Strategic Automation and Decision-making Authority

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Abstract

This paper studies how automation impacts the structure of decision-making in organizations. We develop a theoretical model of a firm, where a principal makes a decision about how much to prioritize the new product development division when the division is led by a manager who holds private information specific to this division and has misaligned preferences with the principal. The principal chooses whether to decentralize this decision by delegating it to the manager, resulting in more informed but unbiased decision. In this setting, we investigate how automation which reduces operational variability may alter this choice of organizational structure. The findings from our analysis show that firms deploy automation resources differently depending on their organizational structure: centralized firms choose to automate divisions that face more uncertainty, while decentralized firms do the opposite. Moreover, increasing access to automation results in higher centralization of decision-making in firms. In the extensions, we show that the strategic use of automation reduces the informativeness of intra-firm communication, and also, that automation can be a strategic substitute to monetary contracts.

Keywords: *Automation, Decision-making, Organizational Structure*

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1 Introduction

There is a long-standing interest in understanding how new technologies interact with organizational structure (Leavitt and Whisler, 1958; Meyer, 1968). At the heart of this interest is whether technology will make decision-making in organizations more decentralized (Acemoglu et al., 2007). The conclusions from studies trying to address this question remain largely inconclusive. While some find support for decentralization (Meyer, 1968), others argue that technology can reinforce authority at the top (Leavitt and Whisler, 1958). Matching these varying predictions, anecdotal evidence also suggests the effects of technology and firms' technology adaption patterns vary significantly (Whisler and Shultz, 1962).

In this paper, we contribute to the discussion on the effects of technology by studying how automation alters the centralization vs decentralization dichotomy. Automation increases stability of a system by making tasks less vulnerable to productivity shocks.[1] In particular, automation aids performing repeated tasks consistently and thereby reduces *variability* (Alford, 2010; McKinsey & Co., 2017). Owing to this property, automation can become a strategic tool that shapes decision-making and the choice between centralization and decentralization in organizations.

At the core of the centralization vs. decentralization decision is the trade-off between informed vs. biased decision-making. Consider, for instance, the decision of an executive (she) at Ford who oversees the development of a new product (e.g., electric vehicles) over an existing one (e.g., gasoline vehicles). The executive needs to make a firm-wise decision that will affect both product lines (e.g., allocation of research budget, qualification of a new supplier, design of common vehicle features). Some information relevant to this decision is privately held by the subordinates. For instance, the manager of the electric vehicle division may have a better understanding of its demand and technological performance. At the same time, subordinates may also have misaligned interests, in that the manager of the electric vehicles division may favor over-investing in his own division. Given the information asymmetry between the executive and the subordinate and their misaligned preferences, the question is if the executive should make the investment decision herself to avoid bias or delegate it to the manager. In this paper, we examine how this trade-off is shaped by the availability and use of automation.

We develop a theoretical model of a firm consisting of two divisions: (i) a "forefront" division focusing on new product development, hence facing uncertainty; and (ii) a "business-as-usual" division focusing on the firm's existing products, hence operating under steady conditions. A principal (i.e., executive) is running the firm, and a subordinate manager is leading the forefront division. The principal needs to make a decision about the investment into the new product division. A higher investment means prioritizing the forefront division, hence increasing its productivity. But at the

[1] Based on the reporting by the International Society of Automation (ISA), a leading organization founded in 1945 for setting the standards of automation and studying its impact.

same time, it means de-prioritizing the business-as-usual division and decreasing its productivity. Prioritizing the forefront division is referred to as "adaptation" strategy in the literature, whereas prioritizing the business-as-usual division is referred to as the "continuity" strategy.

This effect of the investment on the productivity of the divisions can be mitigated by automation. We assume that the principal is endowed with an automation capacity that she can use to automate the tasks within the divisions. When a task is automated, its outcome becomes less dependent on the productivity of the division housing it. Given this effect, the natural questions are: how to utilize automation resources across the firm? How does this utilization depend on the underlying organizational structure? How does the availability of automation impact the choice between centralization vs. decentralization?

Our first finding is, the way a firm allocates its automation capacity depends on its organizational structure: a centralized firm automates its forefront division, whereas a decentralized firm automates its business-as-usual-division. The former strategy helps the principal reduce her reliance on the manager's private information, while the latter strategy helps the principal shield the business-as-usual division from the biased decision of the manager. In the context of new product development, this suggests that centralized firms are more likely to allocate automation resources to new product development, whereas decentralized firms are more likely to allocate them to existing products.

Second, automation affects the fragmentation between firms with respect to their adaptation vs. continuity strategy. It is known that decentralized firms are more *agile* whereas centralized firms are more *stale* in adaptation (Rantakari, 2008). We find that automation strengthens this disparity. As firms have more resources for automation, decentralized firms become increasingly more agile and centralized firms become increasingly more stale. Put differently, with higher automation, decentralized firms may prioritize new product development more compared to the centralized firms.

Third, we uncover that increasing automation capacity favors centralization and reinforces the decision-making authority at the top of organizations. This finding is in contrast with the earlier studies that treat technology as a decentralizing force (e.g., Acemoglu et al., 2007). Our findings support the view that strategic deployment of automation may reduce the scope of managers' role, re-appropriating them to more operational tasks. Importantly, the reduced decision-making authority of the managers does not stem from the automation of *their* duties, but rather from the automation of low-level tasks. Stated differently, the impact of automation can trickle up in an organizational hierarchy.

Fourth, in Section 5.1, we extend our baseline model and introduce cheap talk communication between the principal and the manager in centralization. Automation deployment strategy may also affect the informativeness of communication from the manager in this case. Specifically, compared to any other automation deployment strategy, automating the forefront division results in the least informative communication from the manager. Despite this negative effect, it is optimal to automate the forefront division in centralization even in the presence of communication. This is because reducing the reliance on the manager's private information is still the primary motive in the strategy choice of the principal. Moreover, increasing automation capacity also *reduces* the quality of communication, highlighting that as automation becomes more accessible, a principal needs to prepare for communication challenges within the firm.

Finally, we also demonstrate that automation capacity and monetary contracts serve as strategic substitutes for the principal in managing the conflict. The more automation resources the firm has access to, the less likely the principal is to rely on a contract to align a manager's preferences with hers. This finding implies that the strategic use of automation technology offers an alternative tool for managing conflict within an organization.

Contributions to the Literature

Assigning decision-making rights across their organizations when mid-level managers have different priorities, incentives, and beliefs is a long-standing challenge for executives. As a result, naturally, the study of organizational conflict, decision-making, and communication received lots of attention from scholars in marketing and other disciplines (Simon, 1951; Cyert et al., 1963; Little, 1970; Sah and Stiglitz, 1991; Felli and Villas-Boas, 2000). The center of focus in these studies is a trade-off between (unbiased but less informed) centralized vs. (informed but biased) decentralized decision-making, applied to different contexts (e.g., Grossman and Hart, 1986; Jensen and Meckling, 1995; Aghion and Tirole, 1997; Athey and Roberts, 2001; Dessein, 2002; Rantakari, 2008; Alonso et al., 2008; Chakraborty and Yılmaz, 2017). We contribute to this literature by studying the impact of automation in resolving this trade-off.

Surprisingly, few papers in marketing focus on organizational structure and decision-making, particularly given the relevance of the question to marketing managers. Among these, Balasubramanian and Bhardwaj (2004) focuses on how to coordinate decision-making between the divisions of a firm experiencing conflict (manufacturing and marketing). This paper provides another context for the model we develop, where a firm consists of two divisions with conflicting objectives, and a decision favoring one of them worsens the output for the other. The decision of centralization vs. decentralization has been frequently considered in the vertical integration literature, thinking about whether the manufacturer vs. the retailer should be making the pricing decisions (McGuire and Staelin, 1983). Similarly, a number of papers explicitly considered if pricing authority should be delegated to the sales representatives (e.g., Bhardwaj, 2001; Mishra and Prasad, 2005; Rubel and Prasad, 2015). Our study demonstrates that, as a firm adopts automation in these contexts, the decision-making authority may be reallocated, e.g., moving it from sales force to the executive managing them. Moreover, we study firm communication using a cheap talk framework à la Crawford and Sobel (1982) and demonstrate how the quality of communication is altered by automation. To our knowledge, we are the first to explore this aspect of new technology adoption in organizations.

Finally, we contribute to the literature studying the impact of new technologies on organizations (e.g., Bakos and Treacy, 1986; Seidmann and Sundararajan, 1997; Bakos and Brynjolfsson, 2000; Brynjolfsson and McAfee, 2011; Adamopoulos et al., 2018). Some studies suggested that technologies would flatten organizations by decentralizing decision-making (Meyer, 1968), while others claimed the opposite is likely (Leavitt and Whisler, 1958; Whisler and Shultz, 1962). The growth in automation renewed interest in these topics, with a lens specific to the effects of automation (Acemoglu et al., 2007). In this burgeoning area of research, the prime interest to date has been in the effects of automation on jobs and wages (e.g., Frey and Osborne, 2017; Acemoglu and Restrepo, 2019). A smaller stream focuses on the interaction between automated and non-automated systems (Agrawal et al., 2018a,b) and the changing incentives in the workplace following introduction of automation Dogan and Yildirim (2021). We contribute to this literature by proposing a mechanism to explain the relationship between automation and organizational structure, which is missing in the aforementioned literature. In particular, we show that when deployed strategically, automation can alter the decision-making structure in organizations.

The remainder of this paper is organized as follows. Section 2 describes the theoretical model of the firm. It formulates extensive-form games characterizing the centralized and decentralized structures. Section 3 solves for the game's equilibrium and Section 4 presents our findings on the firm's allocation of automation across the two divisions and the choice of the optimal organizational structure. In Section 5, we extend the baseline model to allow for cheap talk communication between the principal and the manager under centralization (Section 5.1), the automation capacity to be endogenously determined (Section 5.2), and the residual conflict to be managed via a monetary contract (Section 5.3). We show that all results from the baseline model are robust to these modifications. We conclude in Section 6.

2 Model

This section first describes the firm's structure (Section 2.1), then its automation deployment strategy (Section 2.2), and finally the possible organizational structures that it may adopt (Section 2.3).

2.1 Setting and Assumptions

There is a firm (e.g., Ford) that consists of two divisions, Division 0 and Division 1. A principal (she) is the executive head of the firm, and each division is led by a manager (he). Division 1 focuses on new product development (e.g., electric cars), it faces a changing operating environment, and is referred as the "forefront" division. In contrast, Division 0 is in charge of the existing product of the firm (e.g., gasoline cars) and is referred as the "business-as-usual" division as it faces steady conditions.[2] The firm will make a decision, $d \in \Re$, which determines the extent to which the firm prioritizes Division 1 over Division 0. For instance, this decision could characterize the allocation of research budget (e.g., prioritization of battery technologies vs. conventional powertrains), the qualification of a new supplier (e.g., one that competitive for electric vehicle components vs. one that is more diversified), or the design of vehicle features across both product lines (e.g., design choices more tailored to electric vs. gasoline cars). As such, this decision impacts the productivity of both divisions.

The steady conditions of Division 0 are summarized by a constant state $\theta_0 = 0$, which we also refer to as the status quo. The state of Division 1 is a random variable θ_1, which takes its value from the uniform distribution over $[0, 1]$. The value of θ_1 may, for instance, can be a measure of shift in consumer attitudes toward electric cars and transportation sustainability. A higher θ_1 implies a higher deviation from the status quo in the conditions that Division 1 faces. While the distribution of θ_1 is publicly known, its realized value is only *privately* observed by the manager of Division 1. As this information plays a crucial role, he plays a strategic role within the firm. The manager of Division 0, in contrast, does not play such a role. We thus only keep the manager of Division 1 in the model and refer to him as "the manager."

The principal is interested in maximizing the firm's total profit—sum of the profits of Division 0 (Π_0) and Division 1 (Π_1), denoted by $\Pi = \Pi_1 + \Pi_0$. The manager's preferences are more inclined towards his own division compared to that of the principal. He is interested in maximizing $\mathcal{U} = \Pi_1 + \alpha\Pi_0$, for some $\alpha \in [0, 1)$. The parameter α captures a *residual* conflict between the principal and the manager: the larger the value of α, the closer their preferences are.[3]

Division Setup The productivity of each Division i, which we denote by p_i, is a random variable: it can be either high ($p_i = h$) or low ($p_i = l$), with $h > l$. The closer the firm's decision d is to θ_i, the more likely the productivity in Division i is to be high. Specifically:

$$P(p_i = h) = 1 - (\theta_i - d)^2 \qquad \& \qquad P(p_i = l) = (\theta_i - d)^2 \tag{1}$$

[2]Here, Division 0 can be considered as a standalone division of the firm, or a set of multiple divisions operating under business-as-usual conditions.

[3]Incentive contracts offered to division managers are usually tailored to induce division-specific managerial effort and hence naturally reward the divisional performance (instead of the overall firm performance) as it comprises a better measure of his effort (Athey and Roberts, 2001). To keep our focus on the questions of interest, we use a reduced-form model to capture a residual conflict that cannot be resolved by means of monetary incentives. Nevertheless, in Section 5.3, we introduce monetary contracts into our model and show that such a conflict does not necessarily disappear—providing a foundation for the reduced form model here.

Setting d close to $\theta_0 = 0$ can be interpreted as a continuity strategy—well-suited for the business-as-usual division. Vice versa, setting d closer to θ_1 can be interpreted as an adaptation strategy—well-suited for the forefront division. The challenge in setting the variable d lies in the asymmetry of information and the conflict between the principal and the manager.

Each division is in charge of performing a continuum of *tasks*—normalized to a unit mass without loss of generality. Each task can be performed by a human worker ("non-automated task") or an automated machine ("automated task"), and generates an output that contributes to the division's profit. For example, Ford may automate the manufacturing tasks in its electric or gasoline car divisions. Automated and non-automated tasks differ in three aspects. First, automation reduces variability in production uncertainty. To capture this, we assume that the outcome of an automated task does not depend on the productivity of the division. Second, the profit contribution of automated and non-automated tasks may be different. Third, workers choose an effort level that impacts the outcomes of their tasks. In contrast, the output of automated tasks depends on technological capabilities alone.

Non-automated tasks The output of a non-automated task in Division $i = 0, 1$ depends on two factors: (i) the division's productivity p_i, and (ii) the effort exerted by the workers, $e \geq 0$, which comes at a cost $c(e) = ce^2$ for some $c > 0$. The outcome of each non-automated task is then given by $p_i e$.

We assume that workers' effort choices are contractible: they can be observed by the principal, who can then implement the efficient effort choice without leaving any rent to the workers.[4] Each worker's effort choice e therefore maximizes its profit contribution $p_i e - ce^2$. The resulting effort choice, which is contingent on the realized productivity in the corresponding division, then satisfies:

$$e = \begin{cases} \frac{h}{2c} & \text{if } p_i = h, \\ \frac{l}{2c} & \text{if } p_i = l. \end{cases} \tag{2}$$

Thus, the profit contribution of a non-automated task in Division i is $\frac{h^2}{4c}$ if $p_i = h$, and $\frac{l^2}{4c}$ if $p_i = l$.

Automated tasks The output of an automated task is identical across the divisions and does not depend on the productivity of the corresponding division. We denote the profit contribution of each automated task by ρ. This implies that automation eliminates the operational variability in production. By variability, we refer to the variability (in manufacturing tasks) that is associated with (i) the investment decision and (ii) the underlying uncertainty faced by the forefront division. When

[4] In an earlier version of the paper, we considered the case where worker effort is not publicly observed—creating a moral hazard problem. This led to a more complicated exposition, but the same qualitative results and insights.

a task is automated, its productivity becomes less sensitive to (i) and (ii).[5] What automation does in this setting, is to stabilize the output of tasks, and thereby reduce the dependence on the realized productivity of the underlying division, which in turn reduces the dependence on the investment decision.

2.2 Automation Strategy

The firm is endowed with an exogenous *automation capacity* $\zeta > 0$, i.e., the resources available to the firm for the automation of tasks.[6] The principal decides how to allocate this automation capacity between the divisions: ζ_0 and ζ_1 for Division 0 and Division 1, respectively, such that $\zeta_0 + \zeta_1 = \zeta$. We assume $\zeta < 1$, i.e., the principal cannot automate all tasks in a division.[7] This setting is motivated by the fact that the adoption of automated technologies is typically a long term decision of the firm that cannot be constantly re-evaluated, however, they can be re-appropriated across different divisions of a firm in the short term. The allocation of automation is publicly observed and does not alter operating costs. Without loss of generality, we normalize the cost of operation for each automated task to 0.

2.3 Organizational Structure

We consider two alternative organizational structures depending on who is in charge of making the investment decision, *centralization* and *decentralization*:

- Under centralization, the principal makes decision $d \in \Re$ herself based on the distribution of θ_1.[8]
- Under *decentralization*, the principal delegates decision $d \in \Re$ to the manager.

The choice between centralization and decentralization, which is summarized in Figure 1, involves a trade-off between biased. vs. uninformed decision-making. Under centralization, the principal can align the decision with the firm's overall objective, but this decision is uninformed. Under decentralization, the manager has access to perfect information, but may bias his decision towards Division 1.

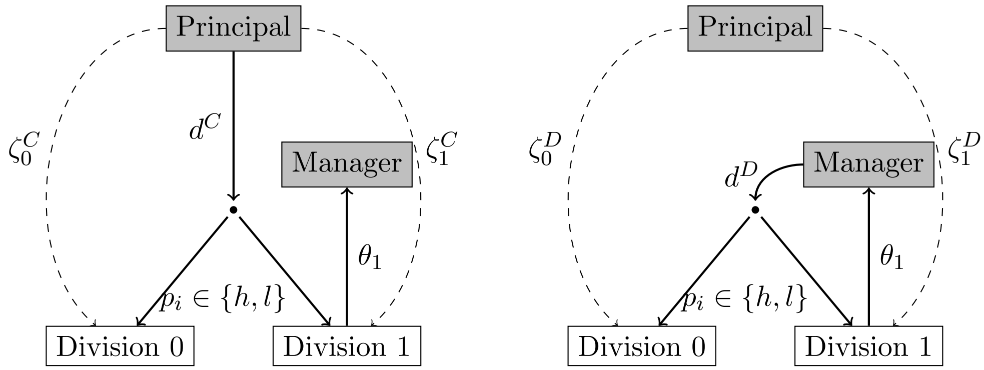
Next, we present the sequence of events and the timing of the strategic interactions under each regime. We use the superscripts C and D to refer to the centralization and decentralization, respectively.

[5]Our results would still hold if automation reduced production variability, rather than eliminating it. For instance, in a model with stochastic ρ, we would get the same results as long as the distribution of ρ is less sensitive to (i) and (ii) compared to the sensitivity of the non-automated tasks.

[6]Section 5.2 extends this setting to an instance where automation capacity is endogenously chosen by the principal.

[7]When $\zeta \geq 1$, the principal can eliminate the conflict by fully automating one of the divisions. In this case, centralization and decentralization result in the same outcome. We thus restrict the analysis to the more interesting case.

[8]In Section 5.1, we allow the principal and the manager to communicate about the realized value of θ_1 in the centralized organization. Such communication may correspond to any report or input that informs top-level executives.



(a) Centralized structure (b) Decentralized structure

Figure 1: Representation of centralized and decentralized structures.

Centralization The principal first determines the allocation of automation capacity between the two divisions (ζ_0^C and ζ_1^C). Then, she sets d^C to maximize the expected profit Π. Next, the productivity of each division realizes (and is publicly observed) based on the decision d^C and θ_1, according to Equation (1). The workers in Division $i = 0, 1$ make their effort choices based on the realized productivity $p_i \in \{h, l\}$ (Equation (2)).

Decentralization Under decentralization, the principal first determines the allocation of automation capacity (ζ_1^D, and ζ_0^D). Then, the manager privately observes the realized θ_1 and makes the decision, which is now defined as a function of the state space, $d^D : [0, 1] \longrightarrow \Re$. Next, the productivity of each division realizes based on decision d^D and θ_1, according to Equation (1). The workers in Division $i = 0, 1$ make their effort choices based on the realized productivity $p_i \in \{h, l\}$ (Equation (2)).[9]

3 Equilibrium Analysis

In this section, we characterize the equilibrium investment decisions under decentralization and centralization, for any given automation deployment strategy (Section 3.1). Then, we discuss the impact of automation deployment and the strategic role that it plays in the firm (Section 3.2).

[9] In practice, one can see one divisional manager making a decision for the entire firm or have some authority over another division. Rantakari (2008) writes that, for instance, "multinational corporations sometimes allocate authority asymmetrically to their subsidiaries to reflect their relative positions" where "one subsidiary can be positioned largely under the control of another subsidiary" (p.1258). The literature also states that the "asymmetries in dependency and other environmental variables sometimes warrant asymmetric governance structures, where the headquarters delegates authority asymmetrically to the divisions" (Rantakari, 2009, p.55).

3.1 Equilibrium Investment Decisions

We follow the game description in Figure 2 and proceed by backward induction.[10] We first derive the profits of each division (Steps $C5$ and $D5$), contingent on realized productivities and automation allocation. We use these expressions to characterize equilibrium decisions under each organizational structure (Steps $C3$ and $D3$). We adopt the Perfect Bayesian Equilibrium solution concept. We identify the players' sequentially rational strategies based on their beliefs determined by available information and Bayes' rule. All proofs are reported in Appendix A.

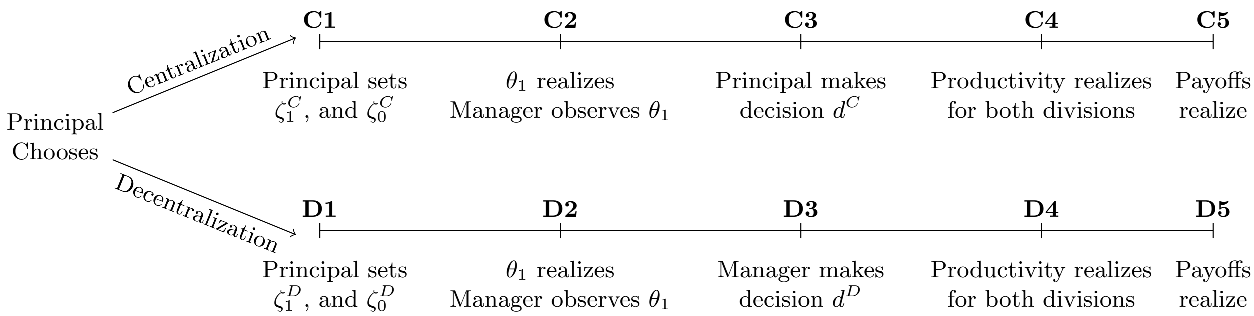


Figure 2: Sequence of events and the timing.

Profit of each division depends on the automation capacity and the realized productivity of that division. Let $\pi_{ih}(\zeta_i)$ and $\pi_{il}(\zeta_i)$ be the profit of Division i under high and low productivity, respectively:

$$\begin{aligned} \pi_{ih}(\zeta_i) &= \underbrace{(1-\zeta_i)\frac{h^2}{4c}}_{\text{non-automated tasks}} + \underbrace{\zeta_i \rho}_{\text{automated tasks}} \\ \pi_{il}(\zeta_i) &= \overbrace{(1-\zeta_i)\frac{l^2}{4c}} + \overbrace{\zeta_i \rho} \end{aligned} \tag{3}$$

The values of $\pi_{ih}(\zeta_i)$ and $\pi_{il}(\zeta_i)$ incorporate the profit contributions of non-automated and automated tasks: weights $1-\zeta_i$ and ζ_i reflect the fractions of non-automated and automated tasks in Division i, respectively. The gain from high productivity in Division $i = 0, 1$ for a given allocation of automation capacity is denoted by $\Delta_i(\zeta_i)$:

$$\Delta_i(\zeta_i) = \pi_{ih}(\zeta_i) - \pi_{il}(\zeta_i) = (1-\zeta_i)\frac{h^2 - l^2}{4c}. \tag{4}$$

Let $\bar{\pi}_i(\zeta_i, d, \theta_i)$ be the *expected profit* of Division i that results from the allocated automation capacity (ζ_i), investment (d), and state (θ_i). This expected profit is expressed as a weighted average of the profit functions π_{ih} and π_{il} given in Equation (3). Here, the expectation is taken over the

[10]Note that, the automation deployment decision takes place before θ_1 realizes. Therefore, there is no reason for the principal to delegate the automation deployment decision to the manager.

realization of the productivity of Division i, which takes the value h with probability $1-(\theta_i-d)^2$ and the value l with probability $(\theta_i-d)^2$:

$$\bar{\pi}_i(\zeta_i,d,\theta_i)=\left(1-(\theta_i-d)^2\right)\pi_{ih}(\zeta_i)+(\theta_i-d)^2\pi_{il}(\zeta_i). \tag{5}$$

We now characterize the equilibrium investment decisions for decentralization and centralization.

Decentralization The manager makes the decision d^D to maximize his expected utility (Step $D3$ of Figure 2), as a function of automation allocations (ζ_1^D and ζ_0^D) and the realized θ_1. His problem is:

$$\max_{d^D}\ \bar{\pi}_1(\zeta_1^D,d^D,\theta_1)+\alpha\bar{\pi}_0(\zeta_0^D,d^D,\theta_0).$$

Lemma 1 characterizes the solution to this problem.

Lemma 1. *Under decentralization, the investment decision satisfies:*

$$d^D(\zeta_1^D,\zeta_0^D,\theta_1)=\beta^D(\zeta_1^D,\zeta_0^D)\theta_1,\quad \textit{where } \beta^D(\zeta_1^D,\zeta_0^D)=\frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D)+\alpha\Delta_0(\zeta_0^D)}. \tag{6}$$

Decentralized decision, as shown in Lemma 1, proportionally adapts to the realized state of Division 1, but only imperfectly. Indeed, we have $\beta^D(\zeta_1^D,\zeta_0^D)<1$, so the manager's decision is such that $d^D<\theta_1$.[11] Put differently, decision d^D strikes a middle ground between a pure continuity strategy ($d=\theta_0=0$) and a pure adaptation strategy ($d=\theta_1$). In the example provided before, the manager's decision supports both the electric and gasoline car divisions, but at different rates. Thus, the manager also cares about the profit in Division 0 as long as $\alpha>0$. The weight he puts on his own division (i.e., the rate of adaptation $\beta^D(\zeta_1^D,\zeta_0^D)$) decreases with lower conflict with the principal (higher α). The manager's decision also depends on the automation deployment strategy, which will be discussed subsequently.

We can now derive the expected profit of the firm under decentralization, $\Pi^D\left(\zeta_1^D,\zeta_0^D\right)$:

$$\Pi^D\left(\zeta_1^D,\zeta_0^D\right)=\int_0^1\left[\bar{\pi}_1(\zeta_1^D,d^D,\theta_1)+\bar{\pi}_0(\zeta_0^D,d^D,\theta_0)\right]d\theta_1. \tag{7}$$

Specifically, the firm's expected profit is equal to the sum of profits across two divisions, averaged out over all realizations of θ_1. Note that, despite θ_0 being deterministic, the profit of Division 0 is subject to uncertainty since the investment decision is a random variable. Proposition 1 provides a closed-form solution of the expected profit of the firm.

[11] When it is clear from the context, we suppress the arguments, $\zeta_1^D,\zeta_0^D,\theta_1$, in functional expressions.

Proposition 1. *Under decentralization, the expected profit of the firm is equal to:*

$$\Pi^D\left(\zeta_1^D, \zeta_0^D\right) = \pi_{1h}(\zeta_1^D) + \pi_{0h}(\zeta_0^D) - \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[\Delta_1(\zeta_1^D) + \alpha^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)\right]^2}. \tag{8}$$

The first two terms in Equation (8) correspond to the firm's total profit when productivity is high in both divisions. The last term reflects the expected loss resulting from productivity uncertainty. Although there is a direct dependency, it is not obvious how the automation strategy impacts this expected loss. We will discuss this dependency in detail when we characterize the principal's automation deployment strategy. The impact of conflict on this expected loss, however, is clear. The more aligned the manager's incentives are with the principal (higher α), the smaller is the expected loss.

Centralization We characterize the centralized investment decision d^C by the principal (Step $C3$ of Figure 2). This decision maximizes the expected profit of the firm as a function of the automation capacity in each division (ζ_1^C and ζ_0^C) and the distribution of θ_1. The problem is:

$$\max_{d^C} \mathbb{E}\left[\bar{\pi}_1(\zeta_1^C, d^C, \theta_1)\right] + \bar{\pi}_0(\zeta_0^C, d^C, \theta_0).$$

Lemma 2 characterizes the centralized decision d^C.

Lemma 2. *Under centralization, the investment decision satisfies:*

$$d^C = \beta^C(\zeta_1^C, \zeta_0^C)\mathbb{E}(\theta_1) = \frac{1}{2}\beta^C(\zeta_1^C, \zeta_0^C), \quad \textit{where } \beta^C(\zeta_1^C, \zeta_0^C) = \frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C)}. \tag{9}$$

We see that in centralized firms, the principal proportionally adapts to the *expected* value of θ_1, which is $\frac{1}{2}$. The rate of adaptation is now $\beta^C(\zeta_1^C, \zeta_0^C) < \beta^D(\zeta_1^C, \zeta_0^C))$, therefore, compared with decentralization, the principal favors the status quo at a greater rate than the manager. Continuing with our example, this would suggest that the higher management at Ford may favor the gasoline car division at a greater rate than the manager of the electric car. What is more interesting is how this disagreement in prioritizing the electric car changes as a firm has more automation capacity at its discretion. We will investigate this question in Section 3.2.

Proposition 2 provides a closed-form expression for the firm's expected profit.

Proposition 2. *Under centralization, the expected profit of the firm is equal to:*

$$\Pi^C\left(\zeta_1^C, \zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{\Delta_1(\zeta_1^C)(\Delta_1(\zeta_1^C) + 4\Delta_0(\zeta_0^C))}{12(\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C))} \tag{10}$$

Similar to the expected profit under decentralization (Proposition 1), the first two terms correspond to the profit under high productivity, and the last term reflects the expected loss due to productivity uncertainty. But in contrast to decentralization, the loss term depends on the choice of automation allocation between the two divisions only, and not the conflict between the principal and the manager, as the principal makes the investment decision on her own.[12]

To summarize the discussion up to now, Figure 7 illustrates the decision of the manager ($d^D(\theta_1)$, in blue line), the decision of the principal (d^C, in red line), and a benchmark representing the principal's *ideal* decision if she had perfect information ($\beta^C(\zeta_1, \zeta_0) \times \theta_1$, in dashed green line) for each value of θ_1. That the dashed green line is flatter than the blue line indicates that, if the principal had access to perfect information, she would push for continuity (e.g., prioritizing the gasoline car division) to a greater extent than the manager. Under centralization, the principal's decision differs from her ideal decision due to the uncertainty regarding the true value of θ_1. For some values of θ_1, the principal may have to choose a policy that features adaptation at an extent that is even higher than preferred by the manager. That is, while on average, the principal's investment decision is more conservative relative to that of the manager, in some cases, she is more liberal at adapting to the new environment relative to the manager as a result of her imperfect foresight.

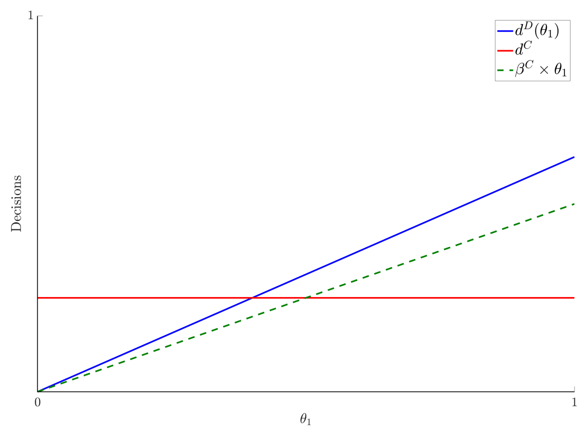


Figure 3: Decisions under centralization, decentralization, and perfect information.

3.2 Effects of Automation

As seen in Lemmas 1-2 and in Propositions 1-2, the automation deployment strategy affects the investment decision and the firm profit under both organizational structures. This section examines these effects of automation in greater detail. Specifically, we discuss the extent to which the automation strategy impacts (i) the disagreement between the principal and the manager about the investment decision and (ii) how much the principal values the private information held by the manager.

[12]As we shall see in Section 5.1, when the principal and the manager communicates about the realized value of θ_1 under centralization, this loss term also depends on the degree of conflict between the two.

(i) Disagreement over the Investment Decision To clarify how automation can alter the disagreement between the ideal investment decisions from the perspectives of the manager and the principal, we introduce a measure of disagreement.

Definition 1. *For any given automation strategy (ζ_1, ζ_0), the disagreement between the manager and the principal in their ideal rates of adaptation is:*

$$r(\zeta_1, \zeta_0) = 1 - \frac{\beta^C(\zeta_1, \zeta_0)}{\beta^D(\zeta_1, \zeta_0)} = \frac{(1-\alpha)\Delta_0(\zeta_0)}{\Delta_1(\zeta_1) + \Delta_0(\zeta_0)} \in (0, 1). \tag{11}$$

A lower r indicates that the principal and the manager have similar preferences for adapting to the new environment. In our setting, there is always disagreement ($r > 0$) since the principal's investment decision favors adaptation to a lesser extent. It is clear that the disagreement rate increases in the conflict within the firm (α). Moreover, this rate also depends on the choice of automation allocation across the divisions, i.e., ζ_1, and ζ_0. Corollary 1 details this dependency.

Corollary 1. *The disagreement between the principal and the manager increases when more of the automation capacity is allocated to Division 1 (higher ζ_1) and decreases when it is allocated to Division 0 (higher ζ_0).*

As the automation capacity increases in a division, its production becomes less sensitive to the investment decision. As a result, the decision-maker (i.e., the principal or the manager, depending on the organizational structure) tends to favor the other division to a greater extent. Thus, the rate of adaptation in decentralization ($\beta^D(\zeta_1, \zeta_0)$) and centralization ($\beta^C(\zeta_1, \zeta_0)$) both decrease in ζ_1 and increase in ζ_0. Corollary 1 indicates that, as the level of automation in Division 1 increases, the rate of adaptation for both the principal and the manager declines, and the reduction in that of the principal is greater than that of the manager.

We next evaluate how the automation strategy influences the value of information for the principal.

(ii) Value of Information Automation also impacts the value of the manager's private information to the principal. For a given allocation of automation capacity, we quantify this value as the difference between the firm's profit under perfect information vs. no information. We already know that the latter is equal to $\Pi^C(\zeta_1, \zeta_0)$ (Proposition 2); and we denote the firm's profit under perfect information by $\bar{\Pi}(\zeta_1, \zeta_0)$, which arises from decision $d = \beta^C(\zeta_1, \zeta_0) \times \theta_1$.

Definition 2. *The value of manager's information to the principal is given by:*

$$VOI(\zeta_1, \zeta_0) = \overline{\Pi}(\zeta_1, \zeta_0) - \Pi^C(\zeta_1, \zeta_0). \tag{12}$$

Corollary 2 shows that, all else equal, larger automation capacity in Division 1 (resp., Division 0) results in smaller (resp., greater) value of information.

Corollary 2. *The value of information is equal to* $VOI(\zeta_1, \zeta_0) = \frac{\Delta_1(\zeta_1)^2}{12(\Delta_1(\zeta_1)+\Delta_0(\zeta_0))}$. *It decreases with* ζ_1 *and increases with* ζ_0.

As the level of automation in Division 1 increases, the reliance of the principal on the manager's private information decreases. On the contrary, as the level of automation in Division 0 increases, the reliance of the principal on the manager's private information increases.

Corollaries 1 and 2 highlight the strategic importance of automation on managing (i) the disagreement between the principal and the manager, and (ii) the value of information held by the manager to the principal. We exploit these results in the next section to interpret the principal's optimal automation deployment strategy.

4 Automation and Organizational Structure

This section characterizes the allocation of automation capacity across the two divisions (e.g., new and existing product divisions) under centralization (Step $C1$) and decentralization (Step $D1$).

4.1 Automation Deployment Strategy

From the firm's expected profits under each organizational structure (Propositions 1 and 2), the corresponding problem under decentralization $\left(\mathcal{P}^D\right)$ is:

$$\begin{aligned} \max_{\zeta_1^D, \zeta_0^D} \quad & \pi_{1h}(\zeta_1^D) + \pi_{0h}(\zeta_0^D) - \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[\Delta_1(\zeta_1^D) + \alpha^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)\right]^2}, \\ \text{s.t.} \quad & \zeta_1^D + \zeta_0^D = \zeta, \qquad \zeta_1^D, \zeta_0^D \geq 0. \end{aligned}$$

Similarly, the corresponding problem under centralization $\left(\mathcal{P}^C\right)$ is:

$$\begin{aligned} \max_{\zeta_1^C, \zeta_0^C} \quad & \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{\Delta_1(\zeta_1^C)(\Delta_1(\zeta_1^C) + 4\Delta_0(\zeta_0^C))}{12(\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C))}, \\ \text{s.t.} \quad & \zeta_1^C + \zeta_0^C = \zeta, \qquad \zeta_1^C, \zeta_0^C, \geq 0. \end{aligned}$$

Proposition 3 characterizes the solutions to the Problems $\left(\mathcal{P}^C\right)$ and $\left(\mathcal{P}^D\right)$ to determine the optimal allocation of automation capacity, ζ_1 and ζ_0, under each organizational structure.

Proposition 3. *(Automation Deployment Strategy) Equilibrium automation deployment strategy is:*

(i) Under the decentralized structure, $\zeta_1^D = 0$, *and* $\zeta_0^D = \zeta$.

(ii) Under the centralized structure, $\zeta_1^C = \zeta$, and $\zeta_0^C = 0$.

The optimal allocation of automation capacity across the divisions features a "bang-bang" property under both organizational structures: capacity is allocated to either of the two divisions. Moreover, the choice of which division to automate differs under each organizational structure: the principal automates Division 0 under decentralization, but Division 1 under centralization.

The intuition for why firms with different organizational structures utilize automation in divisions facing different levels of uncertainty is as follows. In decentralized firms, the main concern of the principal that shapes her automation strategy is manager's biased decision. In this case, she allocates the entire capacity to the business-as-usual division to reduce the division's sensitivity to the manager's investment decision and thereby shield it from manager's bias. In centralized firms, on the contrary, the main concern of the principal that shapes her automation strategy is lack of information about the conditions faced by the forefront division. Thus, the principal allocates automation capacity to the forefront division to reduce her reliance on the manager's private information (Corollary 2).

In the context of our benchmark example, the optimal automation strategy would imply that a centralized Ford is more likely to utilize automation in the new product (electric car) division. In this case, since the principal is less informed compared to the manager, she would use automation to reduce the negative effects of her uninformed decision-making and allocate automation capacity to the electric car division. In a decentralized Ford, the principal is more likely to utilize automation in the current product (gasoline car) division. In this case, since the manager is biased and his decision is more likely to prioritize the electric car division, the principal uses automation as a tool to protect the gasoline car division against this biased decision.

How does automation deployment affect firm's adaptation? For a given allocation of automation across the divisions, ζ_1 and ζ_0, the manager's desired rate of adaptation (i.e., to the conditions faced by the forefront division) is higher than that of the principal, i.e., $\beta^D(\zeta_1, \zeta_0) > \beta^C(\zeta_1, \zeta_0)$. Now, the question is how does the equilibrium adaptation rates compare for a centralized vs a decentralized firm? Plugging in the equilibrium automation deployment strategies, we derive the equilibrium adaptation rate for each regime as follows:

$$\beta^C(\zeta_1^C, \zeta_0^C) = \frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C)} = \frac{1-\zeta}{2-\zeta}$$
$$\beta^D(\zeta_1^D, \zeta_0^D) = \frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)} = \frac{1}{1+\alpha(1-\zeta)},$$

and hence $\beta^D(\zeta_1^D, \zeta_0^D) > \beta^C(\zeta_1^C, \zeta_0^C)$. In words, a centralized firm is more likely to follow a continuity strategy (equivalently, less likely to follow an adaptation strategy) than a decentralized firm. Revisiting our example, a continuity strategy implies that Ford would prioritize its gasoline cars, and focus less on electric car development. An adaptation strategy implies the opposite: Ford would focus on electric car development, if changing market conditions demand new products. In other words, decentralized firms are more likely to prioritize new product development over their existing product lines. Therefore, when it comes to adapting to new market conditions, decentralized firms are "agile" and centralized firms are "stale."

It is also clear that a higher automation capacity ζ results in a higher β^C and in a lower β^D. That is, centralized organizations become increasingly more 'stale' and decentralized organizations become increasingly more 'agile' as automation technologies become more accessible to firms. Thus, cheaper automation may lead to fragmentation among firms with respect to product focus—while some firms are more likely to embrace new conditions, others lag in adapting to them and keep their focus on existing products.

How does automation deployment affect intra-firm disagreement? As alluded to earlier, a measure of interest from a managerial perspective may be the rate of disagreement—or how much the firms' adaptation rate would change—if the investment decision was made by the principal vs. the manager. To analyze this, we compare the ideal adaptation rates of the agents, after the firms' automation deployment strategy has already been decided. Now, the question is how does the equilibrium rates of disagreement compare for a centralized vs a decentralized firm? Plugging in the equilibrium automation deployment strategies, we derive the equilibrium disagreement for each regime as follows:

$$\begin{aligned} r^C(\zeta_1^C, \zeta_0^C) &= \frac{1-\alpha}{2-\zeta}, \\ r^D(\zeta_1^D, \zeta_0^D) &= (1-\zeta)\frac{(1-\alpha)}{2-\zeta}. \end{aligned}$$

It is clear from these expressions that, the disagreement between the ranks of the management is higher in a centralized firm compared to a decentralized firm. Moreover, increasing automation capacity results in higher disagreement in centralized firms, whereas it decreases disagreement in decentralized firms. Thus, technological advancements are not always accompanied by a higher level of consensus between stakeholders. Moreover, earlier studies on firm adaptation (e.g., Rantakari, 2008; Alonso et al., 2008) do not predict different levels of disagreement for centralization vs. decentralization. There is a difference between these regimes only when $\zeta > 0$, which highlights the unique effect that technology has on intra-firm disagreement. The following corollary summarizes this insight.

Corollary 3. *(Automation & Intra-firm disagreement) When automation is strategically allocated, with higher automation capacity, the rate of disagreement between the principal and the manager decreases (resp., increases) in a decentralized (resp., centralized) firm.*

These insights point to the strategic role of automation allocation to manage information asymmetries and intra-firm disagreement. Next, we discuss how a firm structures its organization in anticipation of its downstream implications.

4.2 Optimal Organizational Structure

Recall that the principal (i) can delegate the investment decision to the manager and automate the business-as-usual division (Division 0) to shield it from the manager's biased decision, or (ii) can make the investment decision herself, and automate the forefront division (Division 1) to reduce her reliance on the manager's private information. Proposition 4 characterizes the optimal regime choice depending on the automation capacity (ζ) and the residual conflict (α) within the firm.

Proposition 4. *(Automation Capacity and Organizational Structure) If a firm has high automation capacity ($\zeta \geq g(\alpha)$, where $g(\alpha) \equiv 3 - \frac{1}{\alpha}$), then centralization yields higher profits. Otherwise, if it has low automation capacity ($\zeta \leq g(\alpha)$), decentralization is optimal.*

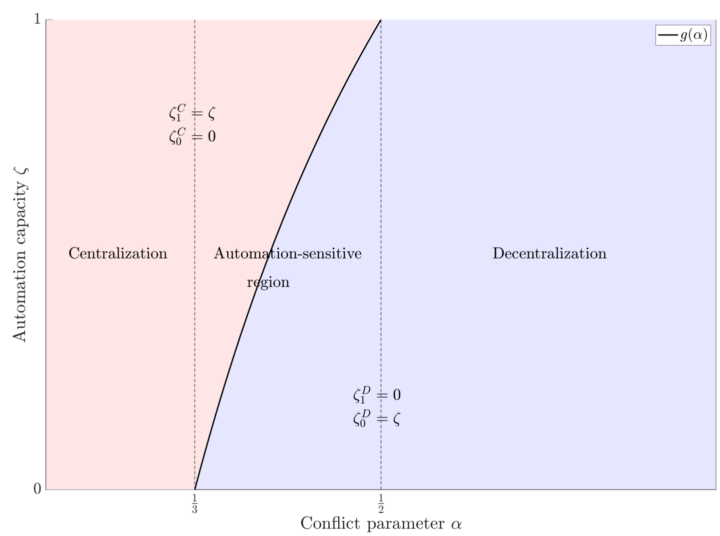


Figure 4: Optimal organizational structure as a function of automation capacity and degree of conflict.

Proposition 4 implies that, all else equal, the greater the automation capacity ζ, the more likely the firm to centralize decision-making. Put differently, automation can become a substitute to the manager's expertise—his possession of private information—if the resources are sufficiently high. To see the intuition, consider a firm with a low automation capacity. In this case, the principal is able to automate only a small fraction of the tasks, and she remains considerably reliant on the manager's private information. Therefore, she delegates the investment decision to the manager, and shields the business-as-usual division (Division 0) from his biased decision by automating the tasks in this division. When the capacity is high, she can automate a higher fraction of the tasks in any division, reducing her reliance on the manager's private information. Therefore, she makes the investment decision herself, and allocates automation capacity to the forefront division (Division 1)—reducing the negative effects of her imperfect information.

Figure 8 illustrates the regions in which each regime is optimal relative to the level of conflict in the firm. As can be seen in the figure, the range of $\alpha \in (0, 1]$ is divided into three regions. First, when $\alpha \leq \frac{1}{3}$, centralization is optimal regardless of the automation capacity. Second, when $\alpha \geq \frac{1}{2}$, decentralization is optimal regardless of the automation capacity. Third, when $\alpha \in (\frac{1}{3}, \frac{1}{2})$ the optimal structure depends on the automation capacity. In this *automation-sensitive region*, decentralization is optimal under low automation capacity, but centralization is optimal under high automation capacity. Put differently, in firms with intermediate level of conflict, with a higher automation capacity, the decision-making authority of the middle manager is reduced. In this case, as automation capacity increases, the role of the manager in the firm may be narrowed down to non-strategic, e.g., operational, tasks. This reduced decision-making authority of the middle manager does *not* stem from the automation of his own duties, but from the automation of low-level tasks within his division and from the reduced value of his private information. Stated differently, automating a low-level task can have broader effects in an organization, trickling up the management hierarchy. Table 1 below summarizes our findings until now.

	Organizational Structure	
	Centralization	**Decentralization**
Decision Authority	Principal	Manager
Automation Allocation	To Division 1: $\zeta_1^C = \zeta$, $\zeta_0^C = 0$	To Division 0: $\zeta_1^D = 0$, $\zeta_0^D = \zeta$
Adaptation Rate	$\beta^C(\zeta_1^C, \zeta_0^C) = \frac{1-\zeta}{2-\zeta}$ Lower adaptation (higher continuity)	$\beta^D(\zeta_1^D, \zeta_0^D) = \frac{1}{1+\alpha(1-\zeta)}$ Higher adaptation (lower continuity)
Decision (d)	$d^C = \beta^C(\zeta_1^C, \zeta_0^C)\mathbb{E}(\theta_1)$	$d^D = \beta^D(\zeta_1^D, \zeta_0^D)\theta_1$
Product Strategy	Prioritize existing product	Prioritize new product

Table 1: Summary of key findings

5 Extensions and Robustness Checks

In this section, we consider three generalizations of our baseline model. Specifically, we allow for (i) cheap talk communication between the principal and the manager under centralization (Section 5.1),

(ii) the automation capacity to be endogenously determined (Section 5.2), and (iii) the residual conflict to be managed via a monetary contract (Section 5.3). We will see that all results from the baseline model are robust to these modifications.

5.1 Communication Between the Principal and Manager

As the principal in a centralized organization is uninformed about the conditions facing Division 1, a natural question is whether communicating with the manager can increase the principal's efficacy and alter our baseline results. To consider this possibility, we modify the baseline model to include a communication stage. Now, the manager provides an informative message about θ_1 to the principal, denoted by $m(\theta_1)$, before she makes the investment decision. Following the seminal paper of Crawford and Sobel (1982), we assume that this communication is based on non-verifiable signals, i.e., *cheap talk*. The rest of the game follows the timeline shown Figure 5.

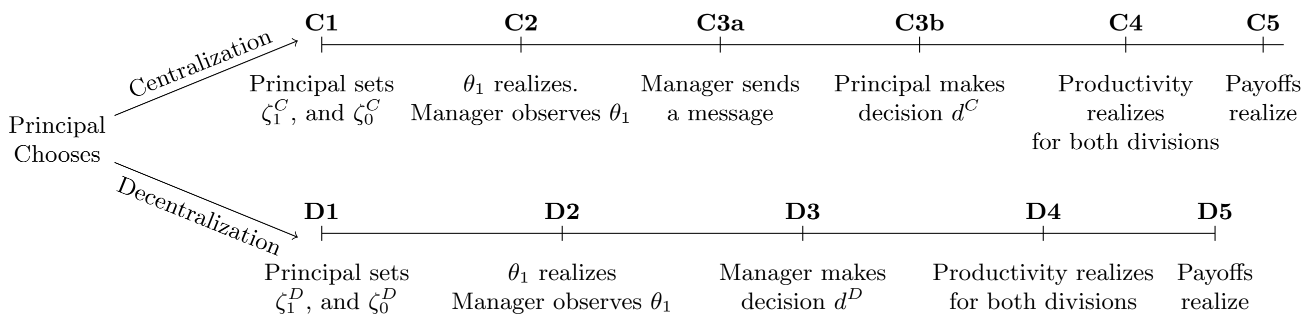


Figure 5: Sequence of events and timing under centralization in the presence of communication.

Let M be the set of messages that can be transmitted by the manager to the principal. The manager's communication strategy is defined as a mapping σ from the state space Θ to the space of probability measures over M (to allow mixed strategies):

$$\sigma : \Theta \longrightarrow \Delta M.$$

After receiving the message, the principal updates her beliefs about the realized value of θ_1 according to Bayes' Rule. This is written as follows:

$$\mathbb{P}\left(\theta_1 = \theta | m\right) = \frac{f(\theta_1)\mathbb{P}\left(\sigma(\theta_1) = m\right)}{\int\limits_{\tilde{\theta}_1 \in \Theta} f(\tilde{\theta}_1)\mathbb{P}(\sigma(\tilde{\theta}_1) = m)d\tilde{\theta}_1}.$$

The principal's investment decision, d^C, is now defined as a function of the manager's message:

$$d^C : M \longrightarrow \Re.$$

Following the update, the principal sets d^C to maximize the expected profit of the firm. Lemma 2 has shown that the principal's decision satisfies $d^C = \beta^C(\zeta_1, \zeta_0)\mathbb{E}(\theta_1)$, where $\mathbb{E}(\theta_1)$ is the expected value of θ_1. Now, in the presence of communication, the expectation is taken conditional on the message received from the manager, i.e., $d^C(m) = \beta^C(\zeta_1^C, \zeta_0^C)\mathbb{E}(\theta_1|m)$.

Equilibrium Communication. We now characterize the equilibrium communication between the principal and the manager (Step $C3a$). As in any cheap talk model, the communication game has multiple equilibria with various levels of informativeness. For instance, we have the totally uninformative *babbling equilibrium* where the manager sends random messages and the principal ignores them. Here, we focus on the most informative one, and refer it to as the *communication equilibrium.*

Proposition 5. *The communication equilibrium, as shown in Figure 6, partitions the state space* $[0, 1]$ *into infinitely many intervals whose boundaries are defined by a decreasing sequence* $\{\psi_n\}_{n=1}^{\infty}$*, where*

$$\psi_n = \left(\frac{\Delta_1(\zeta_1^C) + (2-\alpha)\Delta_0(\zeta_0^C) - 2\sqrt{(1-\alpha)\Delta_0(\zeta_0^C)(\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C))}}{\Delta_1(\zeta_1^C) + \alpha\Delta_0(\zeta_0^C)} \right)^{n-1}.$$

For each $\theta_1 \in (\psi_{n+1}, \psi_n]$*, the manager's message to the principal is* $\sigma(\theta_1) = m_n$*.*

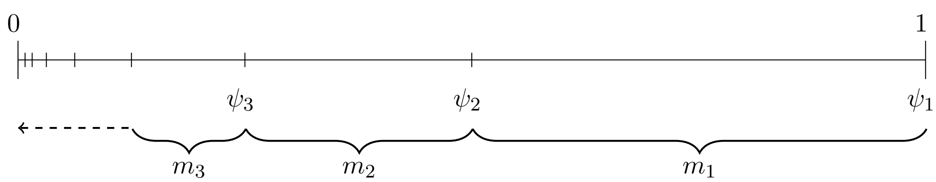


Figure 6: The structure of the communication equilibrium.

Proposition 5 demonstrates that the structure of the equilibrium communication depends on the conflict (α) and the automation strategy (ζ_0^C, ζ_1^C). When Division 1 faces a stronger change in its operating conditions—as θ_1 deviates more from 0—the manager's messages become *less informative*: the length of the corresponding interval becomes larger. Put differently, the manager provides coarser information in his report to the principal, and the principal ends up with wider confidence bounds around her prediction of the conditions faced by the forefront division (Division 1). These findings are in line with the literature on organizational design (e.g., Rantakari, 2008). Figure 7 illustrates the communication intervals and the equilibrium decision.

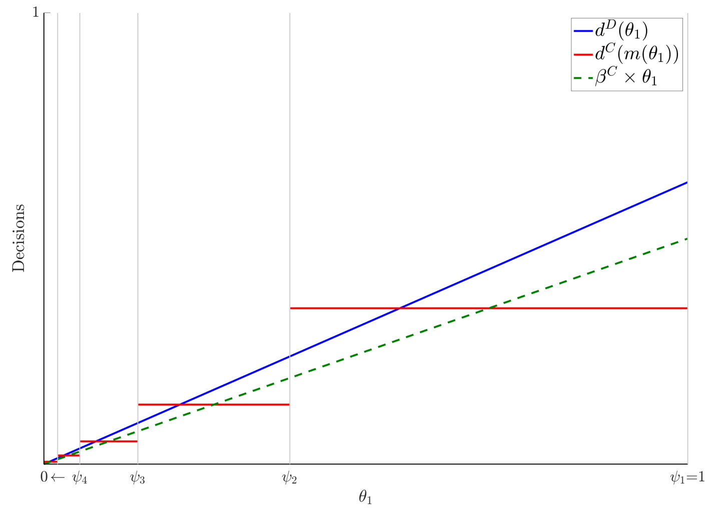


Figure 7: Decisions under centralization with communication, decentralization, and full information.

Based on the characterization of the communication equilibrium, we show in Appendix C (Proposition C.1) that the expected profit of the firm in equilibrium is equal to:

$$\Pi^C\left(\zeta_1^C, \zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{(4-\alpha)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C) + (4-\alpha)\Delta_0(\zeta_0^C)\right]}. \tag{13}$$

Comparing Equation 13 to Equation 10 clearly demonstrates that communication improves the profit of the firm under centralization. Moreover, this expression also shows that the profit now depends on the conflict between the principal and the manager, and higher conflict (lower α) results in lower profit. While a higher conflict implies a lower profit for both centralization and decentralization, the mechanisms behind this effect are different under each regime. Under decentralization, lower conflict triggers a decision from the manager that is more aligned with that of the principal, resulting in a higher expected profit. Under centralization, in contrast, lower conflict leads to a more informative communication from the manager to the principal, resulting in a higher expected profit.

Using the expression for the expected profit in Equation 13, we characterize the optimal automation deployment strategy under centralized organization without communication in Appendix C (Proposition C.2). Our findings indicate that allowing communication does not alter the automation deployment strategy in a centralized structure, that is, $\zeta_1^C = \zeta$, and $\zeta_0^C = 0$.

When we introduce communication, as it was in the baseline model, the principal continues to use automation to reduce her reliance on the manager's private information by automating Division 1 under centralization. However, automating Division 1 also has an additional adverse effect now: the manager's report is less informative as higher automation in Division 1 leads to a higher disagreement between the principal and the manager (by Corollary 1). Put differently, the strategic deployment of automation between the divisions of the firm influences the quality of communication between the ranks of management. Automation allocation that reduces a principal's reliance on a manager's private information leads the employee to strategically send worse messages (relative to a nonstrategic baseline). This is an adverse outcome of the strategic use of automation that has not been studied before in the literature, and it highlights the consequences of using technology more intensively to reduce uncertainty. In addition, similar to the effect that the strategic use of automation has, increasing the overall automation capacity reduces the quality of information in the reporting from the manager to the principal. This result is due to the increased disagreement following an increase in automation capacity under centralization. Once again, the finding highlights that more accessible automation may worsen communication of the subordinates.

Optimal Organizational Structure We now argue how the introduction of communication alters the strategic choice of organizational structure and automation. Proposition 6 is analogous to Proposition 4 and characterizes the optimal organizational structure in the presence of communication.

Proposition 6. *Adding communication between the principal and the manager expands the region where centralization is the optimal structure (hence where the Division 1 is automated). The g function in Proposition 4 becomes* $\hat{g}(\alpha) \equiv \frac{5(\alpha-0.6)}{\alpha^2}$.

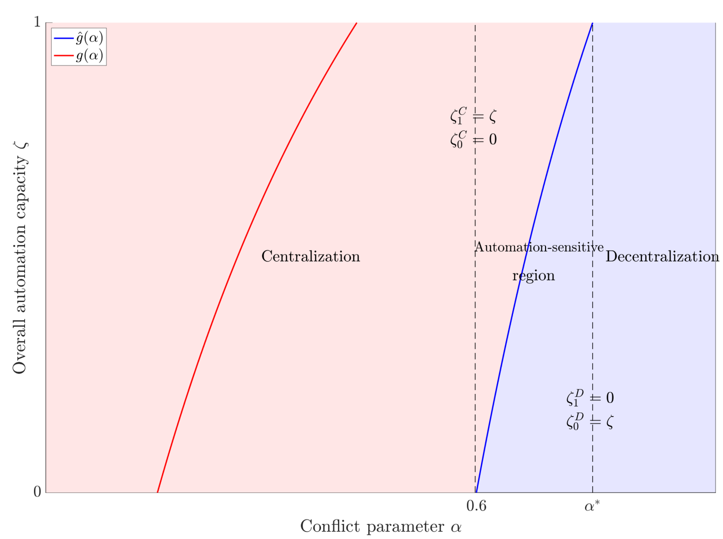


Figure 8: Optimal organizational structure in the presence of communication.

Figure 8 demonstrates the findings and compares the cases with and without communication. The blue curve marks the regions where centralization or decentralization is optimal under the optimal allocation of automation, with communication. The red line is the frontier that governs the optimal organizational structure when there is no communication (Proposition 4). Clearly, the introduction of communication increases the region where centralization is preferred. This is intuitive, as communication improves decision-making under centralization. At the same time, since centralization favors allocating automation capacity to the forefront division, communication makes adaptation less likely—resulting in a more stale firm. The choice of centralization vs. decentralization with respect to α and ζ remains similar to that in Section 4: there are still three regions, one where centralization is optimal independent of automation capacity, one where decentralization is optimal independent of automation capacity, and finally, one the automation-sensitive region ($\alpha \in (0.6, \alpha^*)$ for $\alpha^* = \frac{5-\sqrt{13}}{2}$) where the optimal regime choice depends on the automation capacity and conflict. In this last region, increasing automation capacity makes centralization more likely.

5.2 Endogenous Automation Capacity

Thus far, we have considered an exogenous level of automation ζ that the principal allocates across the two divisions. What if automation becomes cheaper and more accessible, and say Ford could choose its automation capacity? Would it always want to acquire as high an automation capacity as possible? Would decision-making authority be impacted by the endogenous automation capacity decision? To answer these questions, this section endogenizes the choice of ζ. In doing so, we retain the cheap talk communication in centralized structure (Section 5.1). This allows us to obtain unique insights about the effect of intra-firm conflict on the endogenous choice of automation. All proofs are reported in Appendix D.

To endogenize the automation capacity, we introduce an additional stage into the baseline model outlined in Section 2. Specifically, in an initial stage of the game, the principal chooses the automation capacity as well as its allocation across the divisions. Formally, she chooses ζ, ζ_1 and ζ_0, with $\zeta_1 + \zeta_0 = \zeta < 1$. We assume a quadratic cost of increasing capacity such that $C(\zeta) = \tau\zeta^2$, with $\tau > 0$.

Note that, once the optimal automation capacity ζ is set, all subsequent decisions of the manager and the principal remain identical to those provided in the main part of the paper. We already know that only Division 0 will be automated under decentralization and only Division 1 will be automated under centralization. Therefore, the principal's choice of automation capacity under decentralization and centralization are formulated as follows:

$$(\mathcal{P}_\zeta^D) \qquad \max_{\zeta} \quad \pi_{1h}(0) + \pi_{0h}(\zeta) - \frac{\Delta_1(0)\Delta_0(\zeta)\left[\Delta_1(0) + \alpha^2\Delta_0(\zeta)\right]}{3\left[\Delta_1(0) + \alpha\Delta_0(\zeta)\right]^2} - \tau\zeta^2.$$

$$(\mathcal{P}_\zeta^C) \qquad \max_{\zeta} \quad \pi_{1h}(\zeta) + \pi_{0h}(0) - \frac{(4-\alpha)\Delta_1(\zeta)\Delta_0(0)}{3\left[3\Delta_1(\zeta) + (4-\alpha)\Delta_0(0)\right]} - \tau\zeta^2.$$

Appendix D characterizes the solutions to these problems in Proposition D.1, and discusses the implications. Proposition 7 demonstrates the relationship between the optimal level of automation capacity and the residual conflict (α).

Proposition 7. (Optimal Automation Capacity and Residual Conflict) *The optimal automation capacity under decentralization (ζ_D^*) and centralization (ζ_C^*) are decreasing in α.*

The proposition shows that, keeping the cost of automation (τ) and the profit contribution of an automated task (ρ) fixed, under both organizational structures, the principal adopts higher levels of automation as the conflict within the firm increases (i.e., as α decreases). This result emphasizes the strategic role of automation: automation can be an important tool to mitigate the negative consequences of conflict within a firm. Put differently, while there may be other reasons, organizational fabric is an important driver of automation adoption. This result suggests that firms may acquire different automation capacities depending on their organizational characteristics, even when these technologies are equally accessible to all.

Figure 9 illustrates the optimal capacity of automation under each organizational structure depending on α, at a given τ. It also illustrates the optimal organizational structure by comparing the profit levels under centralization and decentralization. Accordingly, the solid lines in the figure correspond to the optimal organizational structure and the dashed lines correspond to the suboptimal one. The figure makes it easy to see that the optimal automation capacity under decentralization and centralization (ζ_D^* and ζ_C^*) increases with conflict (lower α). Moreover, optimal capacity is different under each structure, indicating that firms' technology choice depends on their organizational structure.

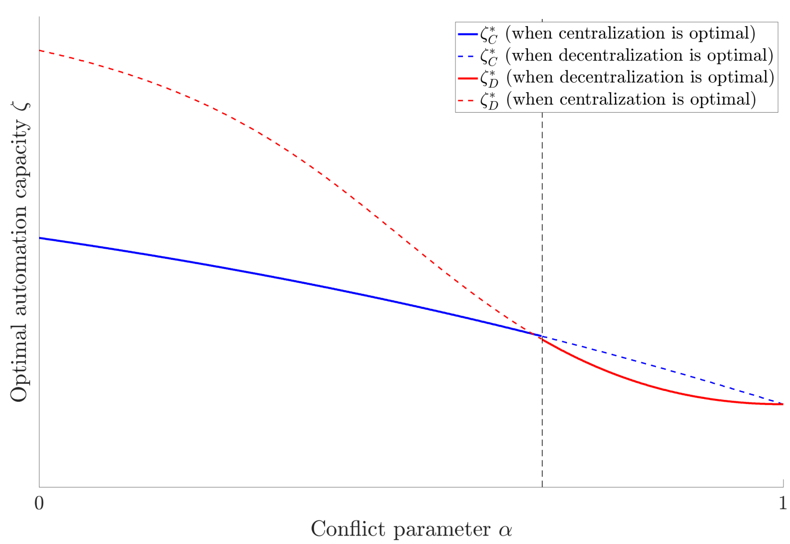


Figure 9: Optimal automation adoption.

The figure also demonstrates a more subtle insight: a firm does not always adopt technology at the highest available level. It rather couples the automation capacity with the organizational structure, and in some cases, chooses a lower capacity despite its productivity benefits. When not coupled with the right organizational structure, the principal may have to compensate for the suboptimal choice by adopting a higher automation capacity. Consequently, for firms whose organizational structures are suboptimal, the acquisition of optimal capacity can be quite costly. This highlights an interesting and empirically testable conclusion that, firms with higher levels of automation technology may be an indicator of an ill-managed organizational structure.

What happens if, over time, the cost of automation technologies decline? How will organizations use automation, as its cost declines? Figure 10 aids to address these questions by treating organizational structure as an outcome of the model with endogenous automation choice. The figure highlights the key insight that, as the cost of automation declines, firms are more likely to have a centralized organizational structure and automate their forefront division. This is because, with high costs of automation, the principal can only afford to automate a small share of tasks, and as explained in Section 5.1, so she remains considerably reliant on the manager's private information, and delegates the investment decision to the manager. Adopting a higher capacity frees the principal from the manager's private information and reverses the optimal organizational structure to centralization, in line with the intuition provided in Section 5.1. In that sense, the effect of increasing ρ (the productivity benefit of an automated task) on the endogenous adoption of automation capacity is similar to that of decreasing τ. That is, keeping τ fixed, as ρ increases, firms are likely to adopt a higher automation capacity.

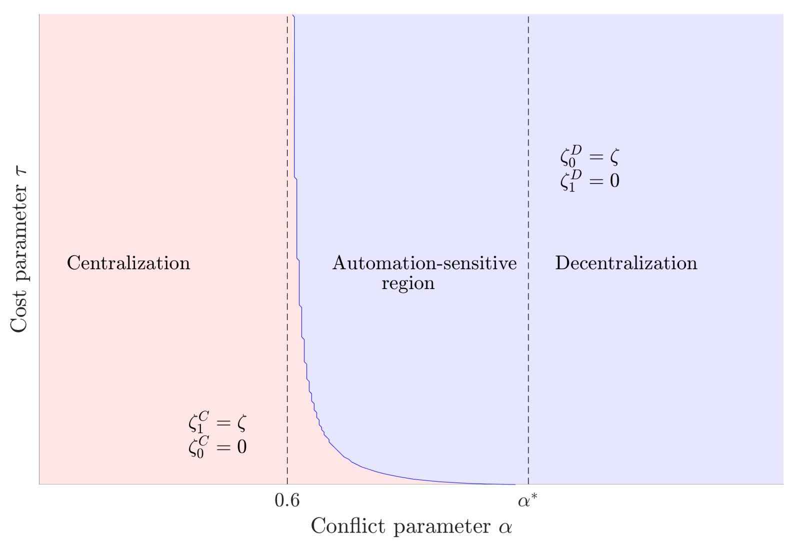


Figure 10: Optimal organizational structure under endogenous automation capacity.

5.3 Endogenous Conflict

Our construction is built on the assumption that the conflict within the firm is residual, ruling out the possibility that the principal could use monetary contracts to manage it. We now relax this assumption, and propose a more general model. The analysis shows that, our findings are robust in the sense that (i) the principal may choose not to use such contracts, and (ii) even when she does, the optimal contract may not fully eliminate the conflict between the principal and the manager. Moreover, it also provides a unique insight: automation technologies can be a substitute to contracts.

Formally, we start with the same payoff structure as in the model in Section 5.1, but allow the principal to use a monetary contract to manipulate the payoff structure and to manage the conflict. We assume that, the principal, in an initial step, sets the contract, and we keep all subsequent stages of the game unchanged. We also retain the communication in the centralized organization. The manager's payoff is still a linear combination of the profits of the two divisions, Π_1 and Π_0, but now the principal can increase the weight of Π_0 by some $\delta > 0$:

$$\mathcal{U} = \Pi_1 + (\alpha + \delta)\Pi_0.$$

With this modification, the principal can better align manager's preferences with Division 0, hence with her own preferences. The choice of δ (the degree of further alignment) comes at a cost for the principal, which equals $\lambda\delta\Pi_0$, where $\lambda > 0$. Then, the principal's payoff is:

$$\mathcal{V} = \Pi_1 + \Pi_0 - \lambda\delta\Pi_0.$$

Here, we provide the solutions for any value of $\lambda > 0$ and discuss the implications of various values that $\lambda > 0$ can take in Appendix E.

Based on the described modifications, for a given value of $\delta \geq 0$, the equilibrium decisions in centralized and decentralized organizations now become:

$$d^D = \beta^D(\zeta_1^D, \zeta_0^D)\theta_1, \quad \text{where } \beta^D(\zeta_1^D, \zeta_0^D) = \frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D) + (\alpha + \delta)\Delta_0(\zeta_0^D)}, \tag{14}$$

$$d^C(m) = \beta^C(\zeta_1^C, \zeta_0^C)\mathbb{E}(\theta_1|m), \quad \text{where } \beta^C(\zeta_1^C, \zeta_0^C) = \frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C) + (1 - \lambda\delta)\Delta_0(\zeta_0^C)}. \tag{15}$$

It is clear from these expressions that the conflict is fully eliminated when $\delta = \bar{\delta}$, with $\bar{\delta} \equiv \frac{1-\alpha}{1+\lambda}$. That is, the ideal decisions of the principal and the manager coincide when $\delta = \bar{\delta}$. Therefore, $\bar{\delta}$ is the maximum degree of further alignment that the principal is willing to bear. Following analogous steps to those in the baseline model in Appendix E, we characterize the equilibrium profits under both organizational structures as a function of δ, ζ_1, and ζ_0 (Proposition E.1). The principal optimizes δ together with the automation deployment strategy, ζ_1 and ζ_0, under both organizational structures based on these expressions. She then determines the optimal structure by comparing the corresponding profits.

Proposition 8. (Use of Contracts)

(i) Under decentralization, it is never optimal to fully eliminate the residual conflict ($\delta^D < \bar{\delta}$). As λ increases until a cutoff $\bar{\lambda}^D$, δ^D strictly decreases. When $\lambda > \bar{\lambda}^D$, the principal does not use monetary incentives for further alignment ($\delta^D = 0$).

(ii) Under centralization, there exists a $\bar{\lambda}^C$ such that when $\lambda \leq \bar{\lambda}^C$, the principal fully eliminates residual conflict by setting $\delta^C = \bar{\delta}$. When $\lambda > \bar{\lambda}^C$, the principal does not use monetary incentives for further alignment ($\delta^C = 0$).

Proposition 8 shows that, under decentralization, the principal never fully eliminates residual conflict—even when the cost of monetary incentives is very small. When λ is larger than a certain threshold, she stops using monetary incentives altogether. Proposition 8 also shows that the optimal use of monetary contracts under centralization paints a similar picture to that of under decentralization. Specifically, it shows that the principal abstain from using monetary contracts as long as their cost (λ) is not too small. However, if the cost is too low, in this case, the principal can use them and fully eliminate the residual conflict. These points are illustrated in Figure 11.

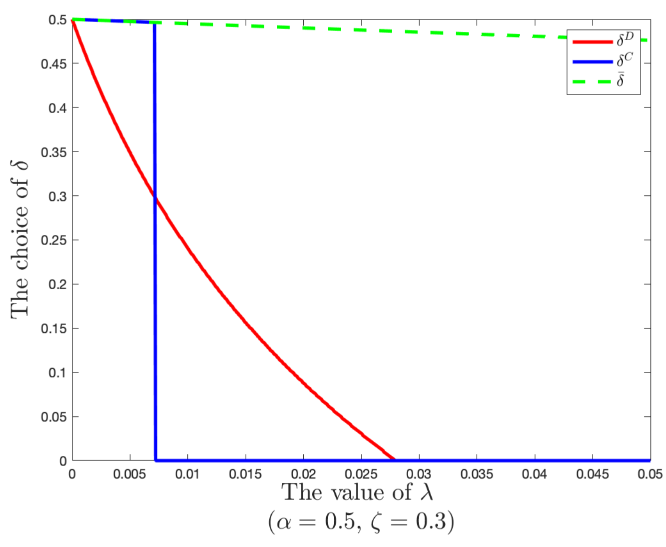


Figure 11: The dependency of δ^D, δ^C on λ.

The following remark highlights that, when the cost of conflict mitigation (λ) is high, the principal uses automation but not contracts, thus retaining the residual conflict. In this setting, the firm's dynamics coincide with those captured in our baseline model.

Remark 1. *When using monetary incentives is sufficiently costly, the principal does not use them and all qualitative results in the baseline model remain unchanged.*

Figure 12 illustrates how the degrees of further alignment chosen by the principal under decentralization (δ^D, in red) and centralization (δ^C, in blue) change with the overall automation capacity in the firm (ζ). The degree of further alignment varies between $\delta = 0$ and $\delta = \bar{\delta}$. The figure highlights the key insight that, under both organizational structures, a higher automation capacity implies a lower incidence of monetary contracts. Put differently, automation and monetary contracts are *strategic substitutes* that can be used by the principal to manage conflict. This is a striking finding, implying that the strategic deployment of automation can substitute for conventional methods of managing subordinates. A higher automation capacity, when used alongside contracts, can make contracts less costly. The return on automated technologies therefore is not confined to the productivity benefits, but also includes indirect benefits such as the savings due to reduced cost of incentivizing subordinates.

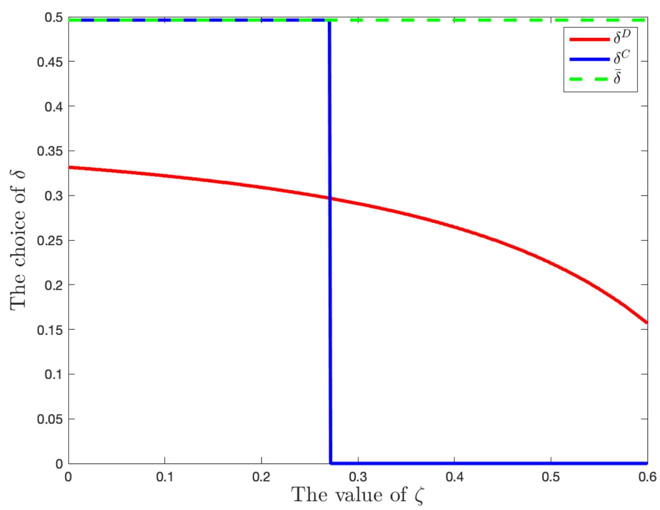


Figure 12: Degree of further alignment (δ^D, δ^C) vs. automation capacity (ζ).

Remark 2. *Automation capacity and monetary contracts are strategic substitutes for the principal to manage conflict.*

Finally, Figure 13 reproduces Figure 8 in the presence of monetary contracts. As earlier, centralization becomes more attractive when the conflict gets stronger, and there exists an *automation sensitive* region where higher automation capacity makes centralization more likely. This indicates once again that our reduced-form baseline model captures the relationships revealed by this more general model.

5.4 Discussion on Additional Considerations

Our model left a number of additional factors out of scope. We briefly discuss them below.

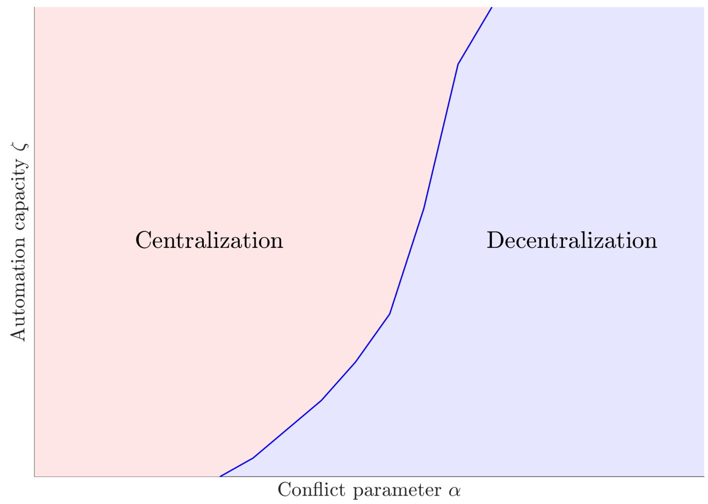


Figure 13: The optimal regime vs. automation capacity and conflict, with monetary contracts.

Scope of Information Asymmetry in an Organization In the benchmark model, we emphasized that misaligned preferences and asymmetric information are the two ingredients creating the trade-off faced by the principal (biased vs. uninformed decision-making). We discussed conflict extensively by studying how the results change with the degree of conflict (α). It is also worthwhile to discuss the implications of the scope of information asymmetry between the principal and the manager. As intuition would suggest, an increase in the extent of uncertainty in the system (e.g., a higher variance in the distribution of θ) would imply a higher value of the manager's private information to the principal. Stated differently, higher uncertainty would make decentralization more attractive over centralization. In order to reduce her reliance on the manager, the principal would need a higher level of automation capacity. In this sense, higher uncertainty (higher variability of θ) may act similarly to a higher degree of conflict (smaller α).

Complementary Technologies to Human Tasks In the baseline model, we assumed that the principal is choosing to automate tasks which would otherwise be carried out by humans—or, automation would displace human work. Could technologies that are complementary to human work, rather than substitute, reverse our findings? In a nutshell, the answer is no. As long as the technology provides the key benefits discussed in the model, such as increasing efficiency and reducing variability, our qualitative insights would follow for such technologies that complement human work as well.

Moral Hazard in Human Tasks In an alternative formulation, one can consider the case where the worker effort is not observed by the principal, creating a moral hazard problem. Specifically, one can assume that each task results in either a "failure" or "success." The success probability of a task carried out by a worker increases with (i) the level of effort exerted by the worker, and (ii) the productivity of the underlying division. Under the optimal compensation scheme, each worker would receive a wage $w \geq 0$ (determined by the principal) for each successful task, and 0 for each failed task. All results that arise in our baseline setting regarding the optimal organizational structure and the optimal automation deployment strategy would carry through in this alternative formulation with moral hazard. The only impact of moral hazard would be to increase the value of automation, resulting in the adoption of a higher automation capacity (Section 5.2). In this sense, moral hazard may act similarly to higher productivity of automated tasks (larger ρ) and lower cost of automation adoption (lower τ).

6 Conclusion

The exponential growth in computing technology has improved automation and artificial intelligence dramatically since the 1960s, and these technologies are transforming today's organizations. Not surprisingly, the interest in the implications of automation on workplaces has grown too, however, a great majority of the studies to date focused on the impact on labor market outcomes such as employment, wages and reallocation of labor between tasks (Acemoglu and Restrepo, 2018, 2019, 2020). Automation's impact in organizations, however, goes beyond. Decision-making authority and thus organizational structure, too, are impacted by the automation of tasks. This study fills a gap in the literature by focusing on these overlooked effects.

Our analysis yields the following key insights. We show that there is heterogeneity among firms' utilization of automation technologies depending on their organizational structure and conflict. In a centralized organization, the principal's main concern is to reduce her reliance on the manager's private information, which leads her to automate forefront (e.g., new product development) division. In a decentralized organization, the main concern is to reduce the negative effects of manager's biased decision-making, which leads her to automate business-as-usual (e.g., existing product) division. This difference also has implications for the disagreement between the principal and the manager regarding the prioritization of a new product over the existing one. In decentralized firms, higher automation results in lower disagreement, while it implies the opposite in centralized firms.

Organizational structure also changes the degree to which firms adapt to changing conditions: decentralized firms are more agile and are more likely to prioritize developing new products, whereas centralized firms are more stale and focus on existing products, thereby adapting to changing conditions to a lesser extent. Importantly, higher automation capacity increases this difference: decentralized firms become increasingly more agile and centralized firms become increasingly more stale. Put differently, automation capacity may influence the degree of heterogeneity in product offerings among firms with different organizational structures—e.g., while Ford may increasingly focus on developing new electric cars, General Motors may increasingly focus on its existing gasoline cars.

Looking at the impact of how access to automation may alter organizations in the long term, we find that as firms obtain higher automation capacity, they centralize decision-making, demonstrating a departure from the conclusions of some earlier studies (e.g., Acemoglu et al., 2007). Automation may thus reduce the strategic role of mid-level managers and re-appropriate them towards more operational tasks, as Leavitt and Whisler (1958) predicted several decades ago. Interestingly, these changes to the scope of a manager's duties are not because *his* tasks are automated—it is the automation of lower level tasks that changes the nature of his responsibilities. Marketing organizations, in particular, are often organized as vertical, decentralized hierarchies in decision-making, as commonly seen in sales organizations, customer service organizations, and retail firms (Anderson and Schmittlein, 1984; Chung et al., 2014; Dukes and Zhu, 2019). Therefore, marketing managers should be well-prepared for the changes that may come with automation.

In the extensions, we first investigate the impact of automation strategy on within-firm communication. We find that the strategic deployment of automation *reduces* the informativeness of communication from the manager to the principal. This finding regarding the effect of automation on communication is significant, as it suggests that managing human capital can be a greater challenge for firms that strategically use technology, as Dogan and Yildirim (2021) argue. Managers should keep in mind that, automating lower-level tasks may influence the communication and reports from the mid-level managers, and, it may impact a principal's reliance on the manager, too.

In a second extension, we verify that our findings are qualitatively robust to the introduction of monetary contracts. We find that automation capacity and monetary contracts serve as strategic substitutes for the principal in managing the conflict. The more automation resources the firm has access to, the less likely the principal is to rely on a contract to align a manager's preferences with hers. To our knowledge, this is the first paper to offer this particular insight.

Table 2 summarizes our findings as guidelines for managers and technology consultants who are thinking about the implications of automating organizations. We list a number of strategic considerations in each row, and next, we describe our prescription, depending on the structure of the firm.

Empirically Testable Hypotheses Our paper offers a rich set of propositions that can be taken to data. For empirically-oriented researchers, we list these testable hypotheses with the hope that they will spur ideas for further examination of the timely and important topics of organizational design and technology.

- For managers, above and beyond efficiency benefits, automation offers a strategic tool to manage the organization.

	Organizational Structure	
Managerial Problem	**Centralized**	**Decentralized**
Which division should be automated?	Low uncertainty (e.g., current product)	High-uncertainty (e.g., new product)
Adaptation vs. continuity?	Focus more on continuity (e.g., prioritize current product)	Focus more on adaptation (e.g., prioritize new product)
How does increasing automation resources affect firm strategy?	Increasing continuity, becoming more stale	Increasing adaptation, becoming more agile
How does automation strategy change agreement among managers?	Increased agreement between top- and mid-managers	Decreased agreement between top- and mid-managers
Preferred organizational structure with more accessible automation:	Becomes more likely	Becomes less likely

Table 2: Managerial Questions about Automation & Prescriptions

- For an automation technology, there may exist substantial heterogeneity among organizations in how they utilize it. Specifically, while organizations with decentralized decision-making structures are more likely to use automation in the divisions where conditions are more certain, centralized firms are more likely to automate divisions facing uncertainty.
- For a given automation level, decentralized firms are better at adapting to new market conditions.
- Firms with greater conflict or ill-managed organizational structures are more likely to invest in higher automation capacity relative to firms with lower conflict.
- As the cost of automation declines, decision-making in organizations is more likely to be centralized, where higher-ranked managers are in charge of strategic decisions.
- Use of contracts with mid-managers for incentive alignment may become less common as a firm has more access to automation resources.

We used a model of a firm focusing on a particular divisional structure to deliver sharp insights with closed-form solutions and without technical complications. We also kept the definition of automation purposefully simple and did not make assumptions about its particular functions, which allows us to produce more generalizable findings. We leave deviations from these assumptions as examinations for the future research.

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Appendix A Proofs of the Statements from Section 3

Proof of Lemma 1.

Recall that, for any values of ζ_0^D, ζ_1^D, the manager's problem is given by:

$$\max_{d^D} \left(1-(\theta_1-d^D)^2\right)\pi_{1h}(\zeta_1^D)+(\theta_1-d^D)^2\pi_{1l}(\zeta_1^D)+\alpha\left\{\left(1-(\theta_0-d^D)^2\right)\pi_{0h}(\zeta_0^D)+(\theta_0-d^D)^2\pi_{0l}(\zeta_0^D)\right\}.$$

Taking the first-order condition, we obtain:

$$2(\theta_1-d^D)\pi_{1h}(\zeta_1^D)-2(\theta_1-d^D)\pi_{1l}(\zeta_1^D)+\alpha\left\{2(\theta_0-d^D)\pi_{0h}(\zeta_0^D)-2(\theta_0-d^D)\pi_{0l}(\zeta_0^D)\right\}=0.$$

Then, with $\Delta_i(\zeta_i)=\pi_{ih}(\zeta_i)-\pi_{il}(\zeta_i)$ for each $i\in\{1,0\}$, together with $\theta_0=0$, this yields:

$$(\theta_1-d^D)\Delta_1(\zeta_1^D)-\alpha d^D\Delta_0(\zeta_0^D)=0.$$

Moreover, the second-order derivative of the expected utility is equal to $-2\left(\Delta_1(\zeta_1^D)+\alpha\Delta_0(\zeta_0^D)\right)$, which is negative. Therefore, the manager's utility-maximizing decision is given by:

$$d^D=\beta^D(\zeta_1^D,\zeta_0^D)\theta_1, \quad \text{where } \beta^D(\zeta_1^D,\zeta_0^D)=\frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D)+\alpha\Delta_0(\zeta_0^D)}.$$

□

Proof of Proposition 1.

For any value of $\pi_{ih}(\zeta_1^D)$, and $\pi_{ih}(\zeta_1^D)$ for each $i\in\{0,1\}$, the expected profit of the firm is given by:

$$\begin{aligned}\Pi^D(\zeta_1^D,\zeta_0^D)=\pi_{1h}(\zeta_1^D)&\int_0^1\left(1-(\theta_1-\beta^D(\zeta_1^D,\zeta_0^D)\theta_1)^2\right)d\theta_1+\pi_{1l}(\zeta_1^D)\int_0^1(\theta_1-\beta^D(\zeta_1^D,\zeta_0^D)\theta_1)^2d\theta_1\\&+\pi_{0h}(\zeta_0^D)\int_0^1\left(1-(\theta_0-\beta^D(\zeta_1^D,\zeta_0^D)\theta_1)^2\right)d\theta_1+\pi_{0l}(\zeta_0^D)\int_0^1(\theta_0-\beta^D(\zeta_1^D,\zeta_0^D)\theta_1)^2d\theta_1.\end{aligned}$$

Since $\theta_0=0$, we get after some algebra:

$$\Pi^D(\zeta_1^D,\zeta_0^D)=\pi_{1h}(\zeta_1^D)+\pi_{0h}(\zeta_0^D)-\frac{(1-\beta^D(\zeta_1^D,\zeta_0^D))^2}{3}\Delta_1(\zeta_1,w)-\frac{(\beta^D(\zeta_1^D,\zeta_0^D))^2}{3}\Delta_0(\zeta_0^D,w).$$

Then by using the fact that $\beta^D(\zeta_1^D,\zeta_0^D)=\frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D)+\alpha\Delta_0(\zeta_0^D)}$ (Equation 6), we reach to:

$$\Pi^D\left(\zeta_1^D,\zeta_0^D\right)=\pi_{1h}(\zeta_1^D)+\pi_{0h}(\zeta_0^D)-\frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[\Delta_1(\zeta_1^D)+\alpha^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D)+\alpha\Delta_0(\zeta_0^D)\right]^2}.$$

$\square$

Proof of Lemma 2.

Recall that, for any values of ζ_0^C, ζ_1^C, and any message m received from the manager, the principal's problem is given by:

$$\max_{d^C} \quad \mathbb{E}\left[\left(1-(\theta_1-d^C)^2\right)\pi_{1h}(\zeta_1^C)+(\theta_1-d^C)^2\pi_{1l}(\zeta_1^C)+\left(1-(\theta_0-d^C)^2\right)\pi_{0h}(\zeta_0^C)+(\theta_0-d^C)^2\pi_{0l}(\zeta_0^C)|m\right].$$

By proceeding as in the proof of Lemma 1, we obtain directly:

$$d^C(m)=\beta^C(\zeta_1^C,\zeta_0^C)\mathbb{E}(\theta_1|m), \quad \text{where } \beta^C(\zeta_1^C,\zeta_0^C)=\frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C)+\Delta_0(\zeta_0^C)}.$$

$\square$

Proof of Proposition 2.

The principal's expected payoff satisfies:

$$\begin{aligned}\frac{\Pi^C\left(\zeta_1^C,\zeta_0^C\right)}{2} &= \pi_{1h}(\zeta_1^C)\int_0^1(1-(\theta_1-d^C)^2)d\theta_1+\pi_{1l}(\zeta_1^C)\int_0^1(\theta_1-d^C)^2d\theta_1 \\ &+\pi_{0h}(\zeta_0^C)\int_0^1(1-(\theta_0-d^C)^2)d\theta_1+\pi_{0l}(\zeta_0^C)\int_0^1(\theta_0-d^C)^2d\theta_1.\end{aligned}$$

Using the fact that $\theta_0=0$, we get:

$$\Pi^C\left(\zeta_1^C,\zeta_0^C\right)=\pi_{1h}(\zeta_1^C)+\pi_{0h}(\zeta_0^C)-\Delta_1(\zeta_1^C)\int_0^1(\theta_1-d^C)^2d\theta_1-\Delta_0(\zeta_0^C)\int_0^1(d^C)^2d\theta_1.$$

But we know that $d^C=\frac{\beta^C(\zeta_1^C,\zeta_0^C)}{2}$, therefore we have:

$$\Pi^C\left(\zeta_1^C,\zeta_0^C\right)=\pi_{1h}(\zeta_1^C)+\pi_{0h}(\zeta_0^C)-\frac{\Delta_1(\zeta_1^C)(\Delta_1(\zeta_1^C)+4\Delta_0(\zeta_0^C))}{12(\Delta_1(\zeta_1^C)+\Delta_0(\zeta_0^C))}.$$

$\square$

Proof of Corollary 1.

First, we want to see how do the decisions under centralization and decentralization depend on the automation deployment strategy. For any value of θ_1, and for any values of ζ_1^D, ζ_0^D, the decision of the manager under the decentralized structure is given by:

$$d^D = \frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)}\theta_1 = \frac{1-\zeta_1^D}{1-\zeta_1^D+\alpha-\alpha\zeta_0^D}\theta_1.$$

We can verify that this expression is a decreasing function of ζ_1^D (keeping ζ_0^D constant), and an increasing function of ζ_0^D (keeping ζ_1^D constant).

Similarly, for any given posterior belief regarding θ_1, and for any values of ζ_1^C, ζ_0^C, the decision of the principal under the centralized structure is given by:

$$d^C = \frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C)}\mathbb{E}(\theta_1|m) = \frac{1-\zeta_1^C}{2-\zeta_1^C-\zeta_0^C}\mathbb{E}(\theta_1|m).$$

We can verify that this expression is a decreasing function of ζ_1^C (keeping ζ_0^C constant), and an increasing function of ζ_0^C (keeping ζ_1^C constant)

For any values of ζ_1, ζ_0, the extent of misalignment is given by:

$$\begin{aligned} r(\zeta_1,\zeta_0) &= 1-\frac{\beta^C(\zeta_1,\zeta_0)}{\beta^D(\zeta_1,\zeta_0)}, \\ &= 1-\frac{\Delta_1(\zeta_1)+\alpha\Delta_0(\zeta_0)}{\Delta_1(\zeta_1)+\Delta_0(\zeta_0)} = \frac{(1-\alpha)\zeta_0}{2-\zeta}. \end{aligned}$$

We can verify that the function r is increasing with ζ_1 (keeping ζ_0 constant) and decreasing with ζ_0 (keeping ζ_1 constant). □

Proof of Corollary 2.

We already know that

$$\Pi^C\left(\zeta_1^C,\zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{\Delta_1(\zeta_1^C)(\Delta_1(\zeta_1^C)+4\Delta_0(\zeta_0^C))}{12(\Delta_1(\zeta_1^C)+\Delta_0(\zeta_0^C))}$$

We now turn to the firm's profit under perfect information, i.e., when $d = \beta^C(\zeta_1,\zeta_0)\times\theta_1$. We can directly use Equation (10) with $\alpha = 1$. This yields:

$$\overline{\Pi}(\zeta_1,\zeta_0) = \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[\Delta_1(\zeta_1^C)+\Delta_0(\zeta_0^C)\right]}$$

Then, we obtain:

$$\begin{aligned} VOI(\zeta_1,\zeta_0) &= \overline{\Pi}(\zeta_1,\zeta_0) - \underline{\Pi}(\zeta_1,\zeta_0) \\ &= \frac{\Delta_1(\zeta_1)^2}{12(\Delta_1(\zeta_1)+\Delta_0(\zeta_0))} \end{aligned}$$

$$= \frac{(1-\zeta_1)^2}{12(2-\zeta_1-\zeta_0)} \frac{h^2-l^2}{4c}$$

Clearly, this expression decreases with ζ_1 and increases with ζ_0. $\square$

Appendix B Proofs of the Statements from Section 4

Proof of Proposition 3.

Problem $\left(\mathcal{P}^D\right)$ is given by:

$$\begin{aligned} \max_{\zeta_1^D, \zeta_0^D} \quad & \pi_{1h}(\zeta_1^D) + \pi_{0h}(\zeta_0^D) - \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[\Delta_1(\zeta_1^D) + \alpha^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)\right]^2}, \\ \text{s.t.} \quad & \zeta_1^D + \zeta_0^D = \zeta, \qquad \zeta_1^D, \zeta_0^D \geq 0. \end{aligned}$$

First, note from Equation (3) that $\pi_{1h}(\zeta_1^D) + \pi_{0h}(\zeta_0^D)$ is independent from how the overall automation capacity is allocated between the divisions. Therefore, Problem $\left(\mathcal{P}^D\right)$ boils down to the following:

$$\min_{\zeta_1^D, \zeta_0^D \in [0,\zeta]} \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[\Delta_1(\zeta_1^D) + \alpha^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)\right]^2}, \quad \text{s.t.} \;\; \zeta_1^D + \zeta_0^D = \zeta.$$

Moreover, we write in the remainder of this proof (Equation (4)):

$$\Delta_i(\zeta_i) = (1-\zeta_i)\kappa \quad \text{with } \kappa = \frac{h^2-l^2}{4c}. \tag{A1}$$

Therefore, Problem $\left(\mathcal{P}^D\right)$ is equivalent to minimizing $h^D(\zeta_1)$, given by:

$$h^D(\zeta_1) = \frac{(1-\zeta_1)(1-\zeta+\zeta_1)(1-\zeta_1+\alpha^2(1-\zeta+\zeta_1))}{(1-\zeta_1+\alpha(1-\zeta+\zeta_1))^2)}.$$

We show that:

$$h^D(0) \leq h^D(\zeta_1), \forall \zeta_1 \in [0,\zeta],$$

i.e.:

$$\frac{(1-\zeta)(1+\alpha^2(1-\zeta))}{(1+\alpha(1-\zeta))^2)} \leq \frac{(1-\zeta_1)(1-\zeta+\zeta_1)(1-\zeta_1+\alpha^2(1-\zeta+\zeta_1))}{(1-\zeta_1+\alpha(1-\zeta+\zeta_1))^2)}, \forall \zeta_1 \in [0,\zeta].$$

First, note that, for each $\zeta_1 \in [0,\zeta]$, we have $(1-\zeta_1)(1-\zeta+\zeta_1) \geq 1-\zeta$. This can easily be verified by noting that $(1-\zeta_1)(1-\zeta+\zeta_1)$ is a concave function of ζ_1 and takes value $1-\zeta$ when $\zeta_1 = 0$ and $\zeta_1 = \zeta$. Therefore, a sufficient condition is that:

$$\frac{1+\alpha^2(1-\zeta)}{(1+\alpha(1-\zeta))^2} \leq \frac{1-\zeta_1+\alpha^2(1-\zeta+\zeta_1)}{(1-\zeta_1+\alpha(1-\zeta+\zeta_1))^2}, \forall \zeta_1 \in [0,\zeta].$$

Let us fix $\zeta_1 \in [0, \zeta]$ and introduce the following notations:

$$x = 1 - \zeta_1.$$
$$y = 1 - \zeta + \zeta_1.$$
$$z = 1 - \zeta.$$

We want to show that:

$$\frac{1 + \alpha^2 z}{(1 + \alpha z)^2} \leq \frac{x + \alpha^2 y}{(x + \alpha y)^2}.$$

After developments, this is equivalent to:

$$x(1-x) + \alpha^2 y(1-y) + 2\alpha x(z-y) + 2\alpha^3 z(1-x)y + \alpha^2 zx(z-x) + \alpha^4 zy(z-y) \geq 0.$$

Moreover, we know that $1 - x = y - z$, and $1 - y = x - z$. Therefore the above inequality is:

$$(1-x)\left[x + 2\alpha^3 zy - 2\alpha x - \alpha^4 zy\right] + (1-y)\left[\alpha^2 y - \alpha^2 zx\right] >$$

This is satisfied since $x, y, z \in [0, 1]$, $z \leq x$ and $z \leq y$. Therefore, $\zeta_1^D = 0$, and $\zeta_0^D = \zeta$ at the optimum.

We now turn to Problem $\left(\mathcal{P}^C\right)$. It is given by:

$$\max_{\zeta_1^C, \zeta_0^C} \quad \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{\Delta_1(\zeta_1^C)(\Delta_1(\zeta_1^C) + 4\Delta_0(\zeta_0^C))}{12(\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C))}, \text{s.t.} \quad \zeta_1^C + \zeta_0^C = \zeta, \qquad \zeta_1^C, \zeta_0^C \geq 0.$$

As before, we know from Equation (3) that $\pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C)$ is independent from how the overall automation capacity is allocated between the divisions. Therefore, Problem $\left(\mathcal{P}^C\right)$ is equivalent to:

$$\min_{\zeta_1^D, \zeta_0^D \in [0, \zeta]} \frac{\Delta(\zeta_1)\left(\Delta_1(\zeta_1^C) + 4\Delta_0(\zeta_0^C)\right)}{12\left(\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C)\right)}, \qquad \text{s.t.} \;\; \zeta_1^D + \zeta_0^D = \zeta.$$

We define a function $h^C(\zeta_1)$ as follows:

$$h^C(\zeta_1) = \frac{(1 - \zeta_1)\left[(1 - \zeta_1) + 4(1 - \zeta + \zeta_1)\right]}{12(2 - \zeta)}.$$

We show that h^C is a concave function of ζ_1. Using the same expressions for x and y that we defined earlier, we have, for all $\zeta_1 \in [0, \zeta]$:

$$(h^C)'(\zeta_1) = \frac{-(1 - \zeta_1) - 4(1 - \zeta + \zeta_1) + 3(1 - \zeta_1)}{12(2 - \zeta)} = \frac{-2 + 4\zeta - 2\zeta_1}{12(2 - \zeta)}$$
$$(h^C)''(\zeta_1) = \frac{-1}{12(2 - \zeta)} < 0$$

Therefore, h^C admits its minimum in $\zeta_1 = 0$ or $\zeta_1 = \zeta$. We have:

$$
\begin{aligned}
h^C(0) &= \frac{5-\zeta}{12(2-\zeta}, \\
h^C(\zeta) &= \frac{(1-\zeta)(5-\zeta)}{12(2-\zeta}.
\end{aligned}
$$

We obtain directly that $h^C(\zeta) \leq h^C(0)$. This shows that $\zeta_1^C = \zeta$, and $\zeta_0^C = 0$ at the optimum. □

Proof of Proposition 4

By using the result of Proposition 3, we can compute the equilibrium profit level under both organizational structures. We denote it by $\widehat{\Pi}^D$ under the decentralized structure and by $\widehat{\Pi}^C$ under the centralized structure. Under the decentralized structure, we have $\zeta_1^D = 0$, and $\zeta_0^D = \zeta$. Therefore:

$$
\begin{aligned}
\widehat{\Pi}^D &= \pi_{1h}(0) + \pi_{0h}(\zeta_0) - \frac{\Delta_1(0)\Delta_0(\zeta)\left[\Delta_1(0) + \alpha^2\Delta_0(\zeta)\right]}{3\left[\Delta_1(0) + \alpha\Delta_0(\zeta)\right]^2}, \\
&= (2-\zeta)\frac{h^2}{4c} + \zeta\rho - \frac{h^2-l^2}{4c}\frac{(1-\zeta)(1+\alpha^2(1-\zeta))}{3(1+\alpha(1-\zeta))^2}.
\end{aligned}
$$

Under the centralized structure, we have $\zeta_1^C = \zeta$, and $\zeta_0^C = 0$. Therefore:

$$
\begin{aligned}
\widehat{\Pi}^C &= \pi_{1h}(\zeta) + \pi_{0h}(0) - \frac{\Delta_1(\zeta)(\Delta_1(\zeta) + 4\Delta_0(0))}{12(\Delta_1(\zeta) + \Delta_0(0))}, \\
&= (2-\zeta)\frac{h^2}{4c} + \zeta\rho - \frac{h^2-l^2}{4c}\frac{(1-\zeta)(5-\zeta)}{12(2-\zeta)}.
\end{aligned}
$$

Therefore, the centralized structure is optimal if and only if:

$$
\frac{(1-\zeta)(5-\zeta)}{12(2-\zeta)} \leq \frac{(1-\zeta)(1+\alpha^2(1-\zeta))}{3(1+\alpha(1-\zeta))^2}.
$$

After simple algebra, one finds that this is equivalent to:

$$
\zeta \geq \frac{1}{3-\zeta}.
$$

□

Appendix C Proof of Statements from Section 5.1

Proof of Proposition 5:

We already know that, for any values of ζ_0^C, ζ_1^C, and any message m, the principal will make a decision $d^C(m)$ given by:

$$d^C(m) = \beta^C(\zeta_1^C, \zeta_0^C)\mathbb{E}(\theta_1|m), \quad \text{where } \beta^C(\zeta_1^C, \zeta_0^C) = \frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C)}.$$

For the ease of the exposition, we omit the dependency of the β^C, Δ_1, Δ_0, π_{1h},π_{1l},π_{0h}, and π_{0l} functions in this proof. First, we show that the equilibrium communication must have an interval structure. In order to prove this, suppose that, for two distinct values of $\theta_a < \theta_b \in [-1, 1]$, the manager sends the message m, which induces $\mathbb{E}(\theta|m) = e_m$. Then our claim is that, in this communication equilibrium, for any $\theta_c \in (\theta_a, \theta_b)$, the manager sends the same message m. We proceed by contradiction. Suppose that the manager finds it strictly better to send another message m', which induce $\mathbb{E}(\theta|m') = e_{m'} \neq e_m$. This means that:

$$\begin{aligned} &\left(1 - (\theta_c - \beta^C e_{m'})^2\right)\pi_{1h} + (\theta_c - \beta^C e_{m'})^2 \pi_{1l} + \alpha\left\{\left(1 - (\theta_0 - \beta^C e_{m'})^2\right)\pi_{0h} + (\theta_0 - \beta^C e_{m'})^2 \pi_{0l}\right\} \\ > &\left(1 - (\theta_c - \beta^C e_m)^2\right)\pi_{1h} + (\theta_c - \beta^C e_m)^2 \pi_{1l} + \alpha\left\{\left(1 - (\theta_0 - \beta^C e_m)^2\right)(\zeta_0^C) + (\theta_0 - \beta^C e_m)^2 \pi_{0l}\right\}. \end{aligned}$$

Given that $\theta_0 = 0$ and $\Delta_i = \pi_{ih}(\zeta_i) - \pi_{il}(\zeta_i)$, for each $i \in \{1, 0\}$, this can be rewritten as:

$$\left((\theta_c - \beta^C e_m)^2 - (\theta_c - \beta^C e_{m'})^2\right)\Delta_1 + \alpha\left((\beta^C e_m)^2 - (\beta^C e_{m'})^2\right)\Delta_0 > 0,$$

or, equivalently:

$$-2\left(\beta^C e_m - \beta^C e_{m'}\right)\Delta_1\theta_c + \left((\beta^C e_m)^2 - (\beta^C e_{m'})^2\right) + \alpha\left((\beta^C e_m)^2 - (\beta^C e_{m'})^2\right)\Delta_0 > 0.$$

But if this is true, then this expression must also be true for at least one of θ_a and θ_b. This contradicts with our assumption that the manager sends the message m for both θ_a and θ_b.

Therefore, the equilibrium communication features a partition of the state space into sub-intervals. Let (ψ_{k+1}, ψ_k), and (ψ_k, ψ_{k-1}) be two consecutive intervals that appear in a communication equilibrium satisfying $0 < \psi_{k+1} < \psi_k < \psi_{k-1}$. In this equilibrium, the manager will be indifferent between sending two messages on the boundaries of these intervals. In other words, there exist messages (m_k, and

m_{k-1}) such that the information transmission strategy of the manager is as follows, for all k:

$$\sigma(\theta_1) = \begin{cases} m_{k-1} & \text{if } \theta_1 \in (\psi_k, \psi_{k-1}], \\ m_k & \text{if } \theta_1 \in (\psi_{k+1}, \psi_k]. \end{cases}$$

Since the state variable θ_1 follows a uniform distribution, the posterior belief of the principal, conditionally on receiving any message m_k, is that θ_1 is uniformly distributed between ψ_{k+1} and ψ_k. Therefore, the principal's decision is such that:

$$d^C(m) = \begin{cases} \beta^C \frac{\psi_k+\psi_{k-1}}{2} & \text{if } m = m_{k-1}, \\ \beta^C \frac{\psi_{k+1}+\psi_k}{2} & \text{if } m = m_k, \end{cases}$$

where $\beta^C = \frac{\Delta_1}{\Delta_1+\Delta_0}$ (Lemma 2).

Therefore, when $\theta_1 = \psi_k$, the expected utility of the manager from sending the message m_k is equal to the following expression, for any values of ζ_0^C, ζ_1^C:

$$(1-(\psi_k - d^C(m_k))^2)\pi_{1h} + (\psi_k - d^C(m_k))^2\pi_{1l} + \alpha\left((1-(d^C(m_k))^2)\pi_{0h} + (d^C(m_k))^2\pi_{0l}\right).$$

Similarly, his expected utility from sending message m_{k-1} is equal to:

$$(1-(\psi_k - d^C(m_{k-1}))^2)\pi_{1h} + (\psi_k - d^C(m_{k-1}))^2\pi_{1l} + \alpha\left((1-(d^C(m_{k-1}))^2)\pi_{0h} + (d^C(m_{k-1}))^2\pi_{0l}\right).$$

Then, the fact that the manager is indifferent between m_k and m_{k-1} when $\theta_1 = \psi_k$ translates into:

$$\left((\psi_k - d^C(m_k))^2 - (\psi_k - d^C(m_{k-1})^2\right)\Delta_1 = (d^C(m_{k-1})^2 - d^C(m_k)^2)\alpha\Delta_0.$$

By plugging the corresponding values of $d^C(m_k)$ and $d^C(m_{k-1})$, we obtain:

$$\left((\psi_k - \beta^C\frac{\psi_{k+1}+\psi_k}{2})^2 - (\psi_k - \beta^C\frac{\psi_k+\psi_{k-1}}{2})^2\right)\Delta_1 = \left((\beta^C\frac{\psi_k+\psi_{k-1}}{2})^2 - (\beta^C\frac{\psi_k+\psi_{k-1}}{2})^2\right)\alpha\Delta_0.$$

After some algebra, we obtain:

$$\left(\tfrac{(\beta^C)^2}{4}\left(\psi_{k+1}^2 - \psi_{k-1}^2\right) - \tfrac{\beta^C(2-\beta^C)}{2}\psi_k\left(\psi_{k+1}-\psi_{k-1}\right)\right)\Delta_1 = \alpha(\beta^C)^2\left(\frac{1}{4}\left(\psi_{k-1}^2 - \psi_{k+1}^2\right) + \tfrac{1}{2}\psi_k\left(\psi_{k-1}-\psi_{k+1}\right)\right)\Delta_0.$$

$$\left(\tfrac{(\beta^C)^2}{4}\left(\psi_{k+1}+\psi_{k-1}\right) - \tfrac{\beta^C(2-\beta^C)}{2}\psi_k\right)\Delta_1 = -\alpha(\beta^C)^2\left(\tfrac{1}{4}\left(\psi_{k-1}+\psi_{k+1}\right) + \frac{1}{2}\psi_k\right)\Delta_0.$$

$$\frac{\beta^C}{4}(\Delta_1+\alpha\Delta_0)\psi_{k+1} + \frac{1}{2}\left(\Delta_0\beta^C\alpha - \Delta_1(2-\beta^C)\right)\psi_k + \frac{\beta^C}{4}(\Delta_1+\alpha\Delta_0)\psi_{k-1} = 0.$$

Therefore, we reach the following difference equation governing the equilibrium communication.

$$\psi_{k+1} + \gamma\psi_k + \psi_{k-1} = 0,$$

where:

$$\gamma = 2\frac{\Delta_0\beta^C\alpha - \Delta_1(2-\beta^C)}{\beta^C(\Delta_1 + \alpha\Delta_0)}.$$

By using the fact that $\beta^C = \frac{\Delta_1}{\Delta_1+\Delta_0}$, we obtain:

$$\gamma = -\frac{2\Delta_1 + (4-2\alpha)\Delta_0}{\Delta_1 + \alpha\Delta_0}.$$

We impose the following initial condition: $\psi_1 = 1$. Since $\alpha < 1$, the characteristic polynomial of this difference equation has two real roots r_A and r_B satisfying:

$$r_A = \left(\frac{\Delta_1 + (2-\alpha)\Delta_0 - 2\sqrt{(1-\alpha)\Delta_0(\Delta_1+\Delta_0)}}{\Delta_1 + \alpha\Delta_0}\right) \in (0,1),$$
$$r_B = \left(\frac{\Delta_1 + (2-\alpha)\Delta_0 + 2\sqrt{(1-\alpha)\Delta_0(\Delta_1+\Delta_0)}}{\Delta_1 + \alpha\Delta_0}\right) > 1.$$

The general solution of the difference equation can be written as:

$$\psi_k = C_A r_A^{k-1} + C_B r_B^{k-1},$$

for some constant values $C_A, C_B \in \Re$. Then, by using the facts that $\psi_1 = 1$ and that $|\psi_k| \leq 1$ for all k, we can see that $C_A = 1$, and $C_B = 0$. Therefore:

$$\psi_k = \left(\frac{\Delta_1 + (2-\alpha)\Delta_0 - 2\sqrt{(1-\alpha)\Delta_0(\Delta_1+\Delta_0)}}{\Delta_1 + \alpha\Delta_0}\right)^{k-1}.$$

□

Proposition C.1. *The expected profit of the firm under centralized organization in the presence of communication is:*

$$\Pi^C\left(\zeta_1^C, \zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{(4-\alpha)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C) + (4-\alpha)\Delta_0(\zeta_0^C)\right]}. \tag{A2}$$

Proof of Proposition C.1.

For the ease of the exposition, we omit the dependency of the β^C, π_{1h}, π_{1l}, π_{0h}, π_{0l}, Δ_1 and Δ_0

functions in this proof.

As the distribution of θ_1 is symmetric around $\theta_0 = 0$, we can express the principal's expected payoff as follows:

$$\frac{\Pi^C\left(\zeta_1^C, \zeta_0^C\right)}{2} = \pi_{1h} \sum_{k=1}^{\infty} \int_{\psi_{k+1}}^{\psi_k} (1 - (\theta_1 - d^C(m_k))^2) \frac{d\theta_1}{2} + \pi_{1l} \sum_{k=1}^{\infty} \int_{\psi_{k+1}}^{\psi_k} (\theta_1 - d^C(m_k))^2 \frac{d\theta_1}{2}$$
$$+\pi_{0h} \sum_{k=1}^{\infty} \int_{\psi_{k+1}}^{\psi_k} (1 - (\theta_0 - d^C(m_k))^2) \frac{d\theta_1}{2} + \pi_{0l} \sum_{k=1}^{\infty} \int_{\psi_{k+1}}^{\psi_k} (\theta_0 - d^C(m_k))^2 \frac{d\theta_1}{2}.$$

Using the fact that $\theta_0 = 0$, we get:

$$\Pi^C\left(\zeta_1^C, \zeta_0^C\right) = \pi_{1h} + \pi_{0h} - \Delta_1 \sum_{k=1}^{\infty} \int_{\psi_{k+1}}^{\psi_k} (\theta_1 - d^C(m_k))^2 d\theta_1 - \Delta_0 \sum_{k=1}^{\infty} \int_{\psi_{k+1}}^{\psi_k} (d^C(m_k))^2 d\theta_1.$$

We develop this expression by using the values of $d^C(m_k) = \beta^C \frac{\psi_k + \psi_{k+1}}{2}$, and the fact that $\psi_k = r_1^{k-1}$, where r_1 is the first root of the second-order equation $r_1^2 - \gamma r_1 + 1 = 0$ (see proof of Proposition 5). We obtain:

$$\begin{aligned}
\int_{\psi_{k+1}}^{\psi_k} (\theta_1 - d^C(m_k))^2 d\theta_1 &= \int_{\psi_{k+1}}^{\psi_k} \left(\theta_1 - \beta^C \frac{r^{k-1} + r^k}{2}\right)^2 d\theta_1, \\
&= \int_{\psi_{k+1}}^{\psi_k} \left[\theta_1^2 - \beta^C \left(r^{k-1} + r^k\right) \theta_1 + \frac{(\beta^C)^2}{4} \left(r^{k-1} + r^k\right)^2\right] d\theta_1, \\
&= \frac{r^{3k-3} - r^{3k}}{3} - \frac{\beta^C}{2} \left(r^{k-1} + r^k\right) \left(r^{2k-2} - r^{2k}\right) + \frac{(\beta^C)^2}{4} \left(r^{k-1} + r^k\right)^2 \left(r^{k-1} - r^k\right), \\
&= \frac{(r_1^{3k-3} - r_1^{3k})(4 + 3(\beta^C)^2 - 6\beta^C) + (r_1^{3k-2} - r_1^{3k-1})(3(\beta^C)^2 - 6\beta^C C)}{12}.
\end{aligned}$$

Similarly:

$$\begin{aligned}
\int_{\psi_{k+1}}^{\psi_k} (d^C(m_k))^2 d\theta_1 &= \int_{\psi_{k+1}}^{\psi_k} \frac{(\beta^C)^2}{4} \left(r^{k-1} + r^k\right)^2 d\theta_1, \\
&= \frac{(\beta^C)^2}{4} \left(r^{k-1} + r^k\right)^2 \left(r^{k-1} - r^k\right), \\
&= \frac{(\beta^C)^2 (r_1^{3k-3} - r_1^{3k} + r_1^{3k-2} - r_1^{3k-1})}{4}.
\end{aligned}$$

Therefore, we obtain:

$$\Pi^C\left(\zeta_1^C,\zeta_0^C\right) = \pi_{1h}+\pi_{0h}-\Delta_1\sum_{k=1}^{\infty}\frac{(r_1^{3k-3}-r_1^{3k})(4+3(\beta^C)^2-6\beta^C)+(r_1^{3k-2}-r_1^{3k-1})(3(\beta^C)^2-6\beta^C)}{12}$$
$$-\Delta_0\sum_{k=1}^{\infty}\frac{(\beta^C)^2(r_1^{3k-3}-r_1^{3k}+r_1^{3k-2}-r_1^{3k-1})}{4}.$$

This yields, by developing the infinite sums and after some algebra:

$$\begin{aligned}
\Pi^C\left(\zeta_1^C,\zeta_0^C\right) &= \pi_{1h}+\pi_{0h}-\Delta_1\frac{(4+3(\beta^C)^2-6\beta^C)}{12}-\Delta_1\frac{3(\beta^C)^2-6\beta^C}{12}\frac{r_1}{1+r_1+r_1^2}-\Delta_0\frac{(\beta^C)^2}{4}\left(1+\frac{r_1}{1+r_1+r_1^2}\right),\\
&= \pi_{1h}+\pi_{0h}+\frac{1}{12}\frac{\Delta_1(\Delta_1+4\Delta_0)}{\Delta_1+\Delta_0}-\frac{1}{4}\frac{\Delta_1^2}{\Delta_1+\Delta_0}\frac{r_1}{1+r_1+r_1^2}\quad \text{because } \beta^C=\frac{\Delta_1}{\Delta_1+\Delta_0},\\
&= \pi_{1h}+\pi_{0h}-\frac{1}{12}\frac{\Delta_1(\Delta_1+4\Delta_0)}{\Delta_1+\Delta_0}+\frac{1}{4}\frac{\Delta_1^2}{\Delta_1+\Delta_0}\frac{\Delta_1+\alpha\Delta_0}{3\Delta_1+(4-\alpha)\Delta_0}\\
&\qquad\qquad \text{because } \frac{r_1}{1+r_1+r_1^2}=\frac{1}{\gamma+1}=\frac{\Delta_1+\alpha\Delta_0}{3\Delta_1+(4-\alpha)\Delta_0},\\
&= \pi_{1h}+\pi_{0h}-\frac{(4-\alpha)\Delta_1\Delta_0}{3(3\Delta_1+(4-\alpha)\Delta_0)}.
\end{aligned}$$

□

Proposition C.2. *The equilibrium automation deployment strategy of the principal under centralization in the presence of communication satisfies* $\zeta_1^C=\zeta$, *and* $\zeta_0^C=0$.

Proof of Proposition C.2.

Problem $\left(\mathcal{P}^C\right)$ is given by:

$$\max_{\zeta_1^C,\zeta_0^C}\quad \pi_{1h}(\zeta_1^C)+\pi_{0h}(\zeta_0^C)-\frac{(4-\alpha)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C)+(4-\alpha)\Delta_0(\zeta_0^C)\right]}, \text{s.t.}\quad \zeta_1^C+\zeta_0^C=\zeta,\qquad \zeta_1^C,\zeta_0^C\geq 0.$$

As before, we know from Equation (3) that $\pi_{1h}(\zeta_1^C)+\pi_{0h}(\zeta_0^C)$ is independent from how the overall automation capacity is allocated between the divisions. Therefore, Problem $\left(\mathcal{P}^C\right)$ boils down to the following:

$$\min_{\zeta_1^D,\zeta_0^D\in[0,1]}\ \frac{(4-\alpha)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C)+(4-\alpha)\Delta_0(\zeta_0^C)\right]},\qquad \text{s.t. }\ \zeta_1^D+\zeta_0^D=\zeta.$$

We define a function $h^C(\zeta_1)$ as follows:

$$h^C(\zeta_1)=\frac{(1-\zeta_1)(1-\zeta+\zeta_1)}{3(1-\zeta_1)+(4-\alpha)(1-\zeta+\zeta_1)}.$$

We show that h^C is a concave function of ζ_1. Using the same expressions for x and y that we defined earlier, we have, for all $\zeta_1 \in [0, \zeta]$:

$$\begin{aligned}(h^C)'(\zeta_1) &= \frac{(x-y)(3x+(4-\alpha)y)-(1-\alpha)xy}{(3x+(4-\alpha)y)^2},\\ (h^C)''(\zeta_1) &= -\frac{6(4-\alpha)(2-\zeta)^2}{(3x+(4-\alpha)y)^3} < 0.\end{aligned}$$

Therefore, h^C admits its minimum in $\zeta_1 = 0$ or $\zeta_1 = \zeta$. We have:

$$\begin{aligned}h^C(0) &= \frac{(4-\alpha)(1-\zeta)}{3(3+(4-\alpha)(1-\zeta))}\kappa,\\ h^C(\zeta) &= \frac{(4-\alpha)(1-\zeta)}{3(3(1-\zeta)+(4-\alpha))}\kappa.\end{aligned}$$

We obtain directly that $h^C(\zeta) \le h^C(0)$. This shows that $\zeta_1^C = \zeta$, and $\zeta_0^C = 0$ at the optimum. $\square$

Proof of Proposition 6

By using the result of Proposition 3, we can compute the equilibrium profit level under both organizational structures. We denote it by $\widehat{\Pi}^D$ under the decentralized structure and by $\widehat{\Pi}^C$ under the centralized structure.

Under the decentralized structure, we have $\zeta_1^D = 0$, and $\zeta_0^D = \zeta$. Therefore:

$$\begin{aligned}\widehat{\Pi}^D &= \pi_{1h}(0) + \pi_{0h}(\zeta_0) - \frac{\Delta_1(0)\Delta_0(\zeta)\left[\Delta_1(0) + \alpha^2\Delta_0(\zeta)\right]}{3\left[\Delta_1(0)+\alpha\Delta_0(\zeta)\right]^2},\\ &= (2-\zeta)\frac{h^2}{4c} + \zeta\rho - \frac{h^2-l^2}{4c}\frac{(1-\zeta)(1+\alpha^2(1-\zeta))}{3(1+\alpha(1-\zeta))^2}.\end{aligned}$$

Under the centralized structure, we have $\zeta_1^C = \zeta$, and $\zeta_0^C = 0$. Therefore:

$$\begin{aligned}\widehat{\Pi}^C &= \pi_{1h}(\zeta) + \pi_{0h}(0) - \frac{(4-\alpha)\Delta_1(\zeta)\Delta_0(0)}{3\left[3\Delta_1(\zeta)+(4-\alpha)\Delta_0(0)\right]},\\ &= (2-\zeta)\frac{h^2}{4c} + \zeta\rho - \frac{h^2-l^2}{4c}\frac{(4-\alpha)(1-\zeta)}{3(3(1-\zeta)+4-\alpha)}.\end{aligned}$$

Therefore, the centralized structure is optimal if and only if:

$$\frac{4-\alpha}{3(1-\zeta)+4-\alpha} \le \frac{1+\alpha^2(1-\zeta)}{(1+\alpha(1-\zeta))^2}.$$

After simple algebra, one finds that this is equivalent to the following expression, for any $\alpha < 1$:

$$\zeta \ge \frac{-5\alpha^2+8\alpha-3}{\alpha^2-\alpha^3}.$$

This simplifies into:

$$\zeta \geq \frac{5(\alpha - 0.6)}{\alpha^2}.$$

When $\alpha = 1$, one can easily verify that the inequality $\frac{4-\alpha}{3(1-\zeta)+4-\alpha} \leq \frac{1+\alpha^2(1-\zeta)}{(1+\alpha(1-\zeta))^2}$ is not satisfied, so the inequality $\zeta \geq \frac{5(\alpha-0.6)}{\alpha^2}$ also holds. $\square$

Appendix D Proof of Statements from Section 5.2

Below, Proposition D.1 states that, when τ is sufficiently large, Problems $\left(\mathcal{P}_\zeta^D\right)$ and $\left(\mathcal{P}_\zeta^C\right)$ both admit interior solutions, which are denoted by ζ_D^* and ζ_C^*, respectively, if and only if ρ is sufficiently large.

Proposition D.1. *There exists $\bar{\tau} \in \Re^+$ such that, for all $\tau \geq \bar{\tau}$, Problems $\left(\mathcal{P}_\zeta^D\right)$ and $\left(\mathcal{P}_\zeta^C\right)$ are concave in ζ. In this case, if $\rho > \bar{\rho}$, the solutions ζ_D^*, ζ_C^* satisfy:*

$$\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{1-(1-\zeta_D^*)(\alpha - 2\alpha^2)}{\left(1+\alpha(1-\zeta_D^*)\right)^3}\right) - 2\tau\zeta_D^* = 0 \tag{A3}$$

$$\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{(4-\alpha)^2}{\left(3(1-\zeta_C^*)+(4-\alpha)\right)^2}\right) - 2\tau\zeta_C^* = 0, \tag{A4}$$

where $\kappa = \frac{h^2-l^2}{4c}$ and $\bar{\rho} = \frac{11}{12}\frac{h^2}{4c} + \frac{1}{12}\frac{l^2}{4c}$. Otherwise, if $\rho \leq \bar{\rho}$ then $\zeta_D^* = \zeta_C^* = 0$.

Proposition D.1 shows that the firm adopts automation if the profit contribution of an automated task (ρ) is larger than a certain threshold ($\bar{\rho}$).[13] From the threshold, we can see that automation adoption is more likely when human effort is costly or when their output is low. Interestingly, this threshold is identical for firms with centralized vs. decentralized organizational structures. Moreover, as seen from Equations A3 and A4, the optimal level of automation capacity also depends on the residual conflict (α).

Proof of Proposition D.1.

The objective functions of Problems $\left(\mathcal{P}_\zeta^D\right)$ and $\left(\mathcal{P}_\zeta^C\right)$ are continuous, so they both admit a maximum over the compact interval $[0, 1]$. This establishes the existence of ζ_D^* and ζ_C^*.

We denote the objective function of Problems $\left(\mathcal{P}_\zeta^D\right)$ and $\left(\mathcal{P}_\zeta^C\right)$ by OBJ^D and OBJ^C respectively. We have, with $\kappa = \frac{h^2-l^2}{4c}$:

$$\frac{\partial OBJ^D}{\partial \zeta}$$

[13] This threshold is defined as a weighted average of the profit contribution of non-automated tasks under high productivity, $\frac{h^2}{4c}$, and under low productivity, $\frac{l^2}{4c}$.

$$
\begin{aligned}
&= \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{\left(1+2\alpha^2(1-\zeta)\right)\left(1+\alpha(1-\zeta)\right)^2 - 2\alpha\left(1+\alpha(1-\zeta)\right)(1-\zeta)\left(1+\alpha^2(1-\zeta)\right)}{\left(1+\alpha(1-\zeta)\right)^4}\right) - 2\tau\zeta \\
&= \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{1-(1-\zeta)(\alpha-2\alpha^2)}{\left(1+\alpha(1-\zeta)\right)^3}\right) - 2\tau\zeta \\
\frac{\partial^2 OBJ^D}{\partial\zeta^2} &= \frac{\kappa}{3}\left(\frac{(\alpha-2\alpha^2)(1+\alpha(1-\zeta)) + 3\alpha\left(1-(1-\zeta)(\alpha-2\alpha^2)\right)}{\left(1+\alpha(1-\zeta)\right)^4}\right) - 2\tau
\end{aligned}
$$

Notice that for τ sufficiently large, the second order derivative of OBJ^D with respect to ζ is negative. This shows that the OBJ^D is concave with respect to ζ when $\tau \geq \bar{\tau}_1^D$ for some $\bar{\tau}_1^D \in \Re^+$.

By defining $\bar{\rho} = \frac{11}{12}\frac{h^2}{4c} + \frac{1}{12}\frac{l^2}{4c}$, we show that the optimal solution ζ_D^* is interior if and only if $\rho > \bar{\rho}$. First, we have:

$$
\begin{aligned}
\left.\frac{\partial OBJ^D}{\partial\zeta}\right|_{\zeta=0} &= \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\underbrace{\frac{1-\alpha+2\alpha^2}{(1+\alpha)^3}}_{\geq\frac{1}{4}} \\
&\geq \rho - \frac{h^2}{4c} + \frac{1}{12}\frac{h^2-l^2}{4c} \\
&= \rho - \bar{\rho}
\end{aligned}
$$

Therefore,

$$
\text{For any } \rho > \bar{\rho},\ \left.\frac{\partial OBJ^D}{\partial\zeta}\right|_{\zeta=0} > 0.
$$

This proves that $\zeta_D^* > 0$. Second, there exists $\bar{\tau}_2^D \in \Re^+$ such that, when $\tau \geq \bar{\tau}_2^D$, $\frac{\partial OBJ^D}{\partial\zeta} < 0$ at $\zeta = 1$. Therefore, $\zeta_D^* \in (0,1)$ and satisfies the following first-order condition.

$$
\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{1-(1-\zeta_D^*)(\alpha-2\alpha^2)}{\left(1+\alpha(1-\zeta_D^*)\right)^3}\right) - 2\tau\zeta_D^* = 0 \tag{A5}
$$

This proves that $\zeta_D^* \in (0,1)$ if $\rho > \bar{\rho}$, and $\zeta_D^* = 0$ otherwise.

We proceed similarly for Problem $\left(\mathcal{P}_\zeta^C\right)$. We have:

$$
\begin{aligned}
\frac{\partial OBJ^C}{\partial\zeta} &= \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\frac{(4-\alpha)^2}{\left(3(1-\zeta)+(4-\alpha)\right)^2} - 2\tau\zeta \\
\frac{\partial^2 OBJ^C}{\partial\zeta^2} &= \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\frac{(4-\alpha)^2}{\left(3(1-\zeta)+(4-\alpha)\right)^2} - 2\tau\zeta
\end{aligned}
$$

As earlier, we have:

$$
\begin{aligned}
\left.\frac{\partial OBJ^C}{\partial \zeta}\right|_{\zeta=0} &= \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\underbrace{\frac{(4-\alpha)^2}{(7-\alpha)^2}}_{\geq \frac{1}{4}} \\
&\geq \rho - \frac{h^2}{4c} + \frac{1}{12}\frac{h^2-l^2}{4c} \\
&= \rho - \bar{\rho}
\end{aligned}
$$

Again, we obtain that:

$$
\text{For any } \rho \geq \bar{\rho}, \ \left.\frac{\partial OBJ^D}{\partial \zeta}\right|_{\zeta=0} > 0.
$$

Moreover, for τ sufficiently large, the second order derivative of OBJ^C with respect to ζ is negative. This shows that the OBJ^C is concave with respect to ζ when $\tau \geq \bar{\tau}_1^C$ for some $\bar{\tau}_1^C \in \Re^+$.

Moreover, $\frac{\partial OBJ^C}{\partial \zeta} > 0$ at $\zeta = 0$ and there exists $\bar{\tau}_2^C \in \Re^+$ such that, when $\tau \geq \bar{\tau}_2^C$, $\frac{\partial OBJ^D}{\partial \zeta} < 0$ at $\zeta = 1$. This proves that, $\zeta_C^* \in (0,1)$ and satisfies the following first-order condition.

$$
\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{(4-\alpha)^2}{\left(3(1-\zeta_C^*)+(4-\alpha)\right)^2}\right) - 2\tau\zeta_C^* = 0 \tag{A6}
$$

This again proves that $\zeta_D^* \in (0,1)$ if $\rho > \bar{\rho}$, and $\zeta_D^* = 0$ otherwise.

We complete the proof by setting $\bar{\tau} = \max\left\{\bar{\tau}_1^D, \bar{\tau}_2^D, \bar{\tau}_1^C, \bar{\tau}_2^C\right\}$. □

Proof of Proposition 7.

We already showed that the optimal solution ζ_D^* satisfies the following first-order condition:

$$
t^D(\alpha, \zeta_D^*) = \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{1-(1-\zeta_D^*)(\alpha-2\alpha^2)}{\left(1+\alpha(1-\zeta_D^*)\right)^3}\right) - 2\tau\zeta_D^* = 0,
$$

We already know that:

$$
\frac{\partial t^D(\alpha,\zeta_D^*)}{\partial \zeta} = \frac{\kappa}{3}\left(\frac{(\alpha-2\alpha^2)(1+\alpha(1-\zeta)) + 3\alpha\left(1-(1-\zeta)(\alpha-2\alpha^2)\right)}{\left(1+\alpha(1-\zeta)\right)^4}\right) - 2\tau < 0
$$

Moreover, we have:

$$
\frac{\partial t^D(\alpha,\zeta_D^*)}{\partial \alpha} = -\frac{\kappa}{3}(1-\zeta)(1-\alpha)\left(\frac{4-2\alpha(1-\zeta)}{\left(1+\alpha(1-\zeta)\right)^4}\right) < 0
$$

Then by using the implicit function theorem we know that:

$$\frac{\partial \zeta_D^*}{\partial \alpha} = -\frac{\frac{\partial t^D(\alpha,\zeta_D^*)}{\partial \alpha}}{\frac{\partial t^D(\alpha,\zeta_D^*)}{\partial \zeta}} < 0.$$

This shows that ζ_D^* is a decreasing function of α.

Following the same logic, we know that ζ_C^* satisfies the following first-order condition:

$$t^C(\alpha, \zeta_C^*) = \rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{(4-\alpha)^2}{\left(3(1-\zeta_C^*) + (4-\alpha)\right)^2}\right) - 2\tau\zeta_C^* = 0$$

Therefore, we get:

$$\frac{\partial t^C(\alpha, \zeta_C^*)}{\partial \zeta} = \frac{\kappa}{3}\left(\frac{6(4-\alpha)^2}{(3(1-\zeta) + (4-\alpha))^3}\right) - 2\tau < 0$$

Moreover we have

$$\begin{aligned}
\frac{\partial s(\alpha, \zeta_C^*)}{\partial \alpha} &= \frac{\kappa}{3}\left(\frac{-2(4-\alpha)\left(3(1-\zeta) + (4-\alpha)\right)^2 + 2\left(3(1-\zeta) + (4-\alpha)\right)(4-\alpha)^2}{(3(1-\zeta) + (4-\alpha))^4}\right) \\
&= \frac{\kappa}{3}\frac{-6(4-\alpha)(1-\zeta)}{(3(1-\zeta) + (4-\alpha))^3} < 0
\end{aligned}$$

Then by using the implicit function theorem we know that:

$$\frac{\partial \zeta_C^*}{\partial \alpha} = -\frac{\frac{\partial t^C(\alpha,\zeta_D^*)}{\partial \alpha}}{\frac{\partial t^C(\alpha,\zeta_D^*)}{\partial \zeta}} < 0.$$

This shows that ζ_C^* is a decreasing function of α. $\square$

Appendix E Proof of Statements from Section 5.3

First, consider the implications of various values of λ. A value of $\lambda = 1$ suggests a one-to-one transfer from the principal to the manager. A value of $\lambda > 1$ reflects additional fixed costs of setting up a contract. A value of $\lambda < 1$ may also be reasonable in the presence of managerial moral hazard.

To see why $\lambda < 1$ may hold, consider the example where the manager's contract prior to any further alignment is linear and of the form $\alpha_1\Pi_1 + \alpha_0\Pi_0$. Thus, α in the manager's initial payoff (as expressed on page 6) can be considered as a relative weight satisfying $\alpha = \frac{\alpha_0}{\alpha_1} < 1$. The reason to offer such a contract may be, for instance, to induce managerial effort (which is not explicitly modeled in our paper). Then, to increase α by some $\delta > 0$, the principal needs to increase α_0 in the above-mentioned linear contract by $\alpha_1\delta$—so that the relative weight of Division 0's profit in manager's payoff becomes $\frac{\alpha_0+\alpha_1\delta}{\alpha_1} = \alpha+\delta$. In this case $\lambda = \alpha_1$, and therefore, an alignment by δ may translate into a $\lambda\delta$ cost for the principal. Then we can interpret the parameter λ as the scale of managerial moral hazard problem. As λ increases, the principal is less likely to use a contract.

Next, we characterize the principal's payoff under each organizational structure, for given values of $\lambda > 0$, and $\delta \in [0, \bar{\delta}]$, in Proposition E.1, and then prove it. Then we proceed to the proof of Proposition 8 presented in Section 5.3.

Proposition E.1. *For given choices of $\delta \in [0, \bar{\delta}]$, ζ_1 and ζ_0 the principal's expected payoffs under decentralization and centralization become, respectively:*

$$\mathcal{V}^D\left(\delta^D, \zeta_1^D, \zeta_0^D\right) = \pi_{1h}(\zeta_1^D) + (1-\lambda\delta^D)\pi_{0h}(\zeta_0^D) - \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[(1-\lambda\delta^D)\Delta_1(\zeta_1^D) + (\alpha+\delta^D)^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + (\alpha+\delta^D)\Delta_0(\zeta_0^D)\right]^2}, \tag{A7}$$

$$\mathcal{V}^C\left(\delta^C, \zeta_1^C, \zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + (1-\lambda\delta^C)\pi_{0h}(\zeta_0^C) - \frac{\left(4(1-\lambda\delta^C) - \left(\alpha+\delta^C\right)\right)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C) + \left(4(1-\lambda\delta^C) - (\alpha+\delta^C)\right)\Delta_0(\zeta_0^C)\right]}. \tag{A8}$$

Proof of Proposition E.1.

Under Decentralization we have:

$$\begin{aligned}\mathcal{V}^D(\zeta_1^D, \zeta_0^D) &= \pi_{1h}(\zeta_1^D) + (1-\lambda\delta)\pi_{0h}(\zeta_0^D) \\ &\quad - \frac{(1-\beta^D(\zeta_1^D, \zeta_0^D))^2}{3}\Delta_1(\zeta_1, w) - (1-\lambda\delta)\frac{(\beta^D(\zeta_1^D, \zeta_0^D))^2}{3}\Delta_0(\zeta_0^D, w).\end{aligned}$$

Then the fact that $\beta^D(\zeta_1^D, \zeta_0^D) = \frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D)+(\alpha+\delta)\Delta_0(\zeta_0^D)}$ gives the expression in Equation A7.

Under centralization, following the same steps with the proof of Proposition 5, one can see that the equilibrium communication partitions the state space Θ into infinitely many intervals, boundaries of which are characterized by $\psi_k = r^k$, where

$$r = \frac{\Delta_1(\zeta_1^C) + \left(2(1-\lambda\delta) - (\alpha+\delta)\right)\Delta_0(\zeta_0^C) - 2\sqrt{\left((1-\lambda\delta) - (\alpha+\delta)\right)\Delta_0(\zeta_0^C)\left(\Delta_1(\zeta_1^C) + (1-\lambda\delta)\Delta_0(\zeta_0^C)\right)}}{\Delta_1(\zeta_1^C) + (\alpha+\delta)\Delta_0(\zeta_0^C)}.$$

Moreover, the principal's expected payoff is

$$\mathcal{V}\left(\zeta_1^C, \zeta_0^C\right) = \pi_{1h} + (1-\lambda\delta)\pi_{0h} - \Delta_1\sum_{k=1}^{\infty}\int_{\psi_{k+1}}^{\psi_k}(\theta_1 - d^C(m_k))^2 d\theta_1 - (1-\lambda\delta)\Delta_0\sum_{k=1}^{\infty}\int_{\psi_{k+1}}^{\psi_k}(d^C(m_k))^2 d\theta_1.$$

We develop this expression by using the values of $d^C(m_k) = \beta^C \frac{\psi_k+\psi_{k+1}}{2}$, and the fact that $\psi_k = r^{k-1}$:

$$\begin{aligned}
\int_{\psi_{k+1}}^{\psi_k} (\theta_1 - d^C(m_k))^2 d\theta_1 &= \int_{\psi_{k+1}}^{\psi_k} \left(\theta_1 - \beta^C \frac{r^{k-1}+r^k}{2}\right)^2 d\theta_1, \\
&= \int_{\psi_{k+1}}^{\psi_k} \left[\theta_1^2 - \beta^C \left(r^{k-1}+r^k\right)\theta_1 + \frac{(\beta^C)^2}{4}\left(r^{k-1}+r^k\right)^2\right] d\theta_1, \\
&= \frac{r^{3k-3}-r^{3k}}{3} - \frac{\beta^C}{2}\left(r^{k-1}+r^k\right)\left(r^{2k-2}-r^{2k}\right) + \frac{(\beta^C)^2}{4}\left(r^{k-1}+r^k\right)^2\left(r^{k-1}-r^k\right), \\
&= \frac{(r^{3k-3}-r^{3k})(4+3(\beta^C)^2-6\beta^C) + (r^{3k-2}-r^{3k-1})(3(\beta^C)^2-6\beta^C)}{12}.
\end{aligned}$$

Similarly:

$$\begin{aligned}
\int_{\psi_{k+1}}^{\psi_k} (d^C(m_k))^2 d\theta_1 &= \int_{\psi_{k+1}}^{\psi_k} \frac{(\beta^C)^2}{4}\left(r^{k-1}+r^k\right)^2 d\theta_1, \\
&= \frac{(\beta^C)^2}{4}\left(r^{k-1}+r^k\right)^2\left(r^{k-1}-r^k\right), \\
&= \frac{(\beta^C)^2(r^{3k-3}-r^{3k}+r^{3k-2}-r^{3k-1})}{4}.
\end{aligned}$$

Therefore, we obtain:

$$\begin{aligned}
\mathcal{V}\left(\zeta_1^C, \zeta_0^C\right) &= \pi_{1h} + (1-\lambda\delta)\pi_{0h} \\
&\quad - \Delta_1 \sum_{k=1}^{\infty} \frac{(r^{3k-3}-r^{3k})(4+3(\beta^C)^2-6\beta^C) + (r^{3k-2}-r^{3k-1})(3(\beta^C)^2-6\beta^C)}{12} \\
&\quad - (1-\lambda\delta)\Delta_0 \sum_{k=1}^{\infty} \frac{(\beta^C)^2(r^{3k-3}-r^{3k}+r^{3k-2}-r^{3k-1})}{4}.
\end{aligned}$$

This yields, by developing the infinite sums and after some algebra:

$$\begin{aligned}
\mathcal{V}\left(\zeta_1^C, \zeta_0^C\right) &= \pi_{1h} + (1-\lambda\delta)\pi_{0h} - \Delta_1\frac{1}{3} - \Delta_1\frac{(\beta^C)^2-2\beta^C}{4}\frac{(1+r)^2}{1+r+r^2} - (1-\lambda\delta)\Delta_0\frac{(\beta^C)^2}{4}\frac{(1+r)^2}{1+r+r^2}, \\
&= \pi_{1h} + (1-\lambda\delta)\pi_{0h} - \Delta_1\frac{1}{3} + \frac{\Delta_1^2}{4(\Delta_1+(1-\lambda\delta)\Delta_0)}\frac{(1+r)^2}{1+r+r^2}, \text{ since } \beta^C = \frac{\Delta_1}{\Delta_1+(1-\lambda\delta)\Delta_0}.
\end{aligned}$$

Then, since $r = \frac{\Delta_1(\zeta_1^C)+(2(1-\lambda\delta)-(\alpha+\delta))\Delta_0(\zeta_0^C)-2\sqrt{((1-\lambda\delta)-(\alpha+\delta))\Delta_0(\zeta_0^C)\left(\Delta_1(\zeta_1^C)+(1-\lambda\delta)\Delta_0(\zeta_0^C)\right)}}{\Delta_1(\zeta_1^C)+(\alpha+\delta)\Delta_0(\zeta_0^C)}$ we get:

$$\mathcal{V}^C\left(\zeta_1^C, \zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + (1-\lambda\delta)\pi_{0h}(\zeta_0^C) - \frac{\left(4(1-\lambda\delta)-(\alpha+\delta)\right)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C) + \left(4(1-\lambda\delta)-(\alpha+\delta)\right)\Delta_0(\zeta_0^C)\right]}.$$

Proof of Proposition 8.

Under Decentralization: The optimal degree of further alignment follows:

$$\delta^D = \arg\max_{\delta} \quad \pi_{1h}(\zeta_1^D) + (1-\lambda\delta)\pi_{0h}(\zeta_0^D) - \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[(1-\lambda\delta)\Delta_1(\zeta_1^D) + (\alpha+\delta)^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + (\alpha+\delta)\Delta_0(\zeta_0^D)\right]^2}.$$

Taking the derivative of the objective function with respect to δ, and by suppressing the arguments in the notations of π_{0h}, Δ_0 and Δ_1, we get:

$$\begin{aligned}
&\frac{\partial \mathcal{V}^D\left(\delta, \zeta_1^D, \zeta_0^D\right)}{\partial \delta} \\
&= -\lambda\pi_{0h} - \frac{\Delta_1\Delta_0}{3}\frac{\left[-\lambda\Delta_1 + 2(\alpha+\delta)\Delta_0\right]\left[\Delta_1 + (\alpha+\delta)\Delta_0\right] - 2\Delta_0\left[(1-\lambda\delta)\Delta_1 + (\alpha+\delta)^2\Delta_0\right]}{\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3} \\
&= -\lambda\pi_{0h} + \frac{\Delta_1\Delta_0}{3}\left[\frac{\lambda\Delta_1^2 + \Delta_0\Delta_1\left[2(1-(\alpha+\delta)) + \lambda(\alpha-\delta)\right]}{\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3}\right] \\
&= -\lambda\underbrace{\left[\pi_{0h} - \frac{\Delta_0\Delta_1^2\left[\Delta_1 + (\alpha-\delta)\Delta_0\right]}{3\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3}\right]}_{>0} + \frac{2\left[1-(\alpha+\delta)\right]\Delta_0^2\Delta_1^2}{3\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3} \qquad \text{(A9)}
\end{aligned}$$

Since $\pi_{oh}(\zeta_0^D) = (1-\zeta_0^D)\frac{h^2}{4c} + \zeta_0^D\rho$, $\Delta_0 = (1-\zeta_0^D)\frac{h^2-l^2}{4c}$, $\Delta_1 = (1-\zeta_1^D)\frac{h^2-l^2}{4c}$, we have $\pi_{0h} > \Delta_0$, and $\pi_{0h} > \Delta_1$. Therefore, the first term in Equation (A9) is negative. This implies that when λ is large enough, the partial derivative $\frac{\mathcal{V}^D(\delta,\zeta_1^D,\zeta_0^D)}{\partial\delta}$ is negative regardless the choice of δ. Hence there is a threshold $\bar{\lambda}^D$ such that whenever $\lambda \geq \bar{\lambda}^D$, we have $\delta^D = 0$.

Moreover, at $\delta = \bar{\delta} = \frac{1-\alpha}{1+\lambda}$, we have $1-\lambda\delta = \alpha+\delta = \frac{1+\alpha\lambda}{1+\lambda}$. Then, by denoting $M = \frac{1+\alpha\lambda}{1+\lambda}$, we get:

$$\frac{\partial \mathcal{V}^D\left(\delta, \zeta_1^D, \zeta_0^D\right)}{\partial \delta}\bigg|_{\delta=\bar{\delta}} = \lambda\left(-\pi_{0h} + \frac{\Delta_1^2\Delta_0}{3(\Delta_1 + M\Delta_0)^2}\right) \qquad \text{(A10)}$$

It is clear to see that, $\frac{\partial\mathcal{V}^D(\delta,\zeta_1^D,\zeta_0^D)}{\partial\delta} < 0$ at $\delta = \bar{\delta}$ regardless the value of λ. Therefore, in a decentralized organization, $\delta < \bar{\delta}$ always holds, and it is never optimal to fully eliminate the conflict.

Finally, we show that δ^D strictly decreases as λ increases over the region $(0, \bar{\lambda}^C$. To this end we will use the implicit function theorem. It is clear from Equation (A9) that $\frac{\partial^2\mathcal{V}^D(\delta,\zeta_1^D,\zeta_0^D)}{\partial\delta^2} < 0$ and hence that $\mathcal{V}^D\left(\delta, \zeta_1^D, \zeta_0^D\right)$ is a concave function of δ^D. Therefore the optimal value of δ^D satisfies the FOC:

$$\lambda\left[\pi_{0h} - \frac{\Delta_0\Delta_1^2\left[\Delta_1 + (\alpha-\delta)\Delta_0\right]}{3\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3}\right] + \frac{2\left[1-(\alpha+\delta)\right]\Delta_0^2\Delta_1^2}{3\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3} = 0.$$

Then we know that $\frac{\partial\delta}{\partial\lambda} = -\frac{\frac{\partial \text{FOC}}{\partial\lambda}}{\frac{\partial \text{FOC}}{\partial\delta^D}} < 0$ since $\frac{\partial\text{FOC}}{\partial\lambda} < 0$ and $\frac{\partial\text{FOC}}{\partial\delta^D} < 0$.

Under Centralization: The principal's problem to optimize the choice of monetary incentives to further align the manager's preferences with her own in a centralized organization is:

$$\delta^C = \arg\max_{\delta} \quad \pi_{1h}(\zeta_1^C) + (1-\lambda\delta)\pi_{0h}(\zeta_0^C) - \frac{(4(1-\lambda\delta)-(\alpha+\delta))\,\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C)+(4(1-\lambda\delta)-(\alpha+\delta))\,\Delta_0(\zeta_0^C)\right]}.$$

We now complete the proof in a number of steps.

<u>Step 1.</u> We will first show that the objective function of the problem above is a convex function of δ. To see this, note that the partial derivative of the objective function with respect to δ, by suppressing the arguments in the notations of π_{0h}, Δ_0 and Δ_1, satisfies:

$$\frac{\partial \mathcal{V}^C\left(\delta,\zeta_1^C,\zeta_0^C\right)}{\partial\delta} = -\lambda\pi_{0h} + \frac{\Delta_1^2\Delta_0(4\lambda+1)}{\left[3\Delta_1+(4(1-\lambda\delta)-(\alpha+\delta))\,\Delta_0\right]^2} \tag{A11}$$

From this expression it is clear to see that the first order derivative is an increasing function of δ and hence the second order derivative derivative is positive. This proves that the objective function is a convex function of δ.

<u>Step 2.</u> The principal either (i) fully eliminates the residual conflict by setting $\delta^C = \bar{\delta}$, or (ii) does not use monetary incentives at all by setting $\delta^C = 0$. This is a direct consequence of the convexity.

<u>Step 3.</u> Now we show that the optimal automation deployment strategy remains as in the baseline setting regardless of whether the principal chooses $\delta^C = \bar{\delta}$ or $\delta^C = 0$. That is the principal allocates the entire automation capacity to Division 1. This is straightforward if principal chooses $\delta^C = 0$ as everything is identical with the baseline setting. Therefore, we need to focus on the case where the principal fully eliminates the residual conflict by choosing $\delta^C = \bar{\delta}$

Suppose that the principal sets $\delta^C = \bar{\delta}$ so that $1-\lambda\delta^C = \alpha+\delta^C = A$. Then the principal's payoff is

$$\pi_{1h}(\zeta_1^C) + A\pi_{0h}(\zeta_0^C) - \frac{3A\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{9\left[\Delta_1(\zeta_1^C)+A\Delta_0(\zeta_0^C)\right]}.$$

Then, in this case, the optimal automation deployment strategy satisfies:

$$\max_{\zeta_1^C,\zeta_0^C} \quad \pi_{1h}(\zeta_1^C) + A\pi_{0h}(\zeta_0^C) - \frac{3A\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{9\left[\Delta_1(\zeta_1^C)+A\Delta_0(\zeta_0^C)\right]}, \text{s.t.} \quad \zeta_1^C+\zeta_0^C=\zeta, \qquad \zeta_1^C,\zeta_0^C\geq 0.$$

Using the expressions for π_{1h}, π_{0h}, Δ_1, and Δ_0 (Equations (3) and (4)), we can rewrite this problem as:

$$\max_{\zeta_1\in[0,\zeta]} (1-\zeta_1)\frac{h^2}{4c} + \zeta_1\rho + A\left[(1-\zeta+\zeta_1)\frac{h^2}{4c}+(\zeta-\zeta_1)\rho\right] - \frac{3A\kappa^2(1-\zeta_1)(1-\zeta+\zeta_1)}{9\kappa\left[(1-\zeta_1)+A(1-\zeta+\zeta_1)\right]}.$$

Taking the second order derivative of the objective function with respect too ζ_1 immediately shows us that the it is a convex function of ζ_1. Therefore, it admits its maximum in $\zeta_1 = 0$ or $\zeta_1 = \zeta$. We have:

$$\text{Objective}\Big|_{\zeta_1=0} = \frac{h^2}{4c} + A\left[(1-\zeta)\frac{h^2}{4c} + \zeta\rho\right] - \frac{3A\kappa^2(1-\zeta)}{9\kappa\left[1 + A(1-\zeta)\right]}$$
$$\text{Objective}\Big|_{\zeta_1=\zeta} = (1-\zeta)\frac{h^2}{4c} + \zeta\rho + A\frac{h^2}{4c} - \frac{3A\kappa^2(1-\zeta)}{9\kappa\left[(1-\zeta) + A\right]}$$

After some algebra, we obtain directly that $\text{Objective}\big|_{\zeta_1=0} < \text{Objective}\big|_{\zeta_1=\zeta}$. This shows that $\zeta_1^C = \zeta$, and $\zeta_0^C = 0$ at the optimum.

Step 4. This step establishes the existence of $\bar{\lambda}^C$. From the previous steps we simply need to compare two payoffs that arise under $\delta^C = 0$ and $\delta^C = \bar{\delta} = \frac{1-\alpha}{1+\lambda}$. In both cases $\Delta_1 = (1-\zeta)\kappa$ and $\Delta_0 = \kappa$, $\pi_{1h} = (1-\zeta)\frac{h^2}{4c} + \zeta\rho$, and $\pi_{0h} = \frac{h^2}{4c}$.

- If principal chooses $\delta^C = \bar{\delta}$, her payoff will be:

$$(1-\zeta)\frac{h^2}{4c} + \zeta\rho + A\frac{h^2}{4c} - \frac{3A\kappa^2(1-\zeta)}{9\kappa\left[(1-\zeta) + A\right]}, \text{ where } A = \frac{1+\lambda\alpha}{1+\lambda}.$$

- If principal chooses $\delta^C = 0$, her payoff will be:

$$(1-\zeta)\frac{h^2}{4c} + \zeta\rho + \frac{h^2}{4c} - \frac{(4-\alpha)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C) + (4-\alpha)\Delta_0(\zeta_0^C)\right]}.$$

It is clear that, the first payoff is a decreasing function of λ while the second one does not depend on λ. This establishes the existence of $\bar{\lambda}^C$. $\square$

Last, we illustrate how do δ^D and δ^C depend on the conflict (α) for a given value of λ and automation capacity (ζ) in Figure A1. As conflict increases (lower α), the principal allocates a higher share of Division 0's profit for further alignment (higher δ).

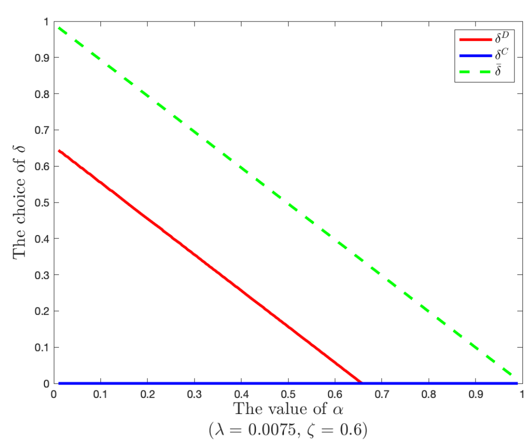

Figure A1: The dependency of δ^D, δ^C on α.