dequiedt and Martimort (2015), who focus on informational opportunism). The payments must be larger if the agents' outside options are improved. Thus, to be granted more attractive payment schedules, the agents may want to merge or decentralize *because* contracts are anticipated.[2] Our results show that such an induced institutional change will take the form of decentralization (if n is small) or centralization (when n is large). In either case, induced institutional change will always harm the principal and increase the total production level, despite the principal's payments for lowering it, unless the principal is willing to offer sufficiently strong contracts.

Environmental policy often takes the form of conservation programs. Tropical deforestation is motivated in part by the profit from selling timber or agricultural products on a common market. Thus, Cournot competition has been used to better understand how deforestation in one district depends on deforestation elsewhere (Burgess et al., 2012). To motivate conservation, funds for Reducing Emissions from Deforestation and forest Degradation (REDD) are offered by the World Bank and by the United Nations thanks to several donor countries, such as Norway. Since these REDD agreements specify payment schedules that depend on the countries' levels of deforestation, they fit particularly well with the contracts analyzed in this paper. Such contracts reduce deforestation if the institutions do not change, but we show that districts or countries may reform their institutions when REDD agreements can be anticipated. If this reform happens, the principal is worse off and the outcome can be more deforestation, despite the payments that are offered for conservation.

Our main extension of traditional contract theory is thus to endogenize the institutions and to allow agents to (de)centralize before the principal can commit to the contracts. We build on Segal (1999), who study contracts in the presence of externalities. Che and Spier (2008) study the effects of the principal's "divide and conquer" strategy, Segal (2003) analyze prohibitions on such strategies, and Genicot and Ray (2006) allow agents to coordinate (but not centralize).[3] None of these papers endogenize the institutional structure, although such an endogeneity is clearly realistic in many contexts. Districts and countries are periodically

[2] Landeo and Spier (2009) show that, in experiments, even nonbinding communication among the agents (or, among the buyers, in their framework) may be sufficient for improving the offer made by the principal. They write (in the abstract): "Two-way non-binding pre-play communication among the buyers lowers the power of exclusive contracts and induces more generous contract terms from the seller."

[3] A related but different literature studies multiple principals making offers to the same agent; see Martimort (2007), for an overview.

reforming their institutions by either centralizing or decentralizing authority. Regarding forest management, the trend over the last few decades has been reforms toward more decentralized management, and such decentralization has often been successful in reducing deforestation; see Agrawal et al. (2008), Irawan and Tacconi (2009), and Berkes (2010). In other words, if the anticipation of REDD agreements leads to centralization instead, the effect on deforestation can be reduced or even reversed. And, in fact, several studies are indeed concerned about the possibility that REDD agreements can lead to centralization. Phelps et al. (2010: 312) summarize some findings by stating that "when presented with strong incentives, central governments have at times reversed forest policy decentralization." Ribot et al. (2006) has a detailed evaluation of donor-induced decentralization in forest management in many countries and of how governments introduced different institutional changes that recentralized forest management in six different countries: Senegal, Uganda, Nepal, Indonesia, Bolivia, and Nicaragua. Larson and Soto (2008) offer similar arguments. Larson and Soto (2008) also argue that central governments often maintain control of forest resources even when countries formally decide to decentralize forest management.

Formally, the model we present in Section 2.1 is one that is also analyzed in our companion paper (Harstad and Mideksa, 2016). This model is a simple extension of the traditional model of Cournot competition with linear demand, where we also permit a direct externality or spillover from one agent's production level to the payoff of another. This spillover can be negative, as when production leads to pollution or biodiversity loss. But the spillover can also be positive since increased production reduces the price, and the lower price reduces the profit from illegally logging forest. When the profit of illegal logging is small, the expenditures on monitoring and enforcement, to protect the forest, are also smaller. In this way, our model continues to be relevant if deforestation is driven by illegal logging and high enforcement costs.

Harstad and Mideksa (2016) apply this model to study the effects of (de)centralization on deforestation, and we there focus on the optimal conservation contracts. The approach in that paper, however, follows approaches in most of the literature by assuming that the institutions are exogenously given. In the present paper, we instead study the districts' incentives to (de)centralize, and how these incentives are influenced by the anticipation of contracts.[4]

The next section first presents the simple model, before we state a benchmark result describing when a reform is beneficial for a subset of agents if neither any contract nor the

[4]Since we here focus on the harmful effects of induced institutional change, we contribute to the literature on explanations of deforestation, see, for example, Burgess et al. (2012); Amacher et al. (2012); Amacher et al. (2007); Mendelsohn (1994); Angelsen and Kaimowitz (1999) and the references therein. Furthermore, our focus on institutional change is different than the papers on REDD that emphasize moral hazard (Gjertsen et al., 2016), private information (Chiroleu-Assouline et al., 2012; Mason, 2015; Mason and Plantinga, 2013), or observability (Delacote and Simonet, 2013).

principal is present. Given this benchmark, Section 3 introduces the principal and the principal's contracts, and describes when the benchmark result is overturned. Section 3 also shows that the induced institutional change will always harm the principal, and describes when the overall effect is that production increases, despite the effects of the contracts in isolation. The final section concludes, while the Appendix contains all proofs.

2 Benchmark: Institutions without Contracts

2.1 The Model

This section presents the benchmark model without the principal being present. There are n agents, firms, or districts, each taking action $x_i \geq 0$, $i \in N \equiv \{1, ..., n\}$. The crucial ingredient in the model is that there are externalities from one agent's action to another's. We allow for both standard (non-pecuniary) externalities and pecuniary externalities, working through the market price. Therefore, our model is basically a classic Cournot game, extended in a simple way. Agent i's payoff is given by:

$$u_i (x_i, x_{-i}) = w_i p x_i - s_i x - v_i x_i, \text{ where} \quad (1)$$

$$p = \overline{p} - ax, \text{ and } x \equiv \sum_{i \in N} x_i. \quad (2)$$

As mentioned, one interpretation of the model is that it is a simple Cournot game where firms produce and thus reduce the profit for each other. In the most standard setting, we would have $s_i = 0$, and v_i, which could be interpreted as the production cost.

Another interpretation of the model is that a district i extracts x_i units of its natural resource which i then sells in the common market at price p. District i's weight on the profit px_i is $w_i > 0$. In addition, i loses v_i when x_i is extracted, and also i loses s_i when the aggregate x increases. Parameter v_i can measure the cost of extracting the resource, or a district's valuation of its resource. District i is influenced by the choice of x_j, $j \neq i$, both because x_j influences the price and also because x_j influences u_i directly, through s_i. Thus, s_i can measure the spillover effect when resources are depleted or greenhouse gases from fossil fuel consumption enter the atmosphere. In these cases, it is reasonable with positive $s_i > 0$.

The model may also have other interpretations, and we do not require s_i to be positive. In fact, it is reasonable with a negative $s_i < 0$ in many cases. Consider, for example, illegal extraction of the resource. The more illegal extraction there is in district j, the smaller is the price, and thus the smaller is the profit from illegally logging also in district i. In these cases,

i may benefit if there is more extraction in district j, since the pressure on i is then reduced. Thus, with illegal extraction, it is reasonable that $s_i < 0$.

To provide a formal microfoundation for the setting with a negative $s_i < 0$, suppose district i has resource stock X_i. If $x_i < X_i$ is extracted, $X_i - x_i$ must be protected. Since the profit of illegally extracting a unit is p, i must ensure that the expected penalty be at least at that level. It is costly to increase the expected penalty when this requires frequent monitoring of every unit of $X_i - x_i$ that is to be protected. Thus, let $c_i > 0$ measure the cost of increasing the expected penalty by one unit for each parcel of the resource that is to be protected. It follows that the total enforcement cost is $c_i p (X_i - x_i)$. If i's benefit from the extracted profit is $b_i > 0$, i's payoff may be written as:

$$\widetilde{u}_i (x_i, x_{-i}) = b_i p x_i - c_i p (X_i - x_i) - v_i x_i .$$

This model is more carefully motivated and analyzed in Harstad and Mideksa (2016). Note that this utility function can be written as (1), minus the constant $c\overline{p}X_i$, if we just define:

$$w_i \equiv b_i + c_i \text{ and } s_i \equiv -c_i a X_i .$$

Thus, "strong districts," with small enforcement costs, are likely to have positive spillovers $s_i > 0$. In contrast, "weak districts," with large enforcement costs, are likely to face negative s_i's. In the following, we will assume that countries have homogeneous w_i's and v_i's. We also refer to the sum of the spillovers as $s \equiv \sum_{i \in N} s_i$.

2.2 Equilibrium Production

Taking the number of agents as given, it is straightforward to derive the Nash equilibrium for the equilibrium quantities:

$$x_i = \frac{w\overline{p} - v - ns_i + \sum_{j \in N \setminus i} s_j}{wa(n+1)}, \text{ and} \quad (3)$$

$$x = \frac{nw\overline{p} - nv - \sum_{i \in N} s_i}{wa(n+1)}. \quad (4)$$

More interesting is the externality from one agent's reduction in production of the others. From the envelope theorem, we get:

$$\begin{aligned} \frac{\partial u_i\left(x_i, x_{-i}\right)}{\partial\left(-x_j\right)} &= awx_i + s_i \\ &= \frac{e}{n+1}, \text{ where} \\ e &\equiv s + w\overline{p} - v, \end{aligned} \tag{5}$$

when we substitute for the equilibrium x_i.

Naturally, the direct externality from s enters in the equation for e. However, note that e depends on the aggregate $s \equiv \sum_{i \in N} s_i$, and not simply on s_i. The reason is that a large s_i reduces the equilibrium choice of x_i, and that effect reduces the benefit for i when j conserves. Simultaneously, when s_j is large, x_j is reduced, and then i finds it optimal to increase x_i. The larger x_i makes it more beneficial for i that j conserves.

In addition, e is large if the weight on profit is large, and if the market size, measured by $\overline{p}$, is large. In these cases, the revenues from producing and selling x_i are important, and i benefits when the others conserve since the equilibrium market price is then larger. If instead v is large, an agent finds it valuable to conserve, it produces less, and thus it becomes less important to obtain a high price for the relatively small quantity that is produced.

At the end of the previous subsection, we explained that we may have a positive $s > 0$ if agents are "strong" and production is motivated by the profit, while we may have a negative $s < 0$ if instead agents are weak and production is illegal and costly to prevent. A larger s implies that e is larger, so we may say that deforestation is sales-driven if e is large, but that deforestation is illegal or driven by the high enforcement costs when e is small and negative.

By combining (1)-(5), i's equilibrium payoff can be shown to be, see (Harstad and Mideksa, 2016):

$$u_i = \frac{1}{aw}\left[\left(\frac{e}{n+1}\right)^2 + vs_i\right].$$

2.3 Equilibrium Institutions

The externalities measured by (5) imply that agents may be better off if they centralize and set the x_i's so that the externalities are taken into account. If $e > 0$, it is optimal to reduce the production levels when other agents' payoffs are taken into account, but if $e < 0$, as when agents are weak, then it would be optimal to conserve less. Regardless of whether the total externality is positive or negative, centralization is always optimal for all the agents combined.[5]

To study institutional change, consider a subset of agents $L \subseteq N$, who are able to centralize authority. Centralization to a single authority would imply that the number of decision-makers in L is reduced from $l \equiv |L|$ to only 1. If this reform increases the equilibrium level of $\sum_{i \in L} u_i$, we will say that L prefers centralization. Otherwise, we will say that L prefers decentralization.

In the following, we actually allow for any general reform that reduces the number of decision-makers in L from l to $l - \Delta \geq 1$, which is not required to be equal to 1. With no other reform, n will be reduced by Δ, as well. Thus, the total number of decision-makers is reduced by Δ after such a reform.

Centralization means that the externalities on the other agents in the merger are taken into account, but also that agents in $N \backslash L$ will react to the reform. Thus, the size of L relative to N will turn out to be crucial for the effect of (de)centralization. We will say that L, considering the reform measured by Δ, is "large" (relative to N) if:

$$\epsilon_L \equiv 1 - \frac{l}{n+1} - \frac{l-\Delta}{n-\Delta+1} < 0. \tag{6}$$

For the set of agents L to be large, it is *necessary* that L contains a majority of the decision-making agents *before* centralization ($l > (n+1)/2$), and it is *sufficient* that L contains a majority *after* centralization ($l - \Delta > (n - \Delta + 1)/2$). If L is not large, we say that L is "small."

Proposition 0. *Suppose $L \subseteq N$ is a subset of agents.*
(i) If L is large, L always prefers centralization.
(ii) If L is small, L always prefers decentralization.

To focus on intuition, all the proofs are kept in the appendix.[6]

If $L = N$, we know that the sum of payoffs is highest under centralization, since externalities make decentralization inefficient. It is thus intuitive that if L is large, L will prefer centralization. Part (i) of Proposition 0 is therefore exactly as one would expect.

Part (ii) states that the opposite happens if the subset of agents is small. When $e > 0$, the reason is that if L decentralizes, L produces more and, as a response, $N \backslash L$ produces less,

[5] From the previous equation, we have:

$$\sum_{i \in N} u_i = \frac{1}{aw}\left[n\left(\frac{e}{n+1}\right)^2 + vs\right],$$

which decreases in n for every $e \neq 0$.

[6] With equation (6), Proposition 0 can be shown to generalize equation (3') in Salant et al. (1983), p. 191, where the firms' incentive to merge is analyzed.

which is beneficial to L when $e > 0$. When $e < 0$, if L decentralizes, L produces less and thus $N \backslash L$ produces more, which again is beneficial to L when $e < 0$. In both cases, the reaction of the other agents, $N \backslash L$, is beneficial to L. When $N \backslash L$ is a large set of agents, their responses are very important and thus L prefers decentralization in order to trigger the response from $N \backslash L$, despite the fact that decentralization also implies that L will internalize fewer of the externalities on each other.

3 Contracts and Institutions

We now consider a principal or "donor" D who benefits from conservation in that $u_D = -dx$, where $d > 0$ measures the damage D faces from the agents' production. D has a quasi-linear utility function for the payoff, $u_D - \sum_{i \in N} \tau_i$, where $\tau_i \geq 0$ is the transfer to agent $i \in M$, where $M \subseteq N$ is the subset of agents that D is able to contract with.[7]

The transfer to $i \in M$ will be in exchange for reduced production. In particular, we assume that D commits to a set of transfer functions before the agents decide on the x_i's. The transfer function to i can be a general function $\boldsymbol{\tau}_i(\mathbf{x})$, where $\mathbf{x} = (x_1, ..., x_n)$ is the vector of actual production levels that are simultaneously chosen by the agents.[8]

If a set of functions $\boldsymbol{\tau}_i(\mathbf{x})$ leads to some equilibrium vector $\mathbf{x}^*$, then $\mathbf{x}^*$ will also be an equilibrium if D simply offers the fixed payment $\widetilde{\boldsymbol{\tau}}_i = \boldsymbol{\tau}_i(\mathbf{x}^*)$ if $\mathbf{x} = \mathbf{x}^*$, and zero otherwise. We assume also that every agent has a utility function that is additive in the transfer τ_i. The problem for D is then simply to maximize $u_D - \sum_{i \in N} \tau_i$ subject to the following $m \equiv |M|$ incentive constraints:

$$u_i\left(x_i^*, x_{-i}^*\right) + \tau_i \geq \max_{\widehat{x}_i \geq 0} u_i\left(\widehat{x}_i, x_{-i}^*\right). \tag{IC$_i$}$$

An agent $i \in N \backslash M$ is simply selecting quantities as a best response to the other production levels, just as in the previous section.

If we solve D's problem subject to the (IC$_i$)'s and derive the equilibrium contracts, we

[7] We ignore the possibility that the donor may value the consumer surplus since exports, and not domestic consumption, are the main drivers of tropical deforestation (DeFries et al., 2010; Rudel, 2007; Rudel et al., 2009). Moreover, the donor should not be interpreted as a benevolent planner, but rather as an NGO or a country offering REDD contracts, such as Norway. Furthermore, allowing D to internalize the consumer surplus would make the analysis somewhat messier, without changing the results qualitatively.

[8] In this model, it turns out to be sufficient for D to consider linear contracts of the type:

$$\boldsymbol{\tau}_i(\mathbf{x}) = \max\left\{0, (\overline{x}_i - x_i)\, t_i\right\},$$

where $\overline{x}_i$ is the baseline for district i, and $t_i \geq 0$ is the subsidy per conserved unit.

get:[9]

$$\begin{aligned}\tau_i^* &= \frac{d^2}{aw\left(n+1\right)^2}, \text{ and} \\ x_i^* &= \frac{w\overline{p} - \left[\left(n+1\right)s_i - s\right] - v}{aw\left(n+1\right)} - \frac{2d\left(n+1-m\right)}{aw\left(n+1\right)^2}, \text{ implying} \\ x^* &= \frac{nw\overline{p} - s - nv}{aw\left(n+1\right)} - \frac{2md}{aw\left(n+1\right)^2}.\end{aligned} \tag{7}$$

Naturally, when d is large, the induced cuts in the x_i^* are larger and thus the transfers must be larger, as well. Given these explicit solutions for quantities and transfers, it is straightforward to derive the total payoff for an agent:

$$\frac{1}{aw}\left[\left(\frac{e+d-2d\left(n-m+1\right)/\left(n+1\right)}{n+1}\right)^2 + vs_i\right].$$

3.1 Induced Institutional Change

In the setting without any principal or contracts, Proposition 0 stated that large coalitions will centralize, while small coalitions will decentralize. The presence of the principal and the anticipation of contracts may change these results. Suppose now that a subset of agents $L \subseteq M$ can centralize and reduce the number of authorities in L by the number Δ. If $\Delta = l-1$, L can centralize to a single authority, but we do not restrict attention to this particular institutional reform. We find it natural to assume that if D can contract with the l agents in L if there is no reform, D can also contract with the $l-\Delta$ decision-makers in L that are present if a reform takes place.

The reform decision of L is made *before* D has committed to the actual contracts with the agents.[10] Thus, the equilibrium contracts offered by D will be influenced by any reform made by L. When L anticipates these effects, Proposition 0 may be overturned, implying that the presence of D and the anticipation of D's contracts lead to *induced institutional change.*

Proposition 1. *With D present in the game, Proposition 0 may be overturned.*
(i) If L is large, L prefers decentralization *if and only if* $e/d \in [\widehat{\epsilon}_L, \overline{\epsilon}_L]$, *where* $\overline{\epsilon}_L > \widehat{\epsilon}_L > \underline{\epsilon}_M > 2\underline{\epsilon}_M < 0$.

[9]See Harstad and Mideksa (2016). Following up on the previous footnote, these contracts can also be implemented by the linear contract:

$$t_i^* = \frac{2d}{n+1}, \text{ and } \overline{x}_i^* = x_i^0 + \frac{4m - 3\left(n+1\right)}{4aw\left(n+1\right)}t_i^*,$$

where x_i^0 is i's production level in the absence of any contracts.

[10]Equivalently, we allow D to revise the contracts after the reform. This is reasonable, since institutional reforms take time, while conservation contracts, for example, can be rapidly adjusted.

(ii) If L is small, L prefers centralization *if and only if* $e/d \in [\bar{\epsilon}_L, \widehat{\epsilon}_L]$, *where* $\bar{\epsilon}_L < \widehat{\epsilon}_L < \underline{\epsilon}_M$. *The thresholds are given by:*

$$\widehat{\epsilon}_L \equiv 1 - \frac{2m}{n+1} + \frac{\frac{2m}{n+1} - \frac{2m-2\Delta}{n-\Delta+1}}{\sqrt{\frac{l}{l-\Delta}\left(\frac{n-\Delta+1}{n+1}\right)} + 1}, \tag{8}$$

$$\bar{\epsilon}_L \equiv 1 - \frac{2m}{n+1} + \frac{\frac{2m}{n+1} - \frac{2m-2\Delta}{n-\Delta+1}}{1 - \sqrt{\frac{l}{l-\Delta}\left(\frac{n-\Delta+1}{n+1}\right)}}, \tag{9}$$

$$\underline{\epsilon}_M \equiv 1 - \frac{m}{n+1} - \frac{m-\Delta}{n-\Delta+1}. \tag{10}$$

Part (i) shows that a large L may prefer to decentralize authority in the presence of the principal. However, this happens only for a set of e's that are so large that $e/d > \underline{\epsilon}_M$. To understand this result, consider the right-hand side of the incentive constraint (IC_i), measuring the outside option. The larger the outside options are, the larger the transfers from D will be. The right-hand side of (IC_i) is i's outside option by deviating alone, keeping the other agents' actions fixed. If L merges, the new outside option is instead to choose the x_i's so as to maximize $\sum_{i \in L} u_i$. This outside option is more attractive if the other agents in L benefit when one x_i increases. This holds if the externality from conservation, as measured by e, is small and negative. If instead this externality is large and positive, the utility sum under such a joint deviation from the contract is smaller than the sum of outside options if each $i \in L$ deviates alone. For this reason, a merger improves the outside options (and thus the transfers from D) if e is small but not if e is large.

The effect on the outside option is important if d is large, so that the contracts will be substantial. If instead d is small, the effect on the (small) transfers is not important enough to overturn the importance of internalizing the externality, so then Proposition 0 will continue to hold. Formally, if $d \to 0$, $|e/d| \to \infty$, so it cannot be that $e/d \in [\widehat{\epsilon}_L, \bar{\epsilon}_L]$ or $e/d \in [\bar{\epsilon}_L, \widehat{\epsilon}_L]$, as is required to overturn Proposition 0.

Part (ii) similarly shows that a small set L may prefer centralization in the presence of D, even if L would always have preferred decentralization when D were absent. This happens only when e is so small that $e/d < \underline{\epsilon}_M$. Under this condition, the externality from producing more is larger, and therefore the sum of the outside options is larger if one considers a joint deviation, as when the agents have centralized authority.

The intuition for the result can also be explained by considering the utilities in the contracts relative to outside options. If the externality from conservation is large ($e/d > \underline{\epsilon}_M$), then centralization would have allowed D to offer less payments, since centralization would have implied that the positive externalities would have been internalized. In this case, decentralization is preferred, even if L is large. If instead the externality from conservation is negative or small ($e/d < \underline{\epsilon}_M$), then centralization would imply that D would find it necessary to offer more in transfers to overcome the hesitation of the central authority who takes the negative effects into account. In this case, the agents prefer centralization, perhaps even for the case in which L is small.

3.2 The Consequence of Induced Institutional Change

Induced institutional change refers to the possibility that a large L decentralizes because D is present in the game, or that a small L centralizes because D is present. When D's presence leads to institutional change, the reforming agents in L are motivated by the prospects of larger transfers from D. It may thus not surprise that the induced institutional change always reduces the payoff to D. In fact, it is easy to show that centralization among a set of agents $L \subseteq M$ always increases D's equilibrium payoff if and only if $e/d > \underline{\epsilon}_M$. Intuitively, a large e means that a central authority will accept conservation for a lower transfer, when the externalities are positive. However, when $e/d > \underline{\epsilon}_M$, Proposition 1(i) states that induced institutional change takes the form of decentralization, thus harming D. If instead $e/d < \underline{\epsilon}_M$, so that D prefers decentralization, Proposition 1(ii) shows that induced institutional change takes the form of centralization. In either case, induced institutional change harms D.

Proposition 2. *Induced institutional change will always make D worse off.*

Induced institutional change will also influence the equilibrium x^*, expressed by equation (7). This equation can be used to show that if $L \subseteq M$ centralizes, x^* declines if and only if $e/d > 2\underline{\epsilon}_M$. It is clearly intuitive that centralization leads to a smaller x^* if and only if the externality from conservation is positive and large, since then a central authority would prefer to produce less, in order to benefit the others. If $d \to 0$, the threshold for e, above which centralization reduces x^*, is simply zero.

A comparison to Proposition 1 leads to the following result.

Proposition 3.
(i) If L is large, induced institutional change always increases x^*.
(ii) If L and M are small, induced institutional change always increases x^*.

Thus, D's presence may motivate institutional changes that, in isolation, is likely to lead to more production, exactly the reverse of what D attempts to achieve. This happens whether the change takes the form of decentralization or centralization. In part (ii), when L is small, then a small M is sufficient but *not* necessary for induced institutional change to increase x^*, as shown in the Appendix.

3.3 Counterproductive Contracts

Given the above findings, one may question whether the larger extraction conservation levels following reform can outweigh the direct effect of the contracts themselves. If so, the very presence of D leads to reform and so much more production that more would have been conserved if D, as well as D's contracts, had been absent. In this case, D's presence is clearly doing more harm than good and D would have preferred to commit to abstaining from offering contracts, if such a commitment were feasible.

Proposition 4. *Contracts can be counterproductive.*
(i) Suppose L is large. If $e/d \in [\widehat{\epsilon}_L, \overline{\epsilon}_L]$*, the presence of D induces decentralization and, despite the contracts,* x^* *increases when* $e/d > \widetilde{\epsilon}_L$*, where:*

$$\widetilde{\epsilon}_L \equiv \frac{2m\,(n-\Delta+1)}{(n+1)\,\Delta} > 0.$$

(ii) Suppose L is small. If $e/d \in [\overline{\epsilon}_L, \widehat{\epsilon}_L]$*, the presence of D induces centralization and, when also* $e/d < -\widetilde{\epsilon}_L$*,* x^* *increases, despite the contracts.*

The results are intuitive. When L is large and $e > 0$, contracts are counterproductive only when d is so large that the anticipation of the contracts leads to induced institutional change, but while d simultaneously is so small that $e/d > \widetilde{\epsilon}_L$. For a larger d, the contracts are stronger, and their effects will outweigh the isolated effect of the induced institutional change. A similar argument holds when L is small and $e < 0$.

To summarize and illustrate the result, suppose $l = m = n$ and that the agents consider to merge ($\Delta = n - 1$). Such centralization would implement the socially efficient first-best outcome, since no third party would be affected by the contracts. However, the thresholds

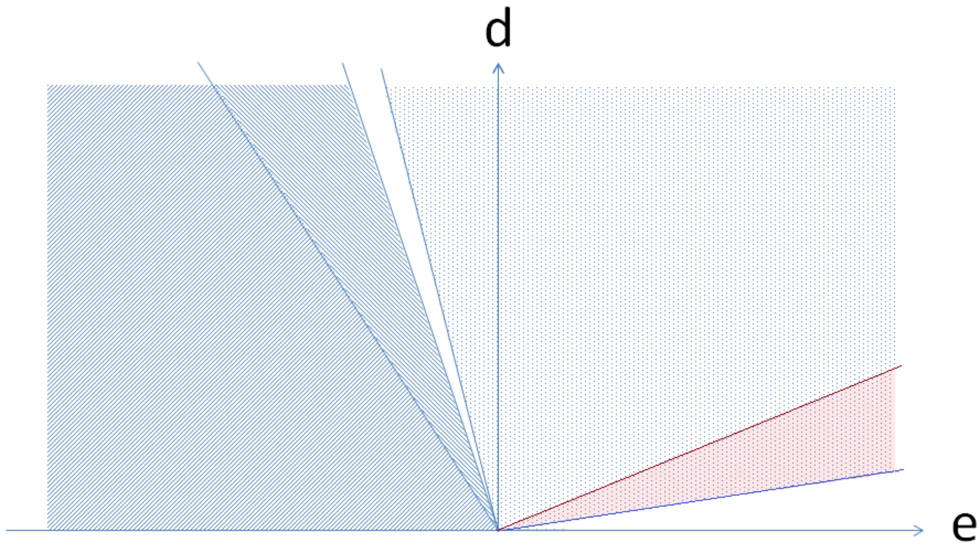

Figure 1: *Even if centralization leads to the first best, the principal prefers decentralized contracts when e and d are small (shaded area), while the agents prefer decentralization when e and d are large (dotted area). In the colored dotted area, the regime change raises production by more than the contracts reduce it. The lines are drawn for an example with two agents.*

become:

$$
\begin{aligned}
\widehat{\epsilon}_L &= -\frac{n-1}{n+1}\left(\frac{\sqrt{n}\left(\frac{2}{n+1}\right)}{\sqrt{n}\left(\frac{2}{n+1}\right)+1}\right), \\
\overline{\epsilon}_L &= \frac{n-1}{n+1}\left(\frac{\sqrt{n}\left(\frac{2}{n+1}\right)}{1-\sqrt{n}\left(\frac{2}{n+1}\right)}\right), \\
\underline{\epsilon}_M &= -\frac{1}{2}\frac{n-1}{n+1}, \\
\widetilde{\epsilon}_L &\equiv \frac{4n}{(n+1)(n-1)} \Rightarrow \\
2\underline{\epsilon}_M &< \underline{\epsilon}_M < \widehat{\epsilon}_L < 0 < \widetilde{\epsilon}_L < \overline{\epsilon}_L.
\end{aligned}
$$

Figure 1 illustrates the various settings for the case in which $n = 2$. Decentralized contracts are preferred by D in the shaded area, where $e/d < \underline{\epsilon}_M = -1/6 \approx -0.17$, even though decentralization increases production when $e/d > 2\underline{\epsilon}_M = -1/3$ (where the shaded area has downward-sloping lines). The agents, however, prefer decentralization only when they are "stronger" and $e/d \in (\widehat{\epsilon}_L, \overline{\epsilon}_L) \approx (-0.16,\ 5.5)$ (i.e., in the dotted area). Furthermore, note that $\widetilde{\epsilon}_L = 8/3 \approx 2.7 \in (\widehat{\epsilon}_L, \overline{\epsilon}_L)$. Thus, for every $e/d \in (2.7,\ 5.5)$, which corresponds to the area that is both colored and dotted, the presence of D motivates the agents to decentralize and the accompanying increase in x^* outweighs the effect of the contracts.

4 Assumptions, Limitations, and Future Research

To keep the paper short and to illustrate the insight in a pedagogical way, we have simplified the model and thus imposed a number of strong assumptions. In this section, we discuss some of these assumptions, and suggest a path for future research.

Regarding the simple game between the agents, we followed the early literature on industrial organization by assuming a linear demand function. This approach resulted in a linear-quadratic utility function for every agent, and simplified the expressions of the solutions. The subsequent literature on industrial organization has relaxed the linear-demand assumption, but the essence of the results regarding mergers has been shown to hold. The best illustration of this robustness is the paper by Gaudet and Salant (1991), already mentioned above, which considers when a subset of firms would benefit from marginally reducing their production levels. Gaudet and Salant (1991: 658) find that "*a marginal contraction is strictly beneficial (strictly harmful) if and only if the number of firms in the designated subset exceeds the 'adjusted' number of firms outside it by strictly more (strictly less) than one. The adjustment factor is unity when cost and demand functions are linear but, more generally, depends on the convexity of the cost and demand curves.*"

Regarding our results in Section 3, these results are driven by the consideration of the agents' outside options, so we are confident that the results continue to hold qualitatively with nonlinear demand. (The proofs in our companion paper, Harstad and Mideksa (2016), do allow for nonlinear demand.)

A limitation that has larger effects on the results is that we have considered the incentive to centralize only among a single set of agents $L \subseteq M$. This assumption ought to be relaxed in two ways. If we permit the reforming set to be among the set of agents which D cannot contract with, $L \subseteq N \backslash M$, then it may not necessarily be that an induced institutional reform by L is always harms D or is always likely to increase x^*. An earlier version of our paper did consider (de)centralization among agents $L \subseteq N \backslash M$, so these results are available upon request.

Future research should also consider the setting in which many subsets of agents can reform simultaneously. For example, the districts in N might be divided amongst different countries, and each country may decide on whether to centralize or decentralize. In this setting, the countries' actions will be strategic complements, since when one subset $L \subseteq M$ centralizes, the total number of decision makers declines, and this decline makes it more likely that also another subset $L' \subseteq M$ will also prefer to centralize. This complementarity would lead to multiple equilibria, and one may search for the best equilibrium and for how the principal may help the agents to coordinate on such an equilibrium.

Empirical research should take the testable predictions above to the data. Proposition 1 predicts that when D is anticipated to be a player in the game, then we may have two types of induced institutional change. First, we predict that a relatively large country may decide to decentralize, but this happens only when the externality e is relatively large, as when districts are "strong" and the enforcement cost c, discussed in Section 2.1, is small. In contrast, a relatively small country may prefer to centralize authority, but only when e is smaller or negative, as when districts are "weak" in that the enforcement cost c is larger. These predictions are testable, and data concerning the effects of conservation contracts will increasingly be available when such contracts become more common.

If one can identify cases with induced institutional change, Proposition 3 further predicts that the isolated effects on x^* may be positive (in that x^* will increase). This prediction may be harder to test, because the increase in x^* is relative to the counter-factual level in which the induced institutional change did not take place. Only when the contracts are so weak (and d is so small) that Proposition 4 is relevant should we be able to easily test this prediction, since then x^* is predicted to increase after the contracts have appeared in the game, accompanied by institutional change, relative to the situation before the contracts and before agents' could reform in the anticipation of the contracts. This possibility is predicted by Proposition 4 only when the externality e and the country L are both quite large (and then induced institutional change takes the form of *decentralization*) or when e and L are both small (and then *centralization* is the predicted reform).

5 Conclusions and Policy Lessons

In the traditional contract theory literature, where the institutional environment is perceived as being exogenous, contracts and payment schedules will have an effect that is to some extent in line with the principal's objective. If institutions are endogenized, however, the anticipation of the contracts may lead to induced institutional change that can harm the principal and result in an outcome that is the opposite of what the principal seeks. This paper analyzes these effects in a simple model that can be applied to settings ranging from industrial organization to environmental policy such as conservation programs. As an example of the mechanics analyzed above, Sandbrook et al. (2010: 332) find that REDD conservation programs are "*likely to create incentives for forest managers to return to past centralized models of forest conservation...Such governance arrangements have often been ineffective at sustaining forests...*"

In our view, our theoretical results should not be interpreted as saying that these effects necessarily are going to be important in the real world. On the contrary, since we specify exact conditions under which the effects will be present, our ambition is to contribute to a better understanding of when contracts are likely to influence institutions, and of when the consequence may be dramatic for the principal and the outcome of interest. For example, it is when the principal's preference is relatively weak, but still sufficiently strong to induce institutional change, that the situation may arise in which the contracts will backfire. By recognizing when these effects may reasonably be expected to arise, one can take steps to avoid them. One policy solution is for the principal to invest in developing a reputation for always contracting with the appropriate jurisdictional level. Similarly, if institutions change in order to elicit more payments from the principal, the principal would benefit from establishing a reputation that penalizes such behavior. These possibilities are in line with how Wunder (2010: 336) respond to the concern of Sandbrook et al.: "*Conditionality is the key conceptual safeguard: if inefficient governments waste rents centrally without avoiding deforestation then international REDD transfers must be stopped.*"

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6 Appendix: Proofs

Proof of Proposition 0. This result follows from Proposition 1 in the special case where $m \to 0$ and $d \to 0$. Thus, the proof is omitted here.

Proof of Proposition 1. We first derive the equilibrium payoff for a single agent. The equilibrium contracts, as presented by (7), are easy to derive from the principal's maximization problem (see, for example, Harstad and Mideksa, 2016). Combined with (1), we can derive an agent's total payoff $u_i + \tau_i$:

$$\frac{1}{aw}\left[\left(\frac{e-(n-m+1)\frac{2}{n+1}d}{n+1}\right)^2 + \left(v+\frac{2}{n+1}d\right)s_i\right] + \frac{\left(\frac{2}{n+1}d\right)^2}{4aw}$$
$$+\frac{2}{n+1}d\frac{e-(n+1)s_i}{aw(n+1)} - \frac{2}{n+1}d\frac{2d(q+1)}{aw(n+1)^2},$$

where $q \equiv n-m$. With some algebra, this payoff can be rewritten as:

$$u_i = \frac{1}{aw}\left[\left(\frac{(e+d)(n+1)-2d(q+1)}{(n+1)^2}\right)^2 + vs_i\right].$$

Consider now a set L of $l = |L|$ agents, taking as given $n-l$. The sum of L's payoffs is:

$$\sum_{i\in L}\frac{1}{aw}\left(\frac{(e+d)(n+1)-2d(q+1)}{(n+1)^2}\right)^2 + v\sum_{i\in L}s_i,$$

where the last term, $\sum_{i\in L}s_i$, stays unchanged if the districts reform. But if the set L centralizes, the new numbers are reduced to $l' = l-\Delta < l$, $m' = m-\Delta$, and $n' = n-\Delta$, while $q = n-m$ stays the same. This change increases total welfare for the set L if and only if:

$$\begin{aligned}
\frac{l}{aw}\left(\frac{(e+d)(n+1)-2d(q+1)}{(n+1)^2}\right)^2 &< \frac{l'}{aw}\left(\frac{(e+d)(n'+1)-2d(q+1)}{(n'+1)^2}\right)^2 \Leftrightarrow \\
\frac{l}{l'}\left(\frac{n'+1}{n+1}\right)^2 &< \left(\frac{e/d+1-\frac{2(q+1)}{(n'+1)}}{e/d+1-\frac{2(q+1)}{(n+1)}}\right)^2 \Leftrightarrow \\
\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right) &< \left|1-\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{e/d-1+\frac{2m}{n+1}}\right|. \qquad (11)
\end{aligned}$$

Lemma 1. *The left-hand side of (11) is smaller than 1 if and only if L is large.*
Proof. Note that

$$\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right) < 1 \Leftrightarrow \frac{l'}{l}\left(\frac{n+1}{n'+1}\right)^2 > 1 \Leftrightarrow \qquad (12)$$
$$\frac{l-\Delta}{l}\frac{(n+1)^2}{(n+1)^2-2\Delta(n+1)+\Delta^2} > 1 \Leftrightarrow$$
$$1-\frac{\Delta}{l} > 1-\frac{2\Delta(n+1)-\Delta^2}{(n+1)^2} \Leftrightarrow$$
$$\frac{l}{1+n} > \frac{n+1}{2(n+1)-\Delta}. \qquad (13)$$

In addition, (12) is equivalent to

$$\begin{aligned} \frac{2(n'+1)\Delta+\Delta^2}{(n'+1)^2} &> \frac{\Delta}{l} \Leftrightarrow \\ \frac{l'}{n'+1} &> \frac{n'+1}{2(n'+1)+\Delta}. \end{aligned} \tag{14}$$

Since (13) and (14) are equivalent, we can also sum them and thus write:

$$\begin{aligned} \frac{l'}{1+n'}+\frac{l}{n+1} &> \frac{n'+1}{2(n'+1)+\Delta}+\frac{n+1}{2(n+1)-\Delta} \\ &= \frac{n'+1}{n+n'+2}+\frac{n+1}{n+n'+2}=1. \quad \| \end{aligned}$$

To further evaluate (11), note that the expression within the absolute sign is negative if and only if:

$$1-\frac{2m}{n+1}<e/d<1-\frac{2m'}{n'+1}. \tag{15}$$

(i) Suppose, first, that L is large, so that the l.h.s. of (11) is smaller than 1. Proposition 0 is overned if and only if (11) fails.

(i-a) Suppose (15) fails. Then, (11) fails if and only if:

$$1-\frac{2m}{n+1}<e/d<1-\frac{2m}{n+1}+\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{1-\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)}.$$

So, in this case, (11) fails if and only if e/d is such that:

$$1-\frac{2m'}{n'+1}<e/d<1-\frac{2m}{n+1}+\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{1-\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)}\equiv\bar{\epsilon}_L \tag{16}$$

$$= 1-\frac{2m'}{n'+1}+\left(\frac{2m}{n+1}-\frac{2m'}{n'+1}\right)\left(\frac{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)}{1-\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)}\right)>1-\frac{2m'}{n'+1}. \tag{17}$$

(i-b) If (15) holds, then (11) can be written as:

$$\begin{aligned} &\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)<\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{e/d-1+\frac{2m}{n+1}}-1 \Leftrightarrow \\ &1-\frac{2m}{n+1}<e/d<1-\frac{2m}{n+1}+\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)+1}\equiv\widehat{\epsilon}_L \\ = {} & 1-\frac{m'}{n'+1}-\frac{m}{n+1}+\left(\frac{m}{n+1}-\frac{m'}{n'+1}\right)\left(\frac{2}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)+1}-1\right), \text{ so} \\ \underline{\epsilon}_M = {} & 1-\frac{m'}{n'+1}-\frac{m}{n+1}<\widehat{\epsilon}_L<\bar{\epsilon}_L. \end{aligned}$$

(i-c) Combined, (11) only fails when e/d is such that:

$$1-\frac{2m}{n+1}+\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)+1}<e/d<1-\frac{2m}{n+1}+\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{1-\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)}.$$

(ii) Suppose, next, that L is small. Proposition 0 is overturned if (11) holds, requiring:
(ii-a) If (15) fails, then (11) holds if and only if:

$$\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)-1 \quad < \quad \frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{1-e/d-\frac{2m}{n+1}} \Leftrightarrow$$

$$\overline{\epsilon}_L=1-\frac{2m}{n+1}-\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)-1} \quad < \quad e/d<1-\frac{2m}{n+1}.$$

(ii-b) If (15) holds, then (11) holds if and only if:

$$\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)<\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{e/d-1+\frac{2m}{n+1}}-1 \Leftrightarrow$$

$$1-\frac{2m}{n+1}<e/d<1-\frac{2m}{n+1}+\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)+1}=\widehat{\epsilon}_L$$

$$=\quad 1-\frac{m'}{n'+1}-\frac{m}{n+1}-\left(\frac{m}{n+1}-\frac{m'}{n'+1}\right)\left(1-\frac{2}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)+1}\right), \text{ so}$$

$$\overline{\epsilon}_L<\widehat{\epsilon}_L<\underline{\epsilon}_M=1-\frac{m'}{n'+1}-\frac{m}{n+1}, \text{ when } \sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)>1.$$

(ii-c) Combined, when L is small, (11) holds if and only if:

$$1-\frac{2m}{n+1}-\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)-1}<e/d<1-\frac{2m}{n+1}+\frac{\frac{2m}{n+1}-\frac{2m'}{n'+1}}{\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right)+1}.$$

Note that Proposition 0 is confirmed in the following result for the special case where $d \to 0 \Rightarrow |e/d| \to \infty$. *Q.E.D.*

Proof of Proposition 2. Given (7), it is straightforward to derive the principal's equilibrium payoff and confirm that D is better off if L centralizes if and only if $e/d > \underline{\epsilon}_M$; see Harstad and Mideksa (2016).

When L is large, L prefers decentralization only for the set of e/d in which $e/d \in [\widehat{\epsilon}_L, \overline{\epsilon}_L]$, but it is easy to check that $\underline{\epsilon}_M < \widehat{\epsilon}_L$, so D always prefer that L centralizes in these cases.

When L is small, L prefers centralization only for the situation in which $e/d \in [\overline{\epsilon}_L, \widehat{\epsilon}_L]$, but, when L is small, it is easy to check that $\widehat{\epsilon}_L < \underline{\epsilon}_M$, so D always prefer decentralization when a small L turns to centralization because $d > 0$. *Q.E.D.*

Proof of Proposition 3. Since x^* as expressed by (7) is a function of m, n, d and $e = s + w\overline{p} - v$, it is easy to consider m' and n' and confirm that if L centralizes, then x^* increases if and only if $e/d < 2\underline{\epsilon}_M$; see Harstad and Mideksa (2016).
(i) When L is large, $2\underline{\epsilon}_M < \underline{\epsilon}_M < 0$. By comparing to the conditions in Proposition 1, it is clear that whenever a large L prefers to decentralize because $d > 0$, then $e/d > 2\underline{\epsilon}_M$, so decentralization increases x^*.

(ii) In general, we cannot rank $2\underline{\epsilon}_M$ and $\widehat{\epsilon}_L$. However, if $L = M$ and L is small, then $\underline{\epsilon}_L = \underline{\epsilon}_M > 0$, so $2\underline{\epsilon}_M > \underline{\epsilon}_M > \widehat{\epsilon}_L$, where the last inequality follows from Proposition 1. Consequently, whenever $L = M$ is small and L prefers centralization because $d > 0$, then L's centralization will increase x^*. More generally, we have that:

$$\begin{aligned} \widehat{\epsilon}_L &< 2\underline{\epsilon}_M \Leftrightarrow \\ \frac{2m}{n+1} + \frac{2m'}{n'+1} - 2 &< \left(1 - \frac{2m'}{n'+1}\right)\left(\sqrt{\frac{l}{l'}}\left(\frac{n'+1}{n+1}\right) - 1\right), \end{aligned}$$

which always holds when M is small. *Q.E.D.*

Proof of Proposition 4.
(i) Suppose L is large. If D is not present, L prefers to centralize, and x^* follows from (7) if we set $d = 0$ and $n = n - \Delta$:

$$x_\Delta^0 = \frac{(n-\Delta)\, w\overline{p} - s - (n-\Delta)\, v}{aw\,(n-\Delta+1)}.$$

If the presence of D discourages $L \subseteq M$ from centralizing, then x^* is as stated by (7). By comparing x_Δ^0 and x^*, we can after a few steps conclude that $x^* > x_\Delta^0$ if and only if:

$$e/d > \widetilde{\epsilon}_L \equiv \frac{2m\,(n-\Delta+1)}{(n+1)\,\Delta}.$$

(ii) If L is small, L prefers to abstain from centralization when D is absent, and x^0 would be:

$$x^0 = \frac{nw\overline{p} - s - nv}{aw\,(n+1)}.$$

If, however, L prefers to centralize because of the presence of D and $d > 0$, then x^* is replaced by:

$$x_\Delta^* = \frac{(n-\Delta)\, w\overline{p} - s - (n-\Delta)\, v}{aw\,(n-\Delta+1)} - \frac{2\,(m-\Delta)\, d}{aw\,(n-\Delta+1)^2}.$$

If we compare x^0 and x_Δ^*, a few steps gives that $x_\Delta^* > x^0$ if and only if:

$$\frac{e}{d} < -\frac{2m\,(n-\Delta+1)}{(n+1)\,\Delta} \equiv -\widetilde{\epsilon}_L. \quad \textit{Q.E.D.}$$