

Aligned Delegation[†]

By ALEXANDER FRANKEL*

A principal delegates multiple decisions to an agent, who has private information relevant to each decision. The principal is uncertain about the agent's preferences. I solve for max-min optimal mechanisms—those which maximize the principal's payoff against the worst case agent preference types. These mechanisms are characterized by a property I call “aligned delegation”: all agent types play identically, as if they shared the principal's preferences. Max-min optimal mechanisms may take the simple forms of ranking mechanisms, budgets, or sequential quotas. (JEL D44, D83, J16)

Consider a principal who delegates a number of decisions to an agent. A school has a teacher assign grades to her students; a firm appoints a manager to choose investment levels in different projects; an organization asks a supervisor to evaluate her employees and give out bonuses. The principal relies on the agent because she observes “states of the world” relevant to the principal's preferences. The teacher knows how well students have done in the class; the manager observes the productivity of potential investments; the supervisor sees the performance of her employees.

If the principal and agent had identical preferences, there would be no reason for the principal to restrict the agent's choices. However, preferences may be only partially aligned. For instance, a teacher and school agree that better students should receive higher grades. But they disagree about the cut-offs. The teacher may be a grade inflator who prefers to give high grades, a grade deflator who gives low grades, or perhaps she tends to fail too many students while giving out too many As. To counteract the teacher's biases, the school requires the teacher to adhere to a grading curve. That is, the principal gives the agent a delegation rule which jointly restricts the actions that the agent can take across all decisions.

A delegation rule which gives the agent more freedom allows the agent to make better use of her private information. But such a rule also gives leeway for biased agents to take actions which are bad for the principal. In this paper, I look for delegation rules that are robust to any biases the agent might have. Formally, I solve for mechanisms which are *max-min* (worst-case) optimal over some class of agent

* University of Chicago Booth School of Business, 5807 S. Woodlawn Ave., Chicago, IL 60637 (e-mail: afrankel@chicagobooth.edu). I'd like to thank my advisers Bob Wilson and Andy Skrzypacz for their support, with a special thanks to Bob for the close guidance he has given me throughout this project. I also thank Manuel Amador, Attila Ambrus, Aaron Bodoh-Creed, Renee Bowen, Eric Budish, Jeremy Bulow, Matt Elliott, Ben Golub, Bengt Holmström, Yair Livne, Michael Ostrovsky, and Ilya Segal for their input, along with the anonymous referees. This work was supported by a grant from the SIEPR Dissertation Fellowship program. The author has no financial or other material interests related to this research to disclose.

[†] Go to <http://dx.doi.org/10.1257/aer.104.1.66> to visit the article page for additional materials and author disclosure statement(s).

preferences. While the principal may not literally be worried about the very worst case, the max-min contract guarantees the principal a lower bound on payoffs for any possible agent biases, i.e., for any agent preference type. This manner of robustness is particularly appealing when the space of agent biases is large; Bayesian contracting would be intractable, and it could be difficult for the principal to even express his priors over the distribution of agent types. Such arguments motivate worst-case analyses in macroeconomics (see Hansen and Sargent 2007) and in the study of algorithms (for example, Cormen et al. 2009).¹

Previous work in contract theory shows that max-min optimality criteria can yield simple mechanisms in complicated environments. Hurwicz and Shapiro (1978) show that a 50 percent tax may be a max-min optimal sharecropping contract. Satterthwaite and Williams (2002) justify double-auctions as worst-case asymptotic optimal in terms of efficiency loss.² Garrett (2012) finds fixed-price cost reimbursement contracts to be worst-case optimal in a procurement setting. In the delegation problem I consider, I show that max-min leads to similarly simple contracts.

When the principal knows only that the agent prefers higher actions in higher states (higher grades to better students), ranking mechanisms are max-min optimal.³ The principal specifies a list of actions in advance and asks the agent to rank states from lowest to highest. Decisions with higher states are then matched to higher actions: the top student gets the best grade from the list, the most productive project gets the largest investment. This corresponds to a strict grading curve for a teacher, where the school fixes in advance the complete distribution of grades.

With more precise knowledge of the agent's preferences, the principal may do better by offering the agent additional flexibility. The teacher may be known to have a preference for uniformly inflating or deflating all students' grades, say. Then a looser grading curve which fixes only the class average grade—a budget mechanism—can do better than one which fixes the entire distribution. If the players have quadratic loss utilities and the agent has some unknown constant bias, budgets are max-min optimal.

As long as players prefer higher actions in higher states, agents will report honest rankings in a ranking mechanism—all preference types play identically. Under the stricter constant bias preferences, all agent biases likewise play identically in a budget mechanism. In either case, subject to the constraints of the mechanism, the agent plays as if she shares the principal's preferences. I refer to this alignment of incentives as aligned delegation. This paper shows how to apply the property of aligned delegation to derive ranking, budgets, and other forms of moment mechanisms as max-min optimal. The same analysis shows that when decisions are made one at a time rather than all at once, sequential quotas or budgets may be max-min optimal.

¹The max-min criterion has been justified in the economic literature in behavioral work on ambiguity aversion; see Gilboa and Schmeidler (1989) for an axiomatization. Algorithmic worst-case analysis has been applied to auction theory in work reviewed by Hartline and Karlin (2007).

²In the context of monopoly pricing with unknown buyer valuations, Bergemann and Schlag (2008, 2011) argue that the criterion of regret minimization may be more relevant than max-min optimality for robust design. Max-min suggests the policy of pricing to the lowest value profitable buyer.

³For each of a number of decisions (students), there is a one-dimensional state (performance in the class) that affects both players' preferences over a one-dimensional action (assigned grade). A player prefers higher actions in higher states if her utility function over actions and states satisfies increasing differences.

My basic model follows the literature on the delegation problem, introduced by Holmström (1977, 1984). An uninformed principal “delegates” decisions by specifying a set of actions from which the agent may choose, and there are no transfer payments. Most previous work in this literature looks at a single one-dimensional decision and a commonly known agent utility function; see, for example, Melumad and Shibano (1991), Martimort and Semenov (2006), Alonso and Matouschek (2008), Kovac and Mylovanov (2009), and Amador and Bagwell (2013). In contrast, I consider multiple decisions along with uncertainty over the agent’s utility function.

A small number of delegation papers do push beyond a single decision with known preferences. Armstrong (1995) considers an agent with uncertain preferences making one decision, although he allows for only a restricted class of interval delegation sets. Koessler and Martimort (2012) study a delegation problem where two decisions depend on a single underlying state, and the agent has known biases which differ across decisions. Frankel (2010) and Malenko (2012) study variants of delegation problems with multiple sequential decisions under the assumption that the agent has state-independent preferences; in these papers, the only way to provide incentives is to fix quotas or budgets over actions. The elicitation of information about multiple decisions from a biased agent has been investigated further in the literature on cheap talk, wherein the principal cannot commit to a mechanism.⁴

In general environments with many decisions, recent work in microeconomic theory has developed a broad intuition that mechanisms which impose some form of quota on a player’s actions can often achieve high payoffs. Most closely related is the cheap talk paper of Chakraborty and Harbaugh (2007), which shows that a ranking protocol gives the principal approximately first-best payoffs when decisions are independent and ex ante identical. Similar logic is explored for private-value allocation problems in Jackson and Sonnenschein (2007) and related work. I show that such mechanisms not only yield high payoffs when there are many independent decisions but can be max-min optimal against agents who may be strongly biased.⁵ This max-min optimality holds for any number of decisions, and any joint distribution of states.

I. The Model

Players and Payoffs.—A principal and an agent are engaged in a decision problem comprising $N < \infty$ distinct decisions. For each decision, players’ preferences over actions depend on the value of an underlying state of the world. At decision i , if state θ_i is realized and action a_i is taken, the principal and agent receive stage utilities

⁴Battaglini (2002), Chakraborty and Harbaugh (2007), and Chakraborty and Harbaugh (2010) show how adding decisions may help the principal obtain higher payoffs, even without commitment power; Levy and Razin (2007) show that commitment is sometimes necessary. Sobel (1985), Benabou and Laroque (1992), and Morris (2001) look at repeated cheap talk games with uncertainty over agent preferences. The decision maker (principal) is uncertain about the agent’s bias and learns about it over time.

⁵One interpretation of this result is that commitment gives little improvement over cheap talk outcomes when biases are extreme. Chakraborty and Harbaugh (2007) show that we can recover the max-min optimal ranking mechanism through cheap talk when states are distributed symmetrically. Chakraborty and Harbaugh (2010) show that if agents maximize a state-independent weighted sum of actions—which can be thought of as a particular limit of constant-bias preferences, with the bias becoming large—then cheap talk may yield an outcome similar to that of the max-min optimal budget mechanism.

of $U_P(a_i|\theta_i)$ and $U_A(a_i|\theta_i)$. A player's total payoff is the sum of the stage utilities across decisions $i = 1, \dots, N$:

$$\text{Principal: } \sum_{i=1}^N U_P(a_i|\theta_i) \quad \text{Agent: } \sum_{i=1}^N U_A(a_i|\theta_i).$$

For instance, a school and teacher will be determining the grades of N students in a class. The state θ_i is student i 's performance in the class, and the action a_i is the assigned grade. $U_P(a|\theta)$ or $U_A(a|\theta)$ is the school's or teacher's payoff if a student of quality level θ is assigned a grade of a . Alternately, a firm and manager invest an amount a_i in a project of productivity θ_i , or an organization and supervisor give a bonus of a_i to an employee of quality θ_i .

States and actions are elements of compact (closed and bounded) subsets of the real line, Θ and \mathcal{A} . The utility functions U_A and U_P are continuous maps from $\mathcal{A} \times \Theta$ into \mathbb{R} .

The agent may be biased in the sense that her utility function may differ from the principal's, giving her different preferences over actions conditional on the underlying state. The agent's bias is the same across all decisions, however. Preferences depend on the underlying state but not on the index of the decision. The teacher doesn't discriminate by gender, or play "favorites."

The assumption that payoffs are additively separable across decisions means that the action taken for one decision doesn't directly affect preferences on other decisions. So the school and teacher are assumed to have preferences over individual student grades but not over the grade distribution itself. The firm and manager making investment decisions face a constant marginal cost of capital over the relevant range, not an increasing cost. In the online Appendix E, I show how the results of this article can extend to nonseparable preferences.

In all of the applications I will discuss, utilities are such that both players weakly prefer higher actions in higher states. So at the very least, the school and teacher agree that better students should get higher grades. Formally, I consider cases where U_P and U_A both satisfy increasing differences: the marginal benefit of increasing an action is greater when the state is higher. A utility function U satisfies *increasing differences* if for all $a'' > a'$ in \mathcal{A} and $\theta'' > \theta'$ in Θ , it holds that $U(a''|\theta'') - U(a'|\theta'') \geq U(a''|\theta') - U(a'|\theta')$. For twice-differentiable utility functions, U has increasing differences if and only if it has a nonnegative cross partial derivative: $\frac{\partial^2 U}{\partial a \partial \theta} \geq 0$.⁶

Information.—The principal's preferences depend on the underlying states of the world, but he does not know the realized state values. He merely has some arbitrary prior belief over the joint distribution of states. For simplicity, I suppose that players share a common prior over this distribution at the start of the relationship; the common prior assumption will not drive any results. Once the agent enters the contract, she privately observes all of the states before any actions are taken.⁷ So only the agent knows exactly which actions the principal would want to take. The teacher observes the students' performances in the class; the school does not. I take state

⁶Chakraborty and Harbaugh (2007) consider preferences of this form in a cheap talk game over many decisions.

⁷Section VI discusses sequential problems in which the agent observes states and takes actions one at a time.

realizations to be exogenous; student quality does not respond to the procedure used to assign grades.

In addition to privately observing the underlying states, the agent has private information on her own preferences. The principal does not know the agent's utility function U_A . Rather, the principal knows that U_A comes from a set of possible utility functions \mathcal{U}_A . In my analysis the principal need not have a prior belief about the distribution of U_A over \mathcal{U}_A .

The Game.—The principal has the ultimate authority to choose actions, but he does not know which actions he prefers. To elicit the agent's information while correcting for her biases, the principal delegates the decision to the agent. He allows her to choose actions subject to certain contractible rules.

The contract is only over the actions which are to be taken; there are no transfer payments.⁸ Moreover, the principal has no way to learn about the state realizations directly. The school cannot audit the graded exams to learn about student quality levels, say. (Allowing the principal additional tools such as audits or transfer payments could only make him better off.) Finally, there is no "participation constraint." The agent accepts whatever rules are given to her. The teacher does not quit if she dislikes the grading curve.

I assume that the principal can commit to accept any outcome of the agent's choices within a given set of rules, formalized as a mechanism. In the terminology of the literature, this models a delegation rather than a cheap talk problem. I allow for the possibility of rules which induce stochastic actions.

The timeline of the game is as follows:

- (i) The principal chooses a mechanism D , which is an initial message space and an interim message space combined with a function mapping message pairs into joint distributions over actions.
- (ii) The agent observes her utility function $U_A \in \mathcal{U}_A$ then sends an initial message.
- (iii) The agent observes the realizations of the states $\theta \in \Theta^N$ then sends an interim message.
- (iv) The actions $\mathbf{a} \in \mathcal{A}^N$ are drawn from a joint distribution which depends on the mechanism and the messages.

By additive separability, payoffs are determined only by the marginal distributions of actions. Call a vector of marginal distributions $(m_1, \dots, m_N) \in \Delta(\mathcal{A})^N$ an *assignment* of actions, indicating that action a_i is drawn from distribution m_i . As a technical condition to guarantee the existence of agent-optimal messages, I assume that in any mechanism the set of possible assignments—both over interim messages

⁸ See Krishna and Morgan (2008) for a delegation model with limited-liability monetary payments, or Ambrus and Egorov (2012) and Amador and Bagwell (2013) for models with nonmonetary punishments conditional on actions taken. Frankel (2010) shows how uncertainty over payoffs in a model with state-independent preferences can make monetary incentives infeasible.

given an initial message, and over initial and interim message pairs—is compact in the sense of weak convergence.⁹

The mechanism form I consider is without loss of generality in the sense that it includes direct mechanisms, which by the revelation principle can replicate the equilibrium of any other mechanism. A direct mechanism would have an initial message space equal to the set of agent utilities \mathcal{U}_A and an interim message space equal to the set of state realizations Θ^N .

In deterministic mechanisms, the agent's interim message can be thought of as a choice of actions from a “delegation set” of possibilities—the teacher's report determines the vector of grades for the students in her class. The initial message corresponds to a choice of delegation sets from a menu—perhaps when the teacher is hired she can choose from a variety of grading curve policies. Stochastic mechanisms allow delegation sets to include not just actions but lotteries over actions.

Equilibrium.—Fixing a mechanism D , the agent of utility type U_A plays in the standard manner. Given her utility, she chooses an optimal (sequentially rational) reporting strategy σ , consisting of an initial message and a function mapping state vectors into interim messages. Let $\Sigma^{*D}(U_A)$ be the set of optimal strategies for an agent with utility function U_A .

Given the principal's prediction of how each agent type will play, he seeks a mechanism which is max-min optimal over the set of possible agent types.

Definition: A mechanism is *max-min optimal* over a set of agent utilities \mathcal{U}_A if it is an arg max of the following problem:¹⁰

$$\max_{\text{Mechanisms } D} \left[\inf_{U_A \in \mathcal{U}_A} \left[\max_{\sigma \in \Sigma^{*D}(U_A)} E_{\theta, a} \left[\sum_i U_P(a_i | \theta_i) | \sigma, D \right] \right] \right].$$

The max-min problem can be thought of one in which the principal picks a mechanism D with the knowledge that an adversary or “devil” will respond by choosing an agent utility type $U_A \in \mathcal{U}_A$ to minimize the principal's payoff. After the mechanism and type are chosen, states are realized, and the agent plays a strategy which is optimal for her type. I consider the worst case over utility realizations, not state realizations. If the devil could choose states as well as utilities, there would be no benefit from linking multiple decisions.

Max-min optimal mechanisms are robust in the sense that they guarantee the principal a lower bound payoff over any agent type that may be realized—the best possible lower bound. This contracting problem with multidimensional state and action spaces would be difficult under complete information or Bayesian uncertainty on preferences,

⁹ A sequence of distributions is said to weakly converge to a limiting distribution if the cumulative distribution functions converge pointwise at all continuity points of the cdf of the limit. A set of assignments is compact if any infinite sequence in the set weakly converges (componentwise) to a limit in the set. By Helly's theorem (Billingsley 1995, Theorem 25.9), the set of all assignments is compact because the action space $\mathcal{A} \subset \mathbb{R}$ is closed and bounded.

¹⁰ If there are multiple optimal strategies for an agent then I take the one preferred by the principal—this is the second “max” in the definition. The expectation over θ is with respect to the exogenous state probabilities, and over a is with respect to any randomization induced by the mechanism itself.

given the lack of transfer payments, but I will show that the max-min approach allows for the derivation of simple contracts across a variety of preference sets.¹¹

II. Motivating Examples

Suppose that the principal and agent have *quadratic loss constant bias* preferences. On decision i , the principal wants to match the action a_i to the state θ_i . The agent is biased; she prefers $a_i = \theta_i + \lambda$ for some $\lambda \in \mathbb{R}$. A positive bias $\lambda > 0$ corresponds to a grade-inflating teacher, while a negative bias corresponds to a stingy grader. The respective utility functions, which satisfy increasing differences, are $U_P(a|\theta) = -(a - \theta)^2$ and $U_A(a|\theta) = -(a - \theta - \lambda)^2$.

When there is a single decision ($N = 1$), previous work (e.g., Melumad and Shibano 1991 or Alonso and Matouschek 2008) studies the optimal delegation set for an agent with a known bias λ . Under certain conditions on the distribution of the state, an agent with a known positive bias should be given flexibility via an action ceiling. However, a ceiling would perform poorly *ex post* if the agent's bias were unknown and turned out to be negative. Indeed, any flexibility at all opens the principal to harmful manipulation from some type of biased agent. An agent with a strong positive bias would always choose the maximum allowed action, and an agent with a strong negative bias would always choose the minimum. So a principal worried about worst-case extreme biases simply fixes the action in advance.

With multiple decisions, though, the principal can get meaningful input from the agent without knowing her bias. This is because he knows that the agent has an identical bias on each decision. He can use this fact to elicit honest information about the relative values of different states, even from an agent who always prefers very high or very low actions. Consider a ranking mechanism:

Definition: A *ranking mechanism* is characterized by a list of N actions, $b^{(1)} \leq b^{(2)} \leq \dots \leq b^{(N)}$ in \mathcal{A} . At the interim stage, the agent ranks states from lowest to highest. The mechanism then assigns the decision with the j th lowest state to action $b^{(j)}$.

A ranking mechanism corresponds to a strict grading curve, where the school specifies the distribution of class grades in advance. In a class of 20 students the teacher must give five As, ten Bs, etc. Any agent with increasing-difference utility ranks states honestly; better students are given weakly higher grades. A false report would lead a low state to be assigned to a high action and a high state to be assigned to a low action. This would give the agent a lower payoff than the assortative assignment.¹²

¹¹ I have exogenously assumed that money is not used, but in a max-min sense money would not help the principal. He would not be able to use monetary bonuses effectively without knowing the agent's trade-off of money against action utility.

¹² Suppose that $\theta' < \theta''$ but the agent reports that $\theta' > \theta''$. Then θ' is incorrectly assigned to an action a'' , and θ'' to a' , with $a' \leq a''$. Switching the report to be truthful increases the agent's payoffs by $(U_A(a''|\theta'') - U_A(a'|\theta'')) - (U_A(a''|\theta') - U_A(a'|\theta'))$, which is greater than or equal to 0 by increasing differences. It is strictly suboptimal to falsely report the ranking of a pair of states if the decisions are to be assigned to distinct actions ($a' < a''$), and if the agent's utility satisfies increasing differences with a strict inequality.

Because all agent types play identically, making honest reports, the principal's payoff in a ranking mechanism does not depend on the agent's bias λ . Ranking mechanisms are robust to any type that may be realized.

EXAMPLE 1: Let states be i.i.d. uniform over $\Theta = [0, 1]$, and let the set of actions \mathcal{A} contain the interval $[0, 1]$. Then the principal's optimal ranking mechanism assigns the j th lowest state to action $b^{(j)} = \frac{j}{N+1}$. Any agent type reports states honestly. This gives the principal a payoff of $-\frac{1}{6(N+1)}$ per decision.¹³

Interpreting this payoff, the principal would get $-\frac{1}{12}$ per decision from no delegation (always taking an uninformed principal's preferred action of $a_i = \frac{1}{2}$) and 0 from first-best ($a_i = \theta_i$ for all i). So the principal's payoff is $\frac{N-1}{N+1}$ of the way from no delegation to first-best.

In the example, the payoff per decision goes to the first-best level of 0 for large N . Chakraborty and Harbaugh (2007) confirm that an optimal ranking mechanism generally gives approximately first-best payoffs when the principal and agent have increasing-difference utility, if states are i.i.d. from a known distribution. Is there a mechanism that does even better than ranking?

For this particular functional form of utilities, in fact, ranking is dominated by budgets. A budget mechanism fixes the sum or mean of actions rather than the entire distribution. The teacher must adhere to a B average, but she chooses on her own how many As to give, how many Bs, etc.

Definition: A *budget mechanism* is characterized by a number $K \in \mathbb{R}$. At the interim stage, the agent chooses actions or distributions of actions for each decision so that $\sum_i E[a_i] = K$.

Budget mechanisms give the agent strictly more flexibility than ranking mechanisms. If it so happens that there are a lot of both great and terrible students in the class, the teacher can give extra As and also extra Bs. Under quadratic loss constant bias preferences, the agent uses this flexibility "for good"—for the benefit of the principal. Teachers with different biases disagree about what average they would prefer, but for any fixed class average they play as if they are unbiased. This is because the agent's payoff $\sum_i -(a_i - \theta_i - \lambda)^2$ can be decomposed as the principal's payoff $-\sum_i (a_i - \theta_i)^2$ plus the expression $2K\lambda - \sum_i (\lambda^2 + 2\lambda\theta_i)$ which is independent of the agent's choices.

¹³ Given the quadratic loss utility, the optimal ranking mechanism for a general joint distribution of states sets $b^{(j)}$ as the principal's expectation of the value of the j th lowest state. If this value is not in \mathcal{A} , the principal chooses the closest feasible action. For the i.i.d. uniform distribution, the j th lowest value of N draws is distributed according to a Beta $(j, N+1-j)$ distribution. This has mean $\frac{j}{N+1}$ and variance $\frac{j(N+1-j)}{(N+1)^2(N+2)}$. The principal's expected lifetime payoff is minus sum of the variances, which can be calculated to be $-\frac{N}{6(N+1)}$.

EXAMPLE 2: Let states be i.i.d. uniform over $\Theta = [0, 1]$, and let the set of actions \mathcal{A} contain the interval $[-\frac{1}{2}, 1\frac{1}{2}]$.¹⁴ Then the optimal budget mechanism specifies that the sum of actions is $K = \frac{N}{2}$, i.e., an average action of $\frac{1}{2}$. After observing states the agent chooses actions so that $a_i - \theta_i$ is constant over i : $a_i = \frac{1}{2} + \theta_i - \frac{1}{N} \sum_{j=1}^N \theta_j$. The principal's expected per-period payoff is $-\frac{1}{12N}$, which corresponds to $\frac{N-1}{N}$ of the way from no delegation to first-best. Compare this to the lower value of $\frac{N-1}{N+1}$ from the optimal ranking mechanism.

In what follows, I will show that budgets cannot be improved upon further. Budgets are max-min optimal mechanisms when the players have quadratic loss constant bias preferences and the agent may have any bias $\lambda \in \mathbb{R}$. Any mechanism which gives additional flexibility does worse for the principal, for some agent type. Under more general preferences, though, budgets do not necessarily work well. Suppose the teacher liked to give out Bs. Facing a budget mechanism specifying a B average, she would just give every student a B. The school would prefer a strict grading curve, i.e., a ranking mechanism. Ranking is max-min optimal when the agent is known only to have an increasing difference utility function of unknown functional form.

III. General Results

In this section, I introduce a general technique for deriving max-min optimal delegation mechanisms. The first step is to define the incentive compatibility notion of *aligned delegation*. In an aligned delegation mechanism, all relevant agent types play exactly as if they were maximizing the principal's utility.

Definition: Fix a principal's utility U_P . A mechanism D is *aligned delegation* over agent types \mathcal{U}_A if there exists some strategy σ^* which is optimal for every type $U_A \in \mathcal{U}_A$ and would also be optimal for an agent of type $U_A = U_P$: $\exists \sigma^*$ such that $\sigma^* \in \Sigma^{*D}(U_A)$ for all $U_A \in \mathcal{U}_A \cup \{U_P\}$.

In an aligned delegation mechanism, I call σ^* an aligned strategy and the principal's expected payoff from σ^* the aligned payoff.

The previous section gives two examples of aligned delegation mechanisms. Budget mechanisms are aligned delegation under quadratic loss constant bias preferences, and ranking mechanisms are aligned delegation for any increasing difference preferences. Players may disagree about their ideal actions, but given the constraints of the mechanism all types agree on how to play optimally.

Budgets and ranking are special cases of moment mechanisms which allow the agent to choose actions freely subject to constraints on certain moments of the aggregate distribution of actions.

¹⁴Including actions outside of $[0, 1]$ may improve payoffs. For instance, say that there are four decisions and the mechanism requires $\sum_i a_i = 2$. If it happens that $\theta_1 = 1$ and $\theta_2 = \theta_3 = \theta_4 = 0$, then given any possible actions in \mathbb{R} , the principal and agent prefer $a_1 = \frac{5}{4}$ and $a_2 = a_3 = a_4 = \frac{1}{4}$. Players never want to take actions outside of the interval $[-\frac{1}{2}, 1\frac{1}{2}]$.

Definition: Fix a sequence of “moment functions” $\Phi = (\varphi^{(j)})_{j \leq J}$, where each $\varphi^{(j)}$ is a continuous map from actions into real numbers. There are J such functions, for $J \in \mathbb{N} \cup \{\infty\}$. A Φ -moment mechanism is characterized by a sequence of “moment values” $\mathcal{K} = (K^{(j)})_{j \leq J}$, with each $K^{(j)} \in \mathbb{R}$.

In the Φ -moment mechanism characterized by \mathcal{K} —the (Φ, \mathcal{K}) -mechanism—there is no initial message. At the interim stage, the agent chooses an assignment of actions or distributions of actions to decisions. The agent reports (m_1, \dots, m_N) , indicating that action a_i is to be drawn independently from distribution $m_i \in \Delta(\mathcal{A})$. The agent is constrained to reports satisfying the moment conditions $\sum_{i=1}^N \mathbb{E}[\varphi^{(j)}(a_i) | a_i \sim m_i] = K^{(j)}$ for each j .

Given an assignment (m_1, \dots, m_N) —each m_i a measure of mass one on the space of actions \mathcal{A} —define the *aggregate distribution* of actions to be $\mu = \sum_i m_i$. This is a measure of mass N describing the total number of times that each action or set of actions is expected to be taken over the N decisions. The (Φ, \mathcal{K}) -mechanism constrains the agent to choose assignments whose aggregate distributions satisfy the moment conditions $\int_{\mathcal{A}} \varphi^{(j)}(a) d\mu(a) = K^{(j)}$.

Some moment mechanisms of particular interest are those defined by $\Phi^J \equiv (\varphi^{(j)})$ such that $\varphi^{(j)}(a) = a^j$ for $j = 1, 2, \dots$ or $J = \infty$. Φ^J -moment mechanisms fix the first J statistical moments of the aggregate distribution of actions. So Φ^1 -moment mechanisms fix $\sum_i \mathbb{E}[a_i]$, the expected sum of actions or equivalently the mean. These are exactly budget mechanisms as defined above. Φ^2 -moment mechanisms fix the sum and sum-squared of actions, i.e., the mean and variance.¹⁵ Φ^∞ -moment mechanisms fix all statistical moments of the aggregate distribution of actions. In other words, they fix the aggregate distribution itself—the expected number of times that each action must be taken.¹⁶ I call Φ^∞ -moment mechanisms *distributional quotas*. In such a mechanism, the agent can choose any assignment of actions subject to the “quota” that each action is taken the correct number of times. Section IV shows that ranking mechanisms are special cases of distributional quotas.

Not all moment values \mathcal{K} are consistent with a Φ -moment mechanism. However, feasible values of \mathcal{K} always exist; any assignment (m_1, \dots, m_N) induces a feasible sequence of moment values $K^{(j)} = \sum_i \mathbb{E}_{a_i \sim m_i}[\varphi^{(j)}(a_i)]$.

Define *aligned-optimal* Φ -moment mechanisms as those which would maximize the principal’s expected payoff over feasible moment values \mathcal{K} if an agent of type $U_A = U_P$ were to play the mechanism. (When a mechanism satisfies aligned delegation, the agent will in fact play as if $U_A = U_P$.)

LEMMA 1: *For any moment functions Φ , there exists an aligned-optimal Φ -moment mechanism.*

(All proofs omitted from the body of the paper are found in online Appendix A.)

¹⁵ One can reconstruct the first k central moments from the first k raw moments.

¹⁶ If there were a single action to be taken, a feasible sequence of Φ^∞ -moment values would uniquely define its distribution (see Billingsley 1995, Theorem 30.1, on a compact space). With multiple actions, a feasible sequence of moments uniquely defines the aggregate distribution.

I will show that aligned-optimal Φ -moment mechanisms are max-min optimal under two conditions. The first condition is that the players' utilities are such that Φ -moment mechanisms satisfy aligned delegation. For instance, under quadratic loss constant bias preferences, both ranking mechanisms and budget mechanisms satisfy aligned delegation. This can be interpreted as a condition that the agent's utility set \mathcal{U}_A is "small enough" that there are no bad types which play differently from the principal.

Second, I require a condition that \mathcal{U}_A is "large enough" that the principal cannot profitably relax any of the moment restrictions. Although ranking is aligned delegation over the quadratic loss constant bias preferences, it imposes too many restrictions. It is better to fix the sum of actions instead of the entire aggregate distribution. Even a budget fixing the sum of actions could be too restrictive if the agent's bias were known to be small. It might be better to give complete freedom rather than to use a budget.

I formalize this second condition on the agent's utility as Φ -richness. A utility set is Φ -rich if under any mechanism, we can find limiting Φ -moment values $\bar{\mathcal{K}}$ so that certain extreme agent types will always play the mechanism to yield moment values close to $\bar{\mathcal{K}}$.

Definition: A utility set \mathcal{U}_A is Φ -rich if for any mechanism D , there exist Φ -moment values $\bar{\mathcal{K}} = (\bar{K}^{(j)})_{j \leq J}$ and a sequence of utilities $(U_A^{(k)})_{k \in \mathbb{N}}$ in \mathcal{U}_A such that for all corresponding sequences of optimal strategies $\sigma^{(k)} \in \Sigma^{*D}(U_A^{(k)})$ and all realized states θ , it holds that $\lim_{k \rightarrow \infty} E[\sum_i \varphi^{(j)}(a_i) | \sigma^{(k)}, D, \theta] = \bar{K}^{(j)}$ for all $j \leq J$.

In online Appendix B, I establish sufficient conditions on utility sets to guarantee various forms of richness. For instance, the increasing difference utilities are Φ^∞ -rich (some agent type approximately fixes the aggregate distribution of actions) and the set of quadratic loss constant bias utilities is Φ^1 -rich (some agent type fixes the sum of actions). The logic is easiest to see for the constant bias utilities. Given some mechanism, let $\bar{K}^{(1)}$ be equal to the highest expected sum of actions over all possible messages. An agent with a very large positive bias wants the sum of actions—the Φ^1 -moment value—to be as high as possible.¹⁷ As an agent's bias λ goes to infinity, the agent plays the mechanism so that the sum of actions is close to $\bar{K}^{(1)}$ under any state realizations.

I can now state the main theorem of the article. Later sections will apply the theorem to derive ranking and budget mechanisms as max-min optimal in appropriate environments.

THEOREM 1: Fix a principal utility U_P , a set of agent utilities \mathcal{U}_A , and a set of moment functions Φ . Suppose that \mathcal{U}_A is Φ -rich, and that any feasible Φ -moment mechanism induces aligned delegation over \mathcal{U}_A . Then the aligned optimal Φ -moment mechanism is max-min optimal.

¹⁷An agent with bias λ has payoff equal to the expectation of $-\sum_i (a_i - \theta_i - \lambda)^2$, which can be written as $-\sum_i (a_i - \theta_i)^2 + \lambda \sum_i a_i$ plus terms which are independent of a_i . The $\lambda \sum_i a_i$ term dominates as λ grows large. We could go through the same exercise with large negative biases, and $\bar{K}^{(1)}$ equal to the lowest possible sum of actions.

PROOF OF THEOREM 1:

Take an arbitrary mechanism D . By definition of Φ -richness, we can find some extreme agent utility type \bar{U}_A for which the moment values $\sum_i E[\varphi^{(j)}(a)]$ under her optimal strategy in D are always close to $\bar{K}^{(j)}$. For each state realization, the assignments induced by the agent's optimal messages under D can be approximated by assignments which are exactly consistent with $\sum_i E[\varphi^{(j)}(a)] = \bar{K}^{(j)}$. In the (Φ, \bar{K}) -mechanism, then, an agent of type \bar{U}_A can approximately replicate the principal's payoff from D .¹⁸ This gives a lower bound for the principal's payoff under the (Φ, \bar{K}) -mechanism: by aligned delegation, agents play this mechanism to maximize the principal's payoff, perhaps doing better than approximating D .

The aligned optimal Φ -moment mechanism gives an expected aligned payoff which is constant over agent types, and which is weakly better than that from any other Φ -moment mechanism. So the expected payoff from the aligned optimal Φ -moment mechanism for any type is at worst better than the approximate payoff from D for some particular agent type. This holds for arbitrarily close approximations. Therefore the aligned optimal Φ -moment mechanism improves on D according to the max-min criterion: the worst-case payoff from D , taking infimum over agent types, is weakly below the payoff from the aligned optimal Φ -moment mechanism under any type.

IV. Increasing Difference Utilities

In this section I consider the case where the principal and agent have increasing difference utilities: they prefer higher actions in higher states. If the principal has no other information about the agent's preferences, then the agent's utility set is Φ^∞ -rich. Given any mechanism, some extreme agent type would choose an aggregate distribution of actions independent of the underlying states. This can be shown by finding a sequence of increasing-difference utility functions which fix each moment in turn, lexicographically minimize or maximize the sum of actions, then the sum-squared, the sum-cubed, etc.

Given that some type will play an aggregate distribution independent of the states, the principal might as well (in a max-min sense) fix the aggregate distribution in advance. But any additional constraints do the principal no good. Distributional quotas which fix an aggregate distribution μ but otherwise give the agent complete freedom satisfy aligned delegation.

LEMMA 2:

- (i) *The set of increasing difference utilities is Φ^∞ -rich.*
- (ii) *If the principal and agent have increasing difference preferences, then distributional quotas (Φ^∞ -moment mechanisms) satisfy aligned delegation.*

¹⁸For each θ , find any limit point of the principal's payoffs due to the play from the sequence of types $U_A^{(k)}$ given by the definition of richness. The limiting payoff is induced by some sequence of assignments, which (by Helly's theorem plus compactness of \mathcal{A}) has a convergent subsequence. The limiting assignment of this subsequence is exactly consistent with the moment values \bar{K} , and gives the principal the limiting payoff as desired.

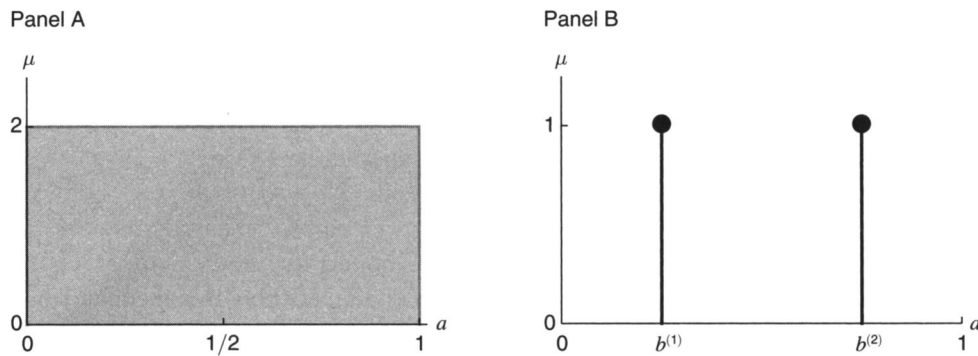


FIGURE 1. RANKING IMPLEMENTS THE ALIGNED-OPTIMAL DISTRIBUTIONAL QUOTA

Notes: (Panel A) Take a distributional quota inducing some aggregate distribution μ . Here we have $N = 2$ and μ uniform on $[0, 1]$. The low state will be assigned an action drawn uniformly from $[0, \frac{1}{2}]$, and the high state action will be drawn from $[\frac{1}{2}, 1]$. (Panel B) The principal prefers to consolidate the leftmost and rightmost units of mass into single points. This induces a ranking mechanism. The action $b^{(1)}$ is taken for the low state, and action $b^{(2)}$ for the high state.

The aligned strategy assigns actions assortatively: the action assigned to the j th lowest state is drawn from the distribution corresponding to the j th lowest unit of measure in the aggregate distribution μ .

For instance, suppose $N = 2$. If the aggregate distribution μ is uniform over $[0, 1]$, then the action assigned to the lower state would be uniform over $[0, \frac{1}{2}]$ and the action assigned to the higher state drawn would be uniform over $[\frac{1}{2}, 1]$. If the aggregate distribution instead places a mass of 1 on each of a low action and a high action, then the mechanism becomes equivalent to ranking. The low action is taken for the decision with the lower state and the high action for the higher state. See Figure 1. In general, if the aggregate distribution μ is a sum of N degenerate action distributions—actions taken with certainty—then the mechanism replicates a ranking mechanism.

By Theorem 1, the lemma implies that the aligned optimal distributional quota is max-min optimal. In fact, aligned-optimal distributional quotas do specify that N actions are each to be taken once. They can be implemented by ranking.

PROPOSITION 1: *If the players have increasing-difference utilities and the agent may have any increasing difference utility function, then the optimal ranking mechanism is max-min optimal.*

When the principal knows only that the agent prefers higher actions in higher states, ranking mechanisms are max-min optimal. The school gives the teacher a strict grading curve, specifying the distribution of course grades. The organization tells the supervisor to pay her best employee some large bonus, her next best employee some smaller bonus, and so forth. The firm requires the manager to allocate investments based only on the relative ranking of projects.

As I show in online Appendix B, it is not necessary that the principal believe that the agent might have any increasing difference utility. For instance, it is enough for the agent's utility set to contain only those increasing difference functions which are concave in actions. Ranking mechanisms remain max-min optimal because preferences are still Φ^∞ rich.

Online Appendix E.1 shows that ranking mechanisms can be max-min optimal even if the players have an additional preference over the distribution of actions itself. For instance, schools or teachers may be averse to giving every student a high grade even when all students perform well, to avoid the appearance of grade inflation; or they may prefer to have a minimum level of grade dispersion across students. Ranking mechanisms fix the grade distribution in advance, so they are unaffected by these new concerns.

V. Quadratic Loss Constant Bias Utilities

Suppose now that the players have quadratic loss constant bias preferences: $U_p = -(a - \theta)^2$, and $U_A = -(a - \theta - \lambda)^2$ for some bias λ . This is not a Φ^∞ -rich class of agent preferences, so the principal may be able to improve upon ranking mechanisms. Indeed, budget mechanisms—i.e., Φ^1 -moment mechanisms—which fix only the sum of actions give the agent strictly more flexibility than ranking and are aligned delegation (see Section II).

LEMMA 3:

- (i) *The set of quadratic loss constant bias utilities is Φ^1 rich.*
- (ii) *If the principal and agent have quadratic loss constant bias preferences, then budgets (Φ^1 -moment mechanisms) satisfy aligned delegation.*

This lemma combined with Theorem 1 immediately implies the following.

PROPOSITION 2: *If the players have quadratic loss constant bias utilities and the agent may have any bias, then the optimal budget mechanism is max-min optimal.*

So when the principal knows only that the agent has some constant bias, budget mechanisms are max-min optimal. The school fixes the teacher's grade point average but does not fix the exact number of As and Bs in advance. The supervisor is given a bonus pool to distribute to her employees. The firm gives the manager a budget of dollars to allocate any way she pleases across projects.

Online Appendix B clarifies that the result goes through so long as the agent may have an extreme bias in some direction—either unboundedly positive or negative. Online Appendix E.2 shows that budget mechanisms are max-min optimal even when firms or managers face a convex cost of capital and so prefer to spend less on one project if they invest a lot of money on other projects.

Budgets can do poorly, however, if the agent's bias is not constant—if the bias direction and magnitude vary with the underlying state. Fixing a class average of B, a moderate-biased teacher might give all students B's, while an extreme-biased

teacher gives out only As and Ds. In online Appendix C, I model extreme and moderate biases in a two-parameter family of *quadratic loss linear bias* preferences: $U(a|\theta) = -(a - \lambda^{(1)}\theta - \lambda^{(0)})^2$. The parameter $\lambda^{(1)} \in \mathbb{R}_+$ determines whether the agent's bias is moderate ($\lambda^{(1)} < 1$), constant ($\lambda^{(1)} = 1$), or extreme ($\lambda^{(1)} > 1$). Under unknown quadratic loss linear bias preferences, the max-min optimal mechanism is a Φ^2 -moment mechanism which fixes the mean and the variance of actions.¹⁹

VI. Sequential Decisions

Suppose that a manager must choose the investment level in today's project before learning the productivity of future projects. A ranking mechanism is no longer feasible; final rankings are not known until all but the last action have already been played. In this section, I consider an alternate *sequential* (as opposed to *simultaneous*) timing of the game in which actions are taken one at a time. The agent sees state θ_i , action a_i is taken, and only then does the agent see state θ_{i+1} .

Moment mechanisms such as budgets and distributional quotas extend straightforwardly to the sequential environment. (Details of the contracting environment are given in online Appendix D.) In period i the agent sees θ_i then chooses action a_i , or a distribution for this action. The action distributions are required to satisfy the relevant moment constraints by the end of the game.

Theorem 1 is unaltered: if utilities are such that Φ -moment mechanisms satisfy aligned delegation and if the agent's utility set is Φ rich, then the aligned optimal Φ -moment mechanism is max-min optimal. And the richness of a utility set is not affected by the change in timing.

However, it is harder for a set of utilities to satisfy aligned delegation in the sequential environment. The example below shows that increasing differences is not sufficient to imply aligned delegation for sequential distributional quotas.

EXAMPLE 3: Let $\Theta = \{0, \frac{1}{2}, 1\}$, with θ_i drawn uniformly from Θ in each of $N = 2$ periods. Let $\mathcal{A} = \{0, 1\}$. Player utility functions are given by

		θ					θ				
		U_P	0	$\frac{1}{2}$	1			U_A	0	$\frac{1}{2}$	1
a	0		10	9	0	a	0		10	0	0
	1		0	0	10		1		0	9	10

Both utilities satisfy increasing differences. So in a simultaneous problem, the players agree on an assortative assignment in any distributional quota.

In a sequential problem, the players no longer agree on a strategy. Consider the quota specifying that actions $a = 0$ and $a = 1$ must each be played once. If the first-period state is $\theta_1 = 0$ or $\theta_1 = 1$, both types prefer to match the first-period

¹⁹This mechanism recalls Cohn (2010), which considers a private-value allocation problem over many decisions. While Jackson and Sonnenschein (2007) advocates mechanisms which fix the distribution of valuation reports, Cohn (2010) restricts only the mean and variance.

action to the state. But if $\theta_1 = \frac{1}{2}$, the principal would prefer $a_1 = 0$ while the agent prefers $a_1 = 1$. Aligned delegation does not hold.

To guarantee that distributional quotas satisfy aligned delegation, I require additional assumptions on preferences. Online Appendix D illustrates one such assumption. Distributional quotas are aligned delegation when preferences are in the Φ^∞ -rich class of *generalized quadratic loss* utilities: $U(a|\theta) = -(c(a) - \theta)^2$ for some weakly increasing function $c(a)$. So sequential distributional quotas are max-min optimal when the agent is known only to have some generalized quadratic loss utility. In the aligned-optimal (and thus max-min optimal) quota, the agent is given a list of N actions and is asked to assign actions to decisions one at a time without replacement.

Under quadratic loss constant bias preferences, sequential budgets do continue to satisfy aligned delegation. So sequential budgets are max-min optimal under the same conditions as in the simultaneous case.

VII. Conclusion

This article considers a complicated contracting environment and shows that simple mechanisms such as ranking and budgets optimally protect the principal against biased agents, in a max-min sense. This max-min argument complements other justifications for using such mechanisms. They give high payoffs when there are many independent decisions (Chakraborty and Harbaugh 2007). They may be easy for an agent to play, since they ask for evaluations on a relative rather than absolute scale.²⁰ And if student performance responds to the grading scheme, or employee output to the bonus schedule, then ranking mechanisms in the form of tournaments may provide efficient incentives for effort; see Lazear and Rosen (1981).²¹

One of the steps in deriving ranking and budgets as max-min optimal was to show that they satisfy aligned delegation, a strong form of incentive compatibility: all agent types play as if they were maximizing the principal's utility. Indeed, aligned delegation is an appealing property on its own. First, it captures a notion of fairness or consistency across agents. In an aligned delegation mechanism, teachers with different biases grade students in an identical manner. Second, in an environment where information is dispersed across multiple agents with different biases, aligned delegation mechanisms incentivize agents to fully and nonstrategically pool their private information. All teachers share their honest evaluations to get the final ranking of students correct. So aligned delegation mechanisms may be useful for eliciting information from agents even when a principal is not worried about extreme biases.

²⁰ Budgets require the agent only to calculate the difference between each state and the sample mean. Ranking mechanisms need no cardinal evaluation at all.

²¹ The literature on tournaments focuses on the incentives provided to those being evaluated—motivating employees or students to work hard. In contrast, I take the qualities of the evaluated to be exogenous, and look at the incentives of the evaluator—the supervisor who pays out bonuses, the teacher who grades her students. Malcomson (1984) and Fuchs (2007) point out that the use of relative comparisons may be a good commitment device for a firm which prefers ex post to pay employees low bonuses. In a ranking or budget mechanism, the firm pays the same total compensation across employees for any reports.

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