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Strategic Automation and Decision-making Authority

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Abstract

This paper studies adoption and utilization of automation within firms of different organizational structures. We develop a theoretical model of organizational design with embedded cheap-talk. Specifically, we study a firm with a principal and two divisional managers, where production tasks can be automated in each division. Our findings show that there exists heterogeneity among firms in how they utilize automation based on their organizational structure. In specific, while more centralized firms may automate divisions facing higher risk and uncertainty, more decentralized firms choose to do the opposite. Moreover, as the overall automation capacity increases, firms follow distinctly different strategies to adapt to changing market conditions. With higher automation capacity, a firm is more likely to centralize decision making at the top, rather than having a decentralized decision-making structure. This suggests that, the structure of firms and the role of managers may change as well, altering the allocation of decision-making rights within organizations. In consequence, as firms automate more and more tasks, mid-level managers become more focused on day-to-day operations and less involved in strategic decision-making on behalf of the firm. Finally, the paper shows that automation can be a strategic substitute to monetary contracts.

Keywords: *Automation, Decision Making, Organizational Structure*

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1 Introduction

Understanding the drivers of new product diffusion and technology adoption is a long-standing research area in marketing (e.g., Manchanda et al., 2008; Iyengar et al., 2011; Aral and Walker, 2011) and economics (Atkin et al., 2017). Today, at the center of this research area lies adoption of automation technologies. Owing to the growth in computing power and big data (Raisch and Krakowski, 2021; McAfee and Brynjolfsson, 2017), the scope of automation has grown to include tasks ranging from automated checkout (Schögel and Lienhard, 2020), robotic warehousing (Azadeh et al., 2019), shelf replenishment (Van Donselaar et al., 2010), pricing (Karlinsky-Shichor and Netzer, 2019), digital content selection (Westcott Grant, 2018), drug discovery (Fleming, 2018) to recruitment of talent (Marr, 2018). This growth, however, does not apply to all firms uniformly (Atkin et al., 2017). Overall investment in automation and deployment of automation capacity varies vastly across firms. Some firms invest heavily in automation, others very little; some firms automate repetitive tasks, others automate tasks that need judgement and reasoning. What characteristics of a firm drive these differences? Are there antecedents of a firm's technology adoption and utilization that are rooted in the way it is organized?

In this paper, we explain the observed heterogeneity among firms' adoption and usage of automated technologies focusing on one particular perspective: organizational structure and conflict within a firm. Industry experts agree that the impact of automation goes beyond merely enhancing productivity or reducing costs of production to result in more profound changes in organizations (De Smet et al., 2017). Our study complements this point of view by jointly studying managerial decision-making and automation. Specifically, we address two novel questions: (i) how does conflict within organizations influence their desire to adopt automation and the way they use automation; and (ii) how do automation strategies in turn impact the organizational dynamics and the allocation of decision-making structure?

To study automation and conflict, we leverage the principal-agent literature.[1] We develop a theoretical model of a firm that has two divisions and is ruled by a principal (e.g., a top-level executive). There is also a manager (e.g., a mid-level executive) running one of the divisions—the "forefront division" facing uncertain operational conditions. The other division is the "business-as-usual division" facing commonly known stable conditions. The principal needs to make a firm-level decision that requires weighting the considerations of both divisions and accounting for the uncertainty associated with the operating conditions

[1] In this literature, two ingredients are necessary to create a conflict between the principal and the agent. First, the principal and agent have partially misaligned preferences. Second, the principal relies on the agent for an output of the firm. This reliance can be due to a hidden effort or private information held by the agent. We assume the latter.

of the forefront division, which is only privately observed by the manager. This information asymmetry, together with misaligned preferences of the principal and the manager, create a conflict within the firm.[2]

We formalize the problem as an extensive-form game with embedded cheap talk communication (Crawford and Sobel, 1982). In this setting, the principal (she) first allocates decision-making rights by choosing an organizational structure between (i) *centralization*, in which the principal makes the firm-level decision based on the communication from the manager (he), or (ii) *decentralization*, in which the principal delegates decision-making to the manager. She then determines which tasks to automate across the two divisions. We first focus on automation deployment, assuming that the firm is endowed with an exogenous automation capacity; we then endogenize the overall level of automation capacity within the firm. The subsequent stages of the game define the resulting communication and decision-making dynamics between the principal and the manager. We solve for the Perfect Bayesian Equilibrium under the centralized and decentralized organizational structures.

The way we introduce automation into our model is based on its common definitions. Specifically, automation is defined as the machine execution of a task that was previously, or could be, carried out by a human (Parasuraman and Riley, 1997). While automation impacts the tasks within a process in hordes of ways, we focus on two key outcomes highlighted by the International Society of Automation (ISA)[3]. First, automation impacts operational *efficiency*—it can increase efficiency by reducing the time to execute a task, waste, and costs. Second, automation aids in repeating tasks consistently, and thereby reduces *variability* (Alford, 2010; McKinsey & Co., 2017). Specifically, automation reduces reliance on skill, experience, and availability of human operators (Archer, 2012), and thus improves Just In Time manufacturing, Total Quality Management, and Six Sigma manufacturing—the three main levers to reduce variability in operations. Similar effects are observed in health care, where automation reduces treatment variability (Kamphuis et al., 2018), and in transportation where automation ensures strict adherence to planned trajectories (Hansen et al., 2009). The first effect of automation—on efficiency—has been well-documented. In contrast, the

[2]Common examples of conflict in marketing are between marketing and other firm divisions such as marketing and sales (Homburg and Jensen, 2007) and marketing and manufacturing (Balasubramanian and Bhardwaj, 2004). Homburg and Jensen (2007) states that the Marketing Science Institute reports conflict as an important concern for marketing managers. Song et al. (2000) write for product development activities that "this knowledge-creating process inherently competes with the firmâs status quo," "producing conflict stemming from general discomfort with change, vested political interests, organizational inertia, and the ownership of ideas. This conflict and the ways to manage it may be affected by several other complex variables, especially if companies and their personnel span multiple cultures. Managers must direct cross-functional tension and conflict skillfully."

[3]ISA is a leading organization founded in 1945 for setting the standards of automation and studying its impact.

second effect—on variability—has received little attention in the literature; and this paper shows that it has important strategic and organizational implications.

Key Findings

Our paper offers a number of important insights to explain the observed differences across firms' utilization of automated technologies. First, we find that 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. As a result of this difference, decentralized and centralized firms adapt to the uncertain or changing operational conditions of a market at different rates: decentralized firms are more 'agile' whereas centralized firms are more 'stale' in adapting to them. This difference increases with firms' automation capacity: as firms' have more and more resources for automation, decentralized firms become increasingly 'agile' and centralized firms become increasingly 'stale'. To the extent that the forefront division houses high-skilled tasks that require judgement and reasoning and the business-as-usual division houses low-skilled, repetitive tasks, automating the former or the latter has implications for displacement of labor of heterogeneous skill levels. This finding suggests that the conventional thinking which assumes automation will displace low-skilled labor may not hold for all firms.

Second, the organizational structure and automation capacity jointly determine the degree of alignment between the manager and the principal within the firm. Interestingly, the impact of automation is not uniform across firms, but depends on the organizational structure. In decentralized firms, higher automation capacity increases the degree of alignment in decision-making. In centralized firms, in contrast, higher automation increases polarization within the firm, leading to less informative communication (reporting) by the managers.

Third, we uncover that increasing automation capacity favors centralization and reinforces the decision-making authority at the top of organizations. This finding is somewhat counter-intuitive since technology has traditionally been considered as a driving force for less hierarchical and more decentralized organizations (Acemoglu et al., 2007). Our findings, therefore, propose a new perspective to the existing literature. These findings do not suggest that vertical hierarchies in firms will disappear; nevertheless, strategic deployment of automation may reduce the strategic role of the managers and re-appropriate them to more operational tasks. Importantly, this reduced decision-making authority of the manager does *not* stem from the automation of the manager's duties, but rather from the automation of low-level tasks within his division. Stated differently, the impact of automation can trickle up in an organizational hierarchy.

Fourth, 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. Ultimately, a firm's decision to adopt automation technologies should rely not only on its benefits in terms of productivity and cost, but also on its benefits in terms of management of the conflict within the firm.

Contributions

Our study contributes to three strands of literature in marketing, economics, management, and organizational science. 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 (Simon, 1951; Cyert et al., 1963; Little, 1970; Sah and Stiglitz, 1991; Felli and Villas-Boas, 2000). These problems are jointly formalized as a trade-off between unbiased (but less informed) centralized decision-making vs. informed (but biased) decentralized decision-making in the literature (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; Yilmaz and Chakraborty, 2017).

Despite high interest from other fields, studies on organizational structure and decision-making and conflict are sorely missing in marketing literature (Anderson and Schmittlein, 1984; Song et al., 2000). To our knowledge, few studies focused on organizational structure and communication between the ranks of an organization in marketing (e.g., Bennett and Savani, 2004; Menon et al., 1996; Balasubramanian and Bhardwaj, 2004; Maltz and Kohli, 2000). Balasubramanian and Bhardwaj (2004), for instance, study the conflict between manufacturing and marketing managers and consider a centralization-decentralization choice in the context of quality and pricing decisions. They argue that firm profits can be larger under higher levels of conflict between the two departments. Rubel and Prasad (2015); Bhardwaj (2001); Mishra and Prasad (2005); Homburg and Jensen (2007) study the allocation of decision-making rights within sales organizations. Another stream studies the allocation of decision-making rights in retail channels, between manufacturers and retailers (e.g., Jerath and Zhang, 2010; Chang and Harrington, 2000). Differently from these studies, our paper explicitly considers conflicting interests and information asymmetry, focusing on its impact on technology adoption and deployment in an organization. Moreover, we study firm communication using a cheap talk framework à la Crawford and Sobel (1982), which has been under-utilized in marketing literature.

Second, we complement the literature on the impact of technology on workers and organizations in general, and the literature on automation in particular (e.g., Bakos and Treacy, 1986; Bakos and Brynjolfsson, 2000; Seidmann and Sundararajan, 1997; Moriarty and Swartz, 1989; Venkatraman, 1994; Adamopoulos et al., 2018; Brynjolfsson and McAfee, 2011). Majority of the studies in this area are focused on documenting the impact of automation on jobs and wages (e.g., Acemoglu and Restrepo, 2019; Frey and Osborne, 2017), assuming firms adopt automation at similar rates. Keynes (1930) and Leontief (1952) famously predicted significant macroscopic and microscopic effects of technological improvements on the economy and organizations. A related but separate track investigates the complementarity and substitution between AI and human judgment (Agrawal et al., 2018a). Agrawal et al. (2018b) discuss the implications for allocating decision-making tasks to humans vs. machines and pricing artificial intelligence software. Dogan and Yildirim (2017) argue that, despite reducing production costs and the scope of moral hazard, automation may still result in sub-optimal outcomes due to the increasing cost of incentive provision. However, to our knowledge, no earlier study has investigated adoption of automation after adoption depending on the degree of conflict within a firm.

Differently from existing studies, this paper does not focus solely on the adoption of automation but also on its strategic utilization, that is, how it should be strategically allocated between the divisions in a firm to manage conflict. Our paper's key contribution is to show that, when deployed strategically, automation can alter the decision-making structure in a firm. We also argue that even when the efficiency benefits of technology are identical to firms, they may not adopt it at the same rate and may utilize it in different ways—based on their organizational structures. Moreover, extending Autor et al. (2003), who argued that automation should have more negative effects on low-skill tasks than high-skill tasks, we argue that high-skilled tasks may face greater automation than low-skilled tasks—again, based on their organizational structures. These predictions augment the literature on automation adoption with new insights and new empirically testable theories.

Implications for Marketing Research and Practice

Marketing managers are increasingly interested in understanding the factors that make their organizations a good fit for automation, and marketing scholars are naturally interested in understanding when automation benefits an organization (e.g., Karlinsky-Shichor and Netzer, 2019; Lam and van der Borgh, 2021). Our study offers novel, prescriptive insights to both groups.

For marketing practitioners who are thinking about automating various functions of their organizations, we first provide the insight that governance within the firm will partially determine the optimal utilization of automation. Specifically, when top-level executives have lower governance and decision-making is decentralized, technology resources should be allocated to manage more routing marketing tasks (e.g., mailing out promotional materials, persuasive efforts from sales people). Vice versa, firms with higher governance and centralized decision-making should automate tasks that require more judgement and reasoning (e.g., inventory planning, sales forecasts, product design).

Second, our findings imply that automation can alter the degree to which firms respond to changing market conditions. Examples of changes to market conditions may include consumer preferences for product attributes, macroeconomic conditions which influence prices, or competition for advertising and other promotions. We find that, while firms which operate with a more decentralized decision-making structure become more 'agile', responding more closely to changes in market conditions, centralized firms follow the opposite strategy and become more 'stale'. Moreover, increasing automation levels increases the gap in the degree of adaptation. In the context of product development, for instance, that with higher levels of automation, one firm in the market (say, BMW) may upgrade products more frequently whereas another may choose the opposite strategy (say, GM) and upgrade products less frequently. In pricing, for instance, higher adaptation would imply that a firm would change its prices more frequently as market conditions change, whereas another would smooth prices over time. In both examples, the firm's automation decision has direct implications for marketing strategies.

Third, we predict that higher centralization will follow from cheaper and more accessible automation. This is particularly salient and impactful for marketing organizations than other organizations, since marketing organizations are traditionally organized in decentralized ways. For instance, sales organizations (Anderson and Schmittlein, 1984; Chung et al., 2014) are supervised by mid-level directors with product- or region-specific expertise. Customer service organizations are managed by mid-tiers of supervisors focused on servicing a particular product line (Dukes and Zhu, 2019). Retail chains typically have supervisors in charge of a region or product category. In turn, failing to adjust organizational structure in preparation for higher automation will be more costly for marketing organizations than others.

Finally, we deliver insights to marketing managers who are selling automation technologies. Automated technologies are almost always marketed with the premise of increased efficiency or reduced cost.[4] However, automation has another key benefit: reducing operational variability. This effect is little emphasized by managers working on the diffusion of automation as a new technology; yet, our study reveals that it is a key driver of automation adoption within firms.

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 outlines the impact of automation on communication and decision-making. Section 4 presents our findings on the firm's allocation of automation across the two divisions and the choice of the optimal organizational structure. Section 5 extends the analysis to a setting where automation capacity is endogenously determined by the principal. We summarize our insights in Section 6.

2 Model

This section introduces the structure of the firm (Section 2.1), and then characterizes the firm's automation deployment (Section 2.2) and the possible centralized and decentralized organizational structures (Section 2.3).

2.1 Setting and Assumptions

There is a principal (e.g., an executive) who is the head of a firm that consists of two divisions, Division 0 and Division 1, each of which is led by a manager.[5] Division 1 faces changes to its operating environment, and is referred as the 'forefront division'. In contrast, Division 0 faces steady conditions, and is referred as the 'business-as-usual' division.[6] The firm will make a *firm level decision* considering the steady conditions of Division 0 and the

[4]For instance, IBM promotes its marketing automation technology called Fuga with the following claim "automates repetitive design tasks, cutting manual processes by 90 percent and helping businesses unleash their designersâ creativity at much lower costs." The company lists other benefits of automation as shortening of production cycles, increasing productivity, and scaling up production. (Fuga Technologies, 2021; IBM, 2021).

[5]We refer to the principal as "she" and a manager as "he" throughout the paper.

[6]For instance, a product engineering division faces continuous updates to its scope of work, whereas the scope of an accounting division is less subject to changes over time.

realized changing conditions of Division 1.[7]

The conditions faced by each division $i \in \{0, 1\}$ is summarized by a "state" variable θ_i. The state of Division 0 is constant and satisfies $\theta_0 = 0$; whereas the state of Division 1, θ_1, is a random variable taking its value from the uniform distribution over $\Theta = [-1, 1]$.[8] The interpretation of this state variable is that the larger $|\theta_1|$, the more the firm is facing changing market conditions. While the distribution of θ_1 is publicly known, its realized value is *privately* observed by the manager of Division 1. He thus will play a strategic role in the firm-level decision as we shall see soon. The manager of Division 0, in contrast, does not play such a role as the state of this division is constant and publicly known. We thus keep this manager out of the model and refer to the manager of Division 1 as "the manager."

The principal is interested in maximizing the firm's total profit—the sum of the profits of Division 0 (Π_0) and Division 1 (Π_1), denoted by $\Pi = \Pi_1 + \Pi_0$. The manager's utility is $\mathcal{U} = \Pi_1 + \alpha\Pi_0$, 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 are the preferences of the principal and the manager.[9]

Conflict between a principal and a manager and the resulting problem of coordination is a long-modeled area of research in economics (e.g., Rantakari, 2008; Alonso et al., 2008; Hart and Holmstrom, 2010; Dessein et al., 2010), finance (e.g., Harris and Raviv, 2010; Yilmaz and Chakraborty, 2017), management (Wall Jr and Callister, 1995), marketing (e.g., Balasubramanian and Bhardwaj, 2004), and operations (Siggelkow and Rivkin, 2005). While there can be a number of different reasons for such a conflict to exist, we do not explicitly model them here. Factors that remain outside of our model, like incentive contracts and career concerns (Wall Jr and Callister, 1995), can indirectly contribute to a managerâs bias towards his own division. For example, the incentive contracts offered to division managers are usually tailored to induce division-specific managerial effort and hence naturally reward

[7]A number of marketing decisions result in a similar trade-off of adaptation to changing conditions vs. keeping with the business-as-usual conditions. For instance, for product upgrades, a firm is adapting to changing consumer preferences, which are often measured with some noise, and are uncertain. Product upgrades can create a tension in marketing and sales divisions (e.g., Homburg and Jensen, 2007) or marketing and engineering divisions (e.g., Balasubramanian and Bhardwaj, 2004). In a second example, consider the decision to change product prices. Product prices impact firm divisions, including marketing and finance, which again may be the source of a conflict between them.

[8]This implies that $\mathbb{E}(\theta_1) = \theta_0$, hence the status quo of Division 1 is identical to the business-as-usual conditions of Division 0.

[9]In our framework, in the absence of asymmetric information, the principal can make all the decisions herself (i.e., centralization) and avoid both biased and uninformed decision-making. In the absence of misaligned incentives, the principal can delegate the firm-level decision to the manager (i.e., decentralization), and can again avoid both biased and uninformed decision-making. It is only in the presence of both asymmetric information and misaligned incentives that the principal faces a non-trivial trade-off in allocation of decision-making rights.

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. Modeling conflict by assuming an exogenous, residual conflict is rather standard in the literature (e.g., Alonso et al., 2008; Rantakari, 2008). Nevertheless, in Section 5.2, 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.

Productivity of Divisions

The firm-level decision, $d \in \Re$, affects the productivity of each Division i, which we denote by p_i. We assume that p_i can be either high ($p_i = h$) or low ($p_i = l$), with $h > l$. The closer the firm's decision is to θ_i, the more likely the productivity in Division i is to be high. Specifically:

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

$$\mathbb{P}(p_i = l) = (\theta_i - d)^2 \tag{2}$$

Setting d close to θ_0 (known with certainty) can be interpreted as a continuity strategy—well-suited for the business-as-usual division. Vice versa, setting the value closer to θ_1 (which realizes with uncertainty) 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 between the principal and the manager and the internal conflict of interest.

Each division is in charge of performing a continuum of *tasks*—normalized to unit mass without loss of generality. Each task generates an output that contributes to the division's profit. In each division, each task can be performed by a human worker ("non-automated task") or an automated machine ("automated task"). Automated and non-automated tasks differ in three aspects. First, automation reduces variability, 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. We keep our setting as general as possible, and we do not make any assumption on the value of this difference. Third, workers choose an effort level, which 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 (denoted by p_i), and (ii) the effort exerted by the workers (denoted by $e \geq 0$). The outcome of each non-automated task is then given by $p_i e$. Workers' effort choice comes at a cost of effort, given by $c(e) = ce^2$ for some $c > 0$.

We assume that 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.[10] 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, satisfies:

$$e = \begin{cases} \frac{h}{2c} & \text{if } p_i = h, \\ \frac{l}{2c} & \text{if } p_i = l, \end{cases} \tag{3}$$

Therefore, the profit contribution of each non-automated task in Division $i = 0, 1$ is equal to $\frac{h^2}{4c}$ 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 variability of the production.[11] However, all results derived in this paper would hold if we assumed that automation reduces production variability, rather than eliminating it.

2.2 Automation Strategy

We start by assuming that the firm is endowed with an exogenous "automation capacity"—the resources available to the firm for the automation of tasks. We denote this automation capacity by ζ. This setting is motivated by the fact that automated technologies typically represent long term investments 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. In Section 5,

[10] In an alternative formulation, 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.

[11] We can alternatively assume that, the contribution of an automated task also depends on the realized productivity of the underlying division. That is, the contribution of an automated task in a division with high productivity (resp., low productivity) is ρ_h (resp., ρ_l) instead of a constant ρ, for some $\rho_h > \rho_l$. This modification does not create any qualitative change on our results, as long as the difference between ρ_h and ρ_l is sufficiently smaller than the difference between h and l—that is, the reduction in production variability due to automation is sufficiently high.

we extend this setting to an instance where automation capacity is endogenously chosen by the principal.

The principal decides how to *allocate* this automation capacity between the divisions. We denote by ζ_0 and ζ_1 the automation capacity allocated to Division 0 and Division 1, respectively, such that $\zeta_0 + \zeta_1 = \zeta$. We assume $\zeta < 1$, i.e., the principal cannot automate all the tasks in any division.[12] 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 firm-level decision, *centralization* and *decentralization*:

- Under *centralization*, the principal is in charge of the decision $d \in \Re$. She asks the manager to send her an informative message about the realized state variable θ_1. In practice, this communication corresponds to any report or input that informs top-level executives.

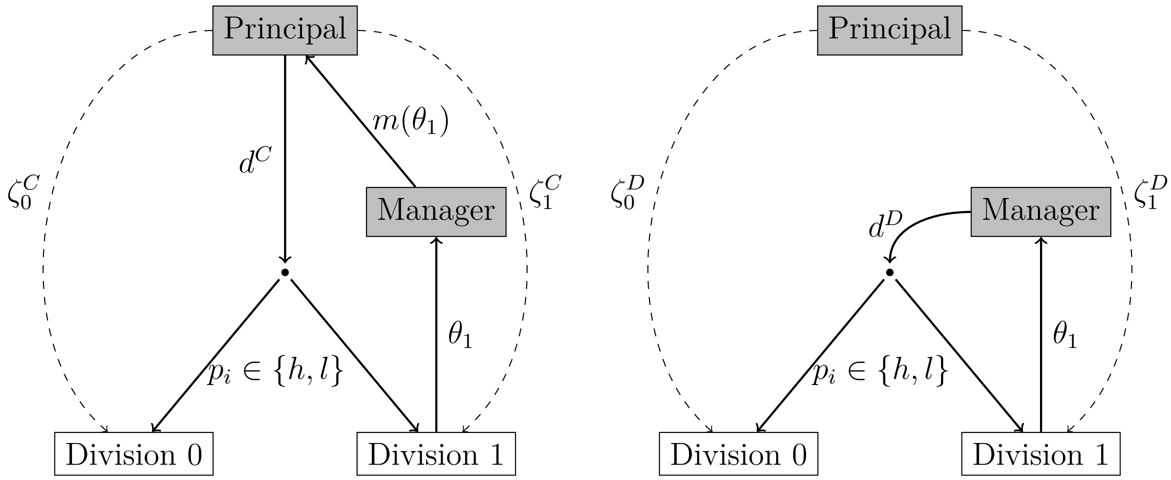
- Under *decentralization*, the principal delegates the decision-making rights to the manager, who then makes the decision $d \in \Re$ on behalf of the entire firm. There is no communication between the principal and the manager, as the informed party is in charge of decision-making.

As discussed in the introduction, this dichotomy involves a trade-off between unbiased. vs. more informed decision-making.[13] Under centralization, the principal can align the decision with the firm's overall objective, but this decision may not be fully informed as the conflict of interest between the principal and the manager may lead to imperfect information transmission. Under decentralization, the manager has access to perfect information but may make a biased decision toward Division 1, which may thus result in a sub-optimal decision from the firm's standpoint.

These two organizational structures are shown in Figure 1. We formalize next the strategic interactions between the principal and the manager under each structure. To represent the events, we use the superscripts C and D to refer to the centralized and decentralized structures, respectively.

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

[13] Throughout the rest of the paper, with 'bias' we will refer to the difference between the firm-level decision of the manager and the executive.



(a) Centralized structure

(b) Decentralized structure

Figure 1: Representation of centralized and decentralized structures.

Centralized Structure

The sequence of events under centralization is shown in Figure 2.

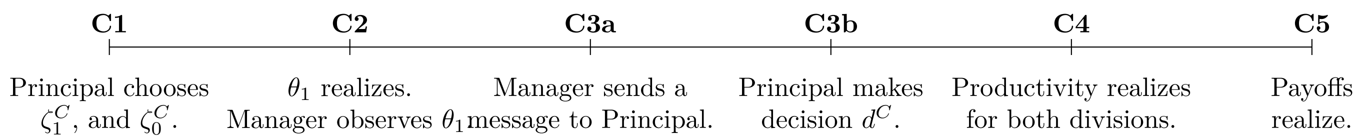


Figure 2: Sequence of events and timing under the centralized structure.

In the first stage, the principal determines the allocation of automation capacity between the two divisions (i.e., ζ_0^C and ζ_1^C).[14] The manager then privately observes the realized value of θ_1. He provides an informative message about θ_1 to the principal, denoted by $m(\theta_1)$. Following the seminal paper of Crawford and Sobel (1982), we assume that the communication between the principal and the manager is *cheap talk*, that is, the information is not verifiable by the principal.

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):

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

[14] Automation deployment is usually a long-term structural strategy of the firm, whereas d captures an operational firm-level decision faced more regularly by the firm. This motivates the timing of events under consideration.

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:

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

Following the update, the principal sets d^C to maximize the expected profit of the firm, Π. The decision is a mapping from the message space to the set of real numbers.[15]

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

Next, the productivity of each division realizes based on the decision d^C and state variable θ_1, according to Equations (1) and (2). The workers in Division $i = 0, 1$ make their effort choices based on the realized productivity $p_i \in \{h, l\}$ (Equation (3)).

Decentralized Structure

The sequence of events under decentralization is shown in Figure 3. The main difference with centralization is that the manager is not asked to report an informative message about θ_1, but is in charge of the decision d.

D1	**D2**	**D3**	**D4**	**D5**
Principal chooses ζ_1^D, and ζ_0^D.	θ_1 realizes Manager observes θ_1.	Manager makes decision d^D.	Productivity realizes for both divisions.	Payoffs realize.

Figure 3: Sequence of events and timing under the decentralized structures.

As under centralization, the principal first determines the allocation of automation capacity (i.e., ζ_1^D, and ζ_0^D). Then, the manager privately observes the realized value of θ_1 and makes the decision. The decision is now defined as a direct mapping from the state space to the set of real numbers.

$$d^D : \Theta \longrightarrow \Re.$$

Next, the productivity of each division realizes based on the decision d^D and state variable θ_1, according to Equations (1) and (2). As it was under centralization, the workers in Division $i = 0, 1$ make their effort choices based on the realized productivity $p_i \in \{h, l\}$ (Equation (3)).

[15] Here, d^C refers to a *function* that maps each message received by the principal to a decision (rather than the decision itself). This slight abuse of notation is meant to make the exposition clearer.

3 Equilibrium Analysis

In this section, we characterize the equilibrium under both organizational structures. We adopt the Perfect Bayesian Equilibrium solution concept. In other words, we identify the players' sequentially rational strategies based on their beliefs determined by available information and Bayes' rule.

We follow the game descriptions in Figures 2 and 3 and proceed by backward induction. We first derive the profits of each division (Steps $C5$ and $D5$ in Figures 2 and 3), contingent on realized productivities and automation allocation. We use the resulting payoff functions to characterize equilibrium firm-level decision under each organizational structure (Steps $C3a$, $C3b$ and $D3$). Last, we formalize the principal's automation allocation strategy and her choice on the organizational structure (Steps $C1$ and $D1$). All proofs are reported in Appendix 7.

3.1 Payoffs

For a given allocation of automation capacity (i.e., ζ_1, and ζ_0), the profit of each division is determined by the realized productivity level (i.e., h or l). We denote by $\pi_{ih}(\zeta_i)$ and $\pi_{il}(\zeta_i)$ the profit of Division i under high and low productivity levels, respectively:

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

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

$$\Delta_i(\zeta_i) = \pi_{ih}(\zeta_i) - \pi_{il}(\zeta_i) = (1-\zeta_i)\frac{h^2 - l^2}{4c}. \tag{5}$$

3.2 Firm-level Decision

We denote the *expected profit* of Division i for any allocated automation capacity (ζ_i), firm's decision (d), and state (θ_i) by $\bar{\pi}_i(\zeta_i, d, \theta_i)$. It is expressed from the profit functions π_{ih} and π_{il}

given in Equation (4). Here, the expectation is taken over the realization of the productivity level of Division i, which takes the value h with probability $1-(\theta_i-d)^2$ and the value l with probability $(\theta_i-d)^2$. Therefore, the expected profit of Division i becomes:

$$\bar{\pi}_i(\zeta_i, d, \theta_i) = \left(1-(\theta_i-d)^2\right)\pi_{ih}(\zeta_i) + (\theta_i-d)^2\pi_{il}(\zeta_i). \tag{6}$$

We now characterize the equilibrium firm-level decisions under decentralization and centralization. We distinguish the two structures using the superscripts D and C, respectively.

3.2.1 Decentralization

The manager makes the decision d^D to maximize his expected utility, as a function of the level of automation in each division (i.e., ζ_1^D and ζ_0^D) and the observed state in Division 1 (i.e., θ_1). This problem is written as:

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

Lemma 1 characterizes the solution to this problem.

Lemma 1. *Under decentralization, the firm-level decision satisfies:*

$$d^D = \beta^D(\zeta_1^D, \zeta_0^D)\theta_1, \quad \text{where } \beta^D(\zeta_1^D, \zeta_0^D) = \frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)}. \tag{7}$$

The decentralized firm-level decision, as shown in Lemma 1, proportionally adapts to the realized state of Division 1, but only imperfectly. This stems from the fact that as long as $\alpha > 0$, i.e., the manager also cares about Division 0, he imperfectly adapts to the realized state in Division 1. Indeed, we have $\beta^D(\zeta_1^D, \zeta_0^D) < 1$, so the manager's decision is such that $\left|d^D\right| < |\theta_1|$. In words, the decision d^D strikes a middle ground between a pure continuity strategy (setting $d = \theta_0 = 0$) and a pure adaptation strategy (setting $d = \theta_1$). This reflects the fact that the manager does account for the profit realized in Division 0 in his decision-making. Moreover, the rate of adaptation ($\beta^D(\zeta_1^D, \zeta_0^D)$) decreases as the manager favors Division 1 to a lesser extent (higher α). When $\alpha = 0$, the manager embraces a pure adaptation strategy by setting $d^D = \theta_1$. This results in high productivity in Division 1 while Division 0's productivity is subject to uncertainty. Finally, the manager's decision does not depend on the *level* of each division's profit, but only on the *difference* between the realized profits in high and low-productivity scenarios (Equation (5)).

From the decentralized decision, we can now derive the expected profit of the firm under decentralization for any allocation of automation capacity. It is denoted by $\Pi^D\left(\zeta_1^D, \zeta_0^D\right)$, and given in Equation (8). 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, even though θ_0 is known deterministically, the profit of Division 0 is also subject to uncertainty given the endogeneity of the manager's decision with respect to the realization of θ_1, which is only known probabilistically.

$$\Pi^D\left(\zeta_1^D, \zeta_0^D\right) = \int\limits_{\Theta} \left[\bar{\pi}_1(\zeta_1^D, d^D, \theta_1) + \bar{\pi}_0(\zeta_0^D, d^D, \theta_0)\right] \frac{d\theta_1}{2} \tag{8}$$

Following some algebra, we derive a closed-form solution of the expected profit of the firm under decentralization in Proposition 1.

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

$$\Pi^D\left(\zeta_1^D, \zeta_0^D\right) = \pi_{1h}(\zeta_1^D) + \pi_{0h}(\zeta_0^D) - \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[\Delta_1(\zeta_1^D) + \alpha^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)\right]^2}. \tag{9}$$

The first two terms in Equation (9) correspond to the firm's total profit when productivity is high in each division. 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 optimal allocation 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 this expected loss.

3.2.2 Centralization

We first characterize the centralized firm-level decision by the principal after she receives a message from the manager and updates her beliefs regarding the realized value of θ_1 (Step $C3b$ of Figure 2). We then use this to identify the equilibrium communication between her and the manager (Step $C3a$ of Figure 2).

For any message m received, the principal chooses d^C to maximize the expected profit of the firm as a function of the automation capacity in each division (ζ_1^C and ζ_0^C). The problem can be formulated as:

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

Lemma 2 characterizes the centralized decision d^C.

Lemma 2. *The centralized firm-level decision, as a function of the message m, is given by:*

$$d^C(m) = \beta^C(\zeta_1^C, \zeta_0^C)\mathbb{E}(\theta_1|m), \quad \textit{where } \beta^C(\zeta_1^C, \zeta_0^C) = \frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C) + \Delta_0(\zeta_0^C)}. \tag{10}$$

The centralized decision proportionally adapts to the *expected* value of the realized state in Division 1, conditional on the message received. The rate of adaptation ($\beta^C(\zeta_1^C, \zeta_0^C)$) is lower than 1, i.e., the principal only partially adapts to her belief regarding the state of Division 1. This reflects the fact that the principal balances the profit outcomes of the two divisions—similar to the manager's strategy under decentralization when $\alpha > 0$. However, we have $\beta^C(\zeta_1^C, \zeta_0^C) < \beta^D(\zeta_1^C, \zeta_0^C)$ when $\alpha < 1$. Therefore, if the principal were to observe the realized value of θ_1, she would favor Division 0 to a greater extent than the manager does under decentralization. This results directly from the fact that the principal assigns a higher weight to Division 0's profit than the manager does.

Equilibrium Communication. We now use the centralized firm-level decision by principal (Step $C3b$) to characterize the equilibrium communication between the principal and the manager (Step $C3a$). As in any cheap talk model, there exists a *babbling equilibrium* under which the principal ignores the message from the manager and the manager randomizes his message. More generally, there exist multiple equilibria, with various levels of information transmission. In this paper, we consider the most informative communication, referred to as *equilibrium communication.*

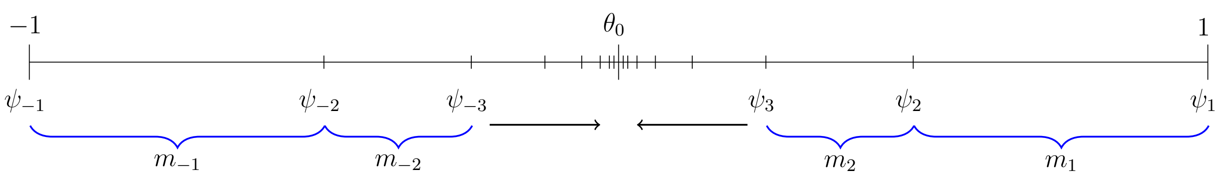


Figure 4: Structure of equilibrium communication.

Proposition 2. *The equilibrium communication is, as shown in Figure 4, such that the state space $\Theta = [-1, 1]$ is partitioned into infinitely many sub-intervals, and the manager informs the principal about to which sub-interval that the realized state belongs.*

Specifically, there are two sequences $\{\psi_{-n}\}_{n=1}^{\infty}$, and $\{\psi_n\}_{n=1}^{\infty}$ satisfying

$$-1 = \psi_{-1} < \psi_{-2} < \psi_{-3} < ..... < \theta_0 = 0 < ...... < \psi_3 < \psi_0 < \psi_1 = 1,$$

and

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

And there exist message sequences $\{m_{-n}\}_{n=1}^{\infty}$ *and* $\{m_n\}_{n=1}^{\infty}$ *such that the manager's report satisfies* $\sigma(\theta_1) = m_n$, $\forall \theta_1 \in (\psi_{n+1}, \psi_n]$, *and* $\sigma(\theta_1) = m_{-n}$, $\forall \theta_1 \in [\psi_{-n}, \psi_{-(n+1)})$.

Proposition 2 makes it clear that the structure of the equilibrium communication depends on the conflict (α) and automation strategy (ζ_0^C, ζ_1^C). We will discuss in Section 4.2, how automation allocation strategy chosen by the principal impacts the informativeness of her subordinate's reports for her firm-level decision.

The impact of conflict on the informativeness of the communication is rather clear. Specifically, manager's messages become less informative as Division 1 faces a stronger change in its operating conditions. That is, as θ_1 deviates more from 0, 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). This stems from the fact that, as $|\theta_1|$ gets larger, the implications of the conflict between the principal and the manager is higher. Moreover, due to the symmetry of the distribution of θ_1, the sub-intervals governing the equilibrium communication are symmetrically distributed around the value of $E(\theta_1) = \theta_0 = 0$.

Upon receiving the message m_n, the principal infers that θ_1 falls into the sub-interval $(\psi_{n+1}, \psi_n]$.[16] Therefore, the principal updates her beliefs, such that the probability distribution of θ_1, conditional on the message, is uniform within the corresponding sub-interval. As a result, we have:

$$\mathbb{E}(\theta_1|m_n) = \frac{\psi_{n+1} + \psi_n}{2}, \forall n \geq 1. \tag{11}$$

Then, from Lemma 2, the centralized decision after receiving message m_n satisfies:

$$d^C(m_n) = \beta^C(\zeta_1^C, \zeta_0^C)\frac{\psi_{n+1} + \psi_n}{2}, \forall n \geq 1. \tag{12}$$

The expected profit of the firm in a centralized organization conditional on the automa-

[16] An analogous version of this statement holds when the principal receives any message m_{-n}, with $n \geq 1$.

tion allocation strategy, which we denote by $\Pi^C\left(\zeta_1^C, \zeta_0^C\right)$, satisfies:

$$\Pi^C\left(\zeta_1^C, \zeta_0^C\right) = \sum_{n=-\infty}^{n=-1} \int_{\psi_{-n}}^{\psi_{-(n+1)}} \left[\bar{\pi}_1(\zeta_1^C, d^C(m_{-n}), \theta_1) + \bar{\pi}_0(\zeta_0^C, d^C(m_{-n}), \theta_0)\right] \frac{d\theta_1}{2}$$
$$+ \sum_{n=1}^{n=\infty} \int_{\psi_{n+1}}^{\psi_n} \left[\bar{\pi}_1(\zeta_1^C, d^C(m_n), \theta_1) + \bar{\pi}_0(\zeta_0^C, d^C(m_n), \theta_0)\right] \frac{d\theta_1}{2} \quad (13)$$

The closed-form solution of this profit equation is provided in Proposition 3.

Proposition 3. *Under centralization, the expected profit of the firm is equal to:*

$$\Pi^C\left(\zeta_1^C, \zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + \pi_{0h}(\zeta_0^C) - \frac{(4-\alpha)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C) + (4-\alpha)\Delta_0(\zeta_0^C)\right]}. \quad (14)$$

The general form of the expected profit of the firm is similar to the one under decentralization (Proposition 1). Indeed, the first two terms correspond to the profit under high productivity, and the last term reflects the expected loss due to productivity uncertainty. And similarly, while the impact of automation on the profit is ambiguous, the profit increases as the conflict between the principal and the manager is reduced (higher α). While, the relationship between conflict and profit is similar for both centralization and decentralization, the mechanisms that drive them under each are different. 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 higher expected profit.

Before moving to the characterization of (i) principal's optimal automation allocation strategy under centralization and decentralization, and (ii) the optimal organizational structure, we discuss the role of automation on the firm-level decision and communication.

3.3 Discussion on the Effects of Automation

Assuming a residual level of conflict that the principal cannot eliminate in the firm, an alternative channel to manage this conflict can be a strategic choice of automation allocation. In this section, we will discuss the extent to which this choice may impact (i) the alignment of the principal's and the manager's firm-level decisions and (ii) the value of information held by the manager to the principal.

Recall that the decentralized decision by the manager is given by $d^D(\theta_1) = \beta^D(\zeta_1, \zeta_0)\theta_1$ (Lemma 1) and the centralized decision by the principal is given by $d^C(m) = \beta^C(\zeta_1, \zeta_0)\mathbb{E}(\theta_1|m)$, where m is the manager's message as a function of θ_1 (Lemma 2). Figure 5 illustrates these decisions by showing, for each value of θ_1: (i) $d^D(\theta_1)$ with the blue line; (ii) $d^C(m(\theta_1))$ with the red line; and (iii) a benchmark representing the principal's ideal decision under perfect information, i.e., $\beta^C\theta_1$ with the dashed green line.

Notice that, the slope of the dashed green line is lower than the slope of the blue line, indicating that the principal ideally prefers the continuity strategy at a greater extent than the manager, as she assigns a higher weight to Division 0's profit than the manager. Under centralization, due to partially-informative communication, there remains uncertainty regarding the true value of θ_1 from the principal's perspective, so her firm-level decision in equilibrium does not necessarily correspond to her ideal decision. For some values of θ_1, the principal may have to choose the adaptation policy at an extent that is higher than preferred by the manager in equilibrium. That is, while on average, the principal's firm-level decision is more conservative relative to that by 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.

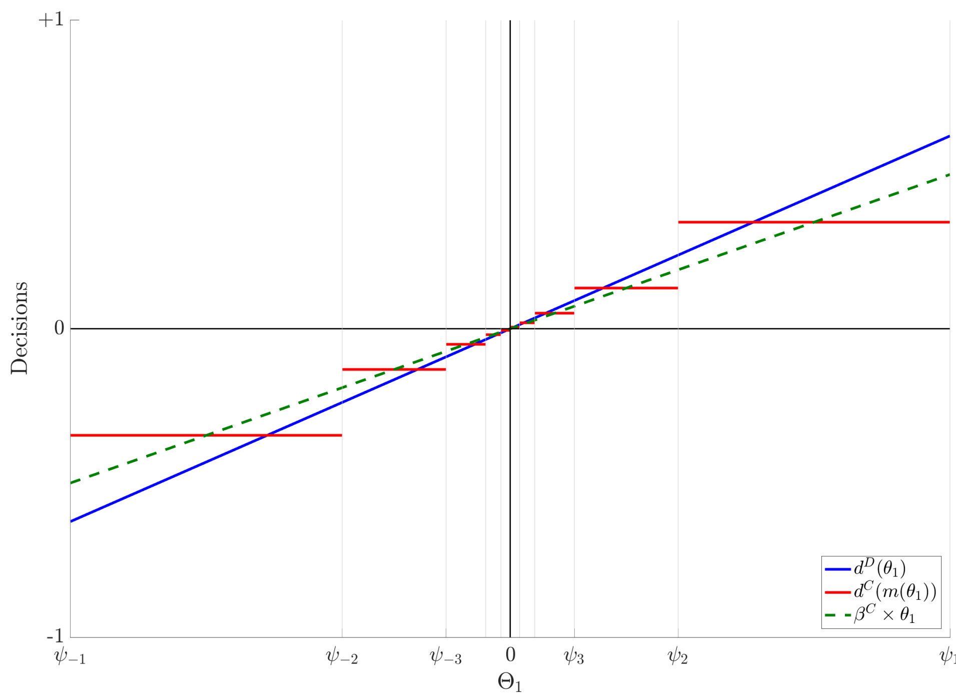


Figure 5: Decisions under centralization, the decentralized structure, and perfect information.

(i) Alignment of Firm-level Decisions

Next, we discuss the role of automation on the firm-level decision under centralized and decentralized structures. First, the more a division is automated, the less favorable the firm's decision is toward this division. Recall that, as automation capacity increases in a division, its production becomes less sensitive to the firm-level 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. That is, if the level of automation increases in Division 1 (Division 0), the firm-level decision moves closer towards the pure continuity (pure adaptation, resp.) strategy. We summarize this result in Corollary 1.

Corollary 1. *The rate of adaptation in decentralized ($\beta^D(\zeta_1, \zeta_0)$) and centralized ($\beta^C(\zeta_1, \zeta_0)$) organizational regimes both decrease in ζ_1 and increase in ζ_0.*

Second, automation impacts the alignment between the firm-level decisions under centralization and decentralization. We quantify this alignment as the ratio of the rates of adaptation under each organizational regime.

Definition 1. The *degree of alignment* is defined as:

$$r(\zeta_1, \zeta_0) = \frac{\beta^C(\zeta_1, \zeta_0)}{\beta^D(\zeta_1, \zeta_0)} = \frac{\Delta_1(\zeta_1) + \alpha\Delta_0(\zeta_0)}{\Delta_1(\zeta_1) + \Delta_0(\zeta_0)} \in [0, 1). \tag{15}$$

Several properties of this measure (r) are noteworthy. A higher degree of alignment r indicates that the firm-level decisions of the principal and the manager are more aligned. However, this alignment is always less than perfect ($r < 1$) since the principal's firm-level decision favors adaptation at a lesser extent than the manager's. We also interpret a lower degree of alignment as higher degree of "polarization" within the firm, and vice versa. Clearly, the degree of alignment decreases, or equivalently polarization increases, in conflict within the firm (α). Last, all else equal, larger automation capacity in Division 1 (resp. Division 0) results in smaller (resp. greater) alignment between the decisions of the principal and the manager. Corollary 2 summarizes this last point related to automation.

Corollary 2. *The degree of alignment decreases with ζ_1 and increases with ζ_0.*

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. As a result, the manager chooses to shield himself from "excessive" accommodation of Division 0 by the principal, and therefore sends less informative messages.[17] In other words, higher automation capacity in Division 1 makes the manager *more* accommodating toward Division 0 under decentralization but *less* informative under centralization. A similar logic applies to unpacking the impact of higher level of automation in Division 0.

(ii) Value of Information

Automation also impacts the value of the manager's private information to the principal. We quantify this value as the difference between the firm's profit under perfect information vs. no information.

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

$$VOI(\zeta_1, \zeta_0) = \overline{\Pi}(\zeta_1, \zeta_0) - \underline{\Pi}(\zeta_1, \zeta_0), \tag{16}$$

where $\underline{\Pi}(\zeta_1, \zeta_0)$ and $\overline{\Pi}(\zeta_1, \zeta_0)$ denote the expected profit of the firm under no information and perfect information, respectively. Formally, we denote by $d^C(m)|_{m=\emptyset}$ the decision that the principal would make if she received no message from the manager and by $d^C(m)|_{m=\theta_1}$ the decision she would make if she received a perfectly informative message. $\underline{\Pi}(\zeta_1, \zeta_0)$ and $\overline{\Pi}(\zeta_1, \zeta_0)$ are then given by:

$$\underline{\Pi}(\zeta_1, \zeta_0) = \mathbb{E}\left[\bar{\pi}_0\left(\zeta_0, d^C(m)|_{m=\emptyset}, \theta_0\right)\right] + \mathbb{E}\left[\bar{\pi}_1\left(\zeta_1, d^C(m)|_{m=\emptyset}, \theta_1\right)\right], \tag{17}$$

$$\overline{\Pi}(\zeta_1, \zeta_0) = \mathbb{E}\left[\bar{\pi}_0\left(\zeta_0, d^C(m)|_{m=\theta_1}, \theta_0\right)\right] + \mathbb{E}\left[\bar{\pi}_1\left(\zeta_1, d^C(m)|_{m=\theta_1}, \theta_1\right)\right]. \tag{18}$$

Corollary 3 shows that, all else equal, larger automation capacity in Division 1 (resp. Division 0) results in smaller (resp. greater) value of information.

Corollary 3. *The value of information is equal to* $VOI(\zeta_1, \zeta_0) = \frac{\Delta_1(\zeta_1)^2}{3(\Delta_1(\zeta_1)+\Delta_0(\zeta_0))}$. *It decreases with* ζ_1 *and increases with* ζ_0.

The above corollary indicates that 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, 2, and 3 highlight the strategic importance of automation on managing (i) the alignment of the principal's and the manager's firm-level decisions and (ii) the value

[17] Less informative communication is reflected by wider sub-intervals in Proposition 2. It can be verified numerically that, for any $n \geq 1$, ψ_n (resp. ψ_{-n}) decreases (resp. increases) with ζ_1 and increases (resp. decreases) with ζ_0.

of information held by the manager to the principal. We exploit these results in the next section to determine the optimal allocation of automation capacity across the two divisions.

4 Automation and Organizational Structure

The main objective of this section is to solve the principal's problem on automation allocation and to determine the optimal organizational structure. First, we focus on the allocation of automation capacity across the two divisions in centralization (Step $C1$ in Figure 2) and decentralization (Step $D1$ in Figure 3). From the firm's expected profits under each organizational structure (Propositions 1 and 3), 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:

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

Clearly, both problems would be equivalent if there was no conflict ($\alpha = 1$), as the communication is fully informative under centralization and the equilibrium firm-level decisions are identical under the two organizational regimes in this case, emphasizing the role that conflict plays in determining the organizational structure. Before solving these problems, we establish a benchmark in which the principal treats the two divisions symmetrically when allocating automation capacity.

4.1 Benchmark: Symmetric Allocation of Automation Capacity

In this benchmark, we assume that the principal allocates automation capacity equally across the two divisions. This is motivated by the fact that both divisions are *ex ante* identical before θ_1 realizes. With $\zeta_1 = \zeta_0 = \frac{\zeta}{2}$, we derive the firm's profits by using Equations (9) and (14) together with Equations (4) and (5). We denote them by Π_S^D and Π_S^C, respectively, where S stands for symmetric.

$$\Pi_S^D = (2-\zeta)\frac{h^2}{4c} + \zeta\rho - \frac{1+\alpha^2}{3(1+\alpha)^2}\left(1-\frac{\zeta}{2}\right)\frac{h^2-l^2}{4c} \tag{19}$$

$$\Pi_S^C = (2-\zeta)\frac{h^2}{4c} + \zeta\rho - \frac{4-\alpha}{3(7-\alpha)}\left(1-\frac{\zeta}{2}\right)\frac{h^2-l^2}{4c} \tag{20}$$

Comparison of these expressions yields the optimal organizational structure under symmetric automation, as given in Proposition 4.

Proposition 4. *(Organization under Symmetric Allocation of Automation) When automation capacity is symmetrically allocated between the two divisions, the centralized structure is optimal if conflict is high ($\alpha \leq 0.6$) and the decentralized structure is optimal if the conflict is low ($\alpha \geq 0.6$).*

The proposition indicates that the degree of conflict within the firm influences the optimal organizational structure. Specifically, if the conflict is high (when α is small), centralization is optimal for the firm and the principal retains the right to make the firm-level decision. Conversely, if conflict is low (when α is large), decentralization is optimal and the principal delegates decision-making rights to the manager. Importantly, the overall automation capacity (ζ) does not play a role in firm's organizational structure when the overall capacity is not deployed strategically. As we shall see next, this result does not hold anymore if the capacity is allocated strategically.

4.2 Optimal Allocation of Automation Capacity

Proposition 5 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 5. *(Optimal Automation Deployment) Optimal allocation of automation capacity is as follows:*

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

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

Under both organizational structures, the optimal allocation of automation capacity features a "bang-bang" property: capacity is allocated to one 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.

In decentralized firms, as the manager is in charge of the firm-level decision, the main concern that shapes the automation strategy is his biased decision. In this case, the capacity is allocated to the business-as-usual division (Division 0) to shield it from the manager's bias. Allocating automation capacity to Division reduces the share of non-automated tasks in this division, and hence reduces its sensitivity to the manager's firm-level decision. In centralized firms, on the contrary, the principal makes the firm-level decision, and the main concern that shapes the automation strategy is the lack of perfect information about the conditions faced by the forefront division. Thus, the principal allocates automation capacity to the forefront division (Division 1) to reduce her reliance on the manager's private information (Corollary 3). Interestingly, this strategy reduces the *degree of alignment* defined in Equation 15. In words, there is a larger gap between the ideal firm-level decision of the principal and the firm-level decision of the manager, which leads to less informative messages from the manager to the principal. The adverse effect of less informative communication, however, is mitigated by the reduced importance of the manager's private information on the principal's firm-level decision.

Using Corollary 2, we can further see how the automation capacity relates to the degree of alignment between the decisions of the manager and the principal. Corollary 4 argues that with higher automation capacity, in centralized firms, the polarization between the ranks of management increases – the preferred firm-level decisions of the manager and the principal are less aligned. Decentralized firms, on the other hand, result in more aligned firm-level decisions and hence less polarization, as automation capacity increases. This corollary provides the important insight that, technological advancements are not always accompanied by an easier decision-making process as they do not necessarily lead to higher level of consensus between stakeholders, and may even become a source of discontent.

Corollary 4. *With higher levels of automation, the degree of alignment between the decisions of the principal and the manager increases in a decentralized firm and decreases in a centralized firm.*

There are several managerial implications of the results presented above. First, the adaptation of the firm to the new environment— "adaptation" vs. "continuity" strategy —differs based on the centralized vs. decentralized organizational structures. A centralized organization is more likely to follow a continuation strategy, and therefore will poorly adapt to the new and changing conditions facing (a part of) the organization. A decentralized organization, in contrast, pursues an adaptation strategy at a higher extent, choosing to embrace the new conditions faced by the forefront division. Put differently, the centralized organizations will be more 'stale' whereas decentralized organizations will be more 'agile' in adjusting to the new conditions.[18]

Second, the results inform us about how the adoption of automation as a new technology should look like in reality. While there is a rich literature on new product diffusion in marketing (e.g. Rogers, 1976; Talukdar et al., 2002; Van den Bulte and Joshi, 2007), in our reading, most studies focus on adoption of new technologies by consumers. There is a gap on understanding how automation technologies are adopted by firms, and more importantly, how their utilization varies within the divisions of a firm. Centralized firms concentrate automation in divisions that face uncertainty, whereas decentralized firms do the opposite. Put differently, the adoption may result in a technological balkanization in firms, where some divisions lag in adoption.

Third, divisions that face uncertainty tend to employ high-skilled labor that specialize in more complex tasks requiring human judgment, problem solving, analytical skills (Acemoglu and Restrepo, 2018), whereas divisions that face little uncertainty or repetitive tasks tend to employ low-skilled workers (Acemoglu and Restrepo, 2018; Brynjolfsson and McAfee, 2014). For instance, finance and product design divisions tend to employ workers with higher-education degrees, as their job requires considerable level of forecasting of demand and judgement in planning. As centralized organizations allocate automation to uncertain divisions, on average, higher skilled workers are likely to face displacement. In decentralized organizations, on the other hand, since automation is mainly geared towards the business-as-usual division, in expectation, lower-skilled workers should face displacement. These predictions make a significant contribution to the literature studying the labor market effects of automation, since existing studies assume a uniform exposure of firm divisions to automation (e.g. Acemoglu and Restrepo, 2019) without taking the differences within a firm into account and assume that low-skilled jobs are more likely to be automated (Autor et al., 2003). Our study suggests that the impact is more nuanced such that, depending on the organizational structure, high-skilled tasks may face higher rates of automation than low-skilled ones.

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

[18]Adaptation vs. continuation trade-offs are common in marketing. Take, for instance, the decision of product upgrades. A continuation strategy would favor keeping current product design and therefore would lean towards not releasing a product upgrade. An adaptation strategy would suggest the opposite, as market conditions change, e.g., when consumers demand new features or competitors release new products. A more agile firm would release more product upgrades as market conditions change. Consider another example, where the firm is considering setting prices of a product for the new season in an inflationary market. A continuation strategy would keep prices close to its current levels, and an adaptation strategy would raise prices along with market levels.

4.3 Optimal Organizational Structure

We next characterize the firm's optimal organizational structure. Recall that the principal (i) can delegate firm-level decision to the manager and automate the business-as-usual division (Division 0) to shield it from the manager's biased decision-making, or (ii) can make the firm-level decision herself, and automate the forefront division (Division 1) to reduce her reliance on the manager's private information. Proposition 6 characterizes the optimal organizational structure for the firm depending on the overall automation capacity (ζ) and the residual conflict (α)—shown visually in Figure 6.

Proposition 6. *If the automation capacity is high ($\zeta \geq g(\alpha)$, where $g(\alpha) \equiv \frac{5(\alpha-0.6)}{\alpha^2}$), the centralized structure is optimal. Otherwise, if automation capacity is low ($\zeta \leq g(\alpha)$), the decentralized structure is optimal.*

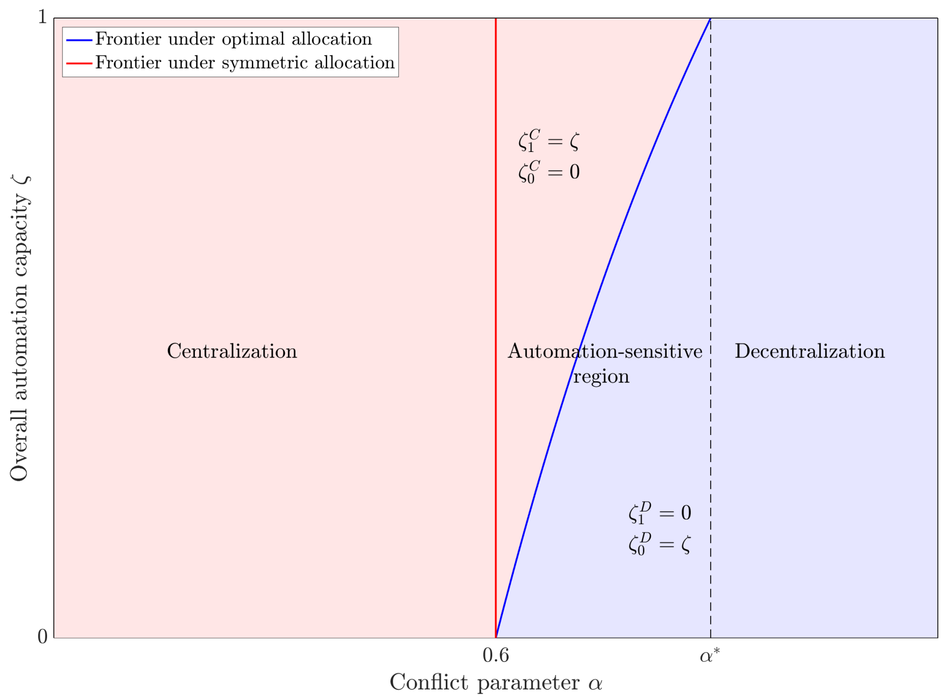


Figure 6: Optimal organizational structure as a function of overall automation capacity and degree of conflict.

The first implication of Proposition 6 is that a centralized organization is optimal in firms with higher levels of conflict (lower α); vice versa, a decentralized organization is optimal in firms with lower levels of conflict (higher α).[19] In Figure 6, the blue curve marks the regions where centralization or decentralization is optimal under the optimal allocation of automation. The red line does the same for the symmetric allocation benchmark (Proposition 4).

That the lower the conflict between the principal and the manager, the more inclined the principal is to delegate the firm-level decision to the manager is in line with the findings under symmetric allocation benchmark. But in contrast, the optimal organizational structure now depends on the overall automation capacity. Specifically, the range of $\alpha \in (0, 1]$ is divided into three regions. First, when $\alpha \leq 0.6$, centralization is optimal regardless of automation capacity. Second, there exists $\alpha^* = \frac{5-\sqrt{13}}{2} \simeq 0.697$ such that, when $\alpha \geq \alpha^*$, decentralization is optimal regardless of automation capacity. Third, when $\alpha \in (0.6, \alpha^*)$, the choice of centralization vs. decentralization depends on automation capacity. In this region—referred to as *automation-sensitive region*—decentralization is optimal under low automation capacity but centralization is optimal under high automation capacity. All else equal, the greater automation capacity ζ, the more inclined the principal is to make the firm-level decision to herself.

The second implication from Proposition 6 is that, above a threshold level, automation capacity becomes a substitute to the manager's expertise. To see the intuition, consider a firm with low automation capacity in the automation-sensitive region. With low capacity, the principal is able to automate only a small fraction of the tasks in any division and she remains considerably reliant on the private information of the manager. Therefore, she delegates the firm-level decision to the manager, and shields the business-as-usual division (Division 0) from the manager's biased decision by automating the tasks in this division. When the capacity is high, on the other hand, 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 firm-level decision herself, and allocates automation capacity to the forefront division (Division 1) — reducing the negative effects of her imperfect information.

An important conclusion from the insights above is that, 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.

[19] This follows from the fact that the condition $\zeta \geq g(\alpha)$ elicited in Proposition 6 is equivalent to $\alpha \leq g^{-1}(\zeta)$. Formally, the function g is bijective over (0.1]. Its inverse is given by: $g^{-1}(\zeta) = \frac{5-\sqrt{25-12\zeta}}{2}$. Thus, centralization is optimal if $\alpha \leq g^{-1}(\zeta)$ and decentralization is optimal if $\alpha \geq g^{-1}(\zeta)$.

5 Extensions

In this section, we will extend our baseline model to allow for the automation capacity to be endogenously determined (Section 5.1) and the residual conflict to be managed via a monetary contract (Section 5.2). We will see that all results from the baseline model are robust to these modifications.

5.1 Endogenous Automation Capacity

Thus far, we have considered an exogenous level of automation ζ, which the principal allocated across the two divisions. In this section, we relax this restriction to endogenize the choice of ζ. All proofs are reported in Appendix 9.

To endogenize the capacity choice, we will introduce an additional step to the baseline model outlined in Section 2. Specifically, in the first stage of the game (Step $C1$ in Figure 2 and Step $D1$ in Figure 3), let the principal determine the automation capacity as well as its allocation across the two divisions. Formally, the principal determines ζ, ζ_1 and ζ_0, with $\zeta_1 + \zeta_0 = \zeta \leq 1$. We refer to the corresponding problems under the decentralized and centralized structures as $\left(\mathcal{P}_\zeta^D\right)$ and $\left(\mathcal{P}_\zeta^C\right)$, respectively. 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. From Proposition 5, we know that only Division 0 will be automated under decentralization and only Division 1 will be automated under centralization. Therefore, by using Propositions 1 and 3, the problems are formulated as follows:

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

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

Proposition 7 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 7. *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:

$$\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{1-(1-\zeta_D^*)(\alpha-2\alpha^2)}{(1+\alpha(1-\zeta_D^*))^3}\right) - 2\tau\zeta_D^* = 0 \tag{21}$$

$$\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{(4-\alpha)^2}{(3(1-\zeta_C^*)+(4-\alpha))^2}\right) - 2\tau\zeta_C^* = 0, \tag{22}$$

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 7 shows that the firm adopts automation if the profit contribution of an automated task (ρ) is larger than a certain threshold ($\bar{\rho}$).[20] 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 21 and 22, the optimal level of automation capacity also depends on the residual conflict (α). Proposition 8 demonstrates this relationship.

Proposition 8. *The optimal automation capacity chosen both 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 use of automation: the decision to automate tasks within an organization can be strategic to mitigate the consequences of a residual conflict between the manager and the principal. Put differently, while there may be many other reasons for firms' adoption of automation technologies, organizational fabric is as well an important driver, and predicts that firms will not all automate their organizations at the same level — even when such technologies are equally costly, equally productive, and equally accessible to all.

Figure 7 illustrates the optimal capacity of automation under each organizational structure depending on the degree of residual conflict (α), at a given cost of automation (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, both ζ_D^* and ζ_C^*, in-

[20] 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, $\frac{l^2}{4c}$.

creases with conflict (lower α). Moreover, optimal capacity under each structure is different, indicating that the technology choice depends on the organizational structure.

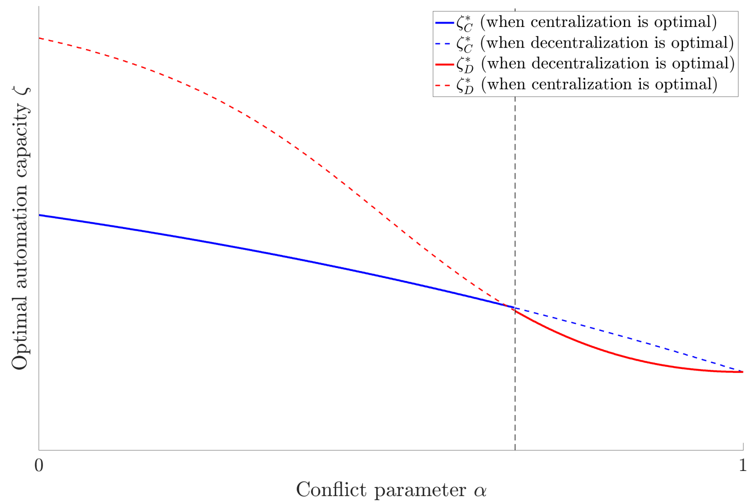


Figure 7: Optimal automation adoption.

The figure also demonstrates a more subtle insight: a firm does not always adopt the highest level of technology available. It rather couples the optimal level of technology with the organizational structure, and in some cases, chooses a lower technology capacity despite its productivity benefits. When not coupled with the right organizational structure, the principal may have to compensate for the losses associated with a suboptimal organizational structure by investing into a higher automation capacity. Consequently, the technology investment of firms whose organizational structures are suboptimal can be quite costly. This highlights an interesting and empirically testable conclusion that, firms with higher levels of automation technology investment 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 8 aids to address these questions by treating organizational structure as an outcome of the model with endogenous automation choice. The figure partitions the α-τ space into three regions. When conflict is high ($\alpha \leq 0.6$), centralization is optimal regardless of the value of the cost of automation (τ). When conflict is low ($\alpha \geq \alpha^*$) decentralization is optimal, similarly regardless of automation cost (τ). Cost of automation only matters in the 'automation-sensitive region' where conflict is intermediate ($\alpha \in (0.6, \alpha^*)$). Specifically, in this region, centralization is optimal for lower values of τ (that is, when automation adoption is less expensive) and decentralization is optimal for the higher values of τ (that is, when automation adoption is more expensive). Put differently, declining costs favor a centralized organizational structure over a decentralized structure. 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 4.3, remains considerably reliant on the manager's private information and she decentralizes the firm-level decision. As costs decline, the firm is able to adopt a higher capacity, freeing the principal from the manager's private information and reversing the optimal organizational structure decision to favor centralization, in line with the intuition provided in Section 4.3.

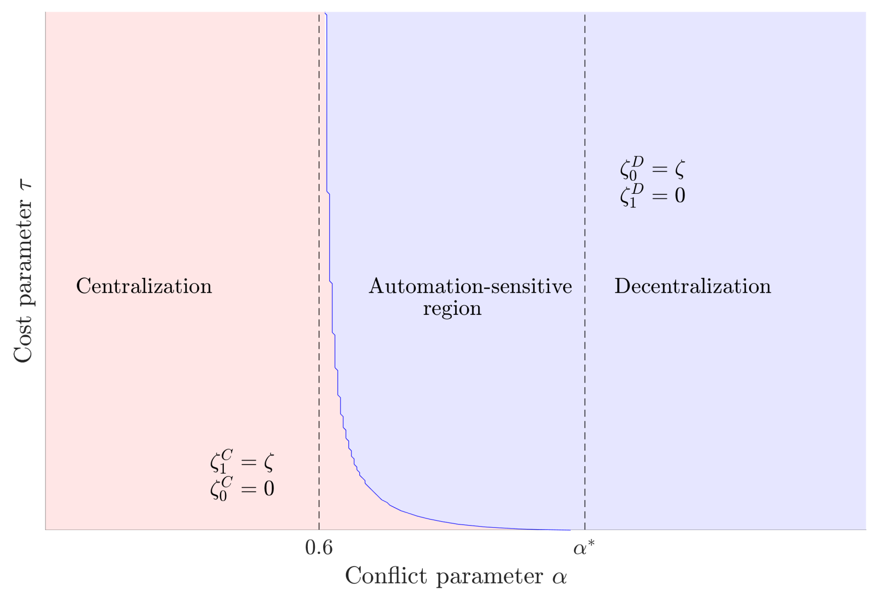


Figure 8: Optimal organizational structure as a function of the cost of automation and the degree of conflict.

Most common definitions of automation in the literature and trade publications focus on its productivity/efficiency benefits. How does increased productivity impact adoption of automation? In our model, the productivity benefit of an automated task relative to a non-automated task increases with ρ. Naturally, keeping τ fixed, as ρ increases, firms are likely to invest in higher automation capacity. Therefore, all else equal, a higher productivity will generate similar findings to those coming from a lower cost of adoption.

5.2 Endogenous Conflict

To this point, we assumed a residual conflict within the firm and ruled out the possibility that the principal could use monetary contracts to manage this conflict. In this section, we justify this assumption with a more general model. Specifically, we start with the same payoff structure as in Section 2, 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 monetary contract, and we keep all subsequent stages of the game unchanged. As we will show, (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. Thus our results from the baseline model carry over to this more general setting.

Let the manager's payoff be a linear combination of the profits of the two divisions of the firm, Π_1 and Π_0, as in Section 2. But now, the principal can increase the weight of Π_0 in manager's payoff by some $\delta > 0$:

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

With this modification, the principal can better align manager's preferences with the outcome of the business-as-usual division (Π_0)—hence with her own preferences. We will refer to δ as the "degree of further alignment" in the rest of the discussion. This further alignment comes at a cost for the principal: a choice of δ costs the principal $\lambda\delta\Pi_0$, where $\lambda > 0$ scales the cost of further alignment. Then, the principal's payoff function is:

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

We provide the solutions for any value of $\lambda > 0$. 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.[21] As λ increases, the principal is less likely to use a contract.

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

$$d^D = \beta^D(\zeta_1^D, \zeta_0^D)\theta_1, \quad \text{where } \beta^D(\zeta_1^D, \zeta_0^D) = \frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D) + (\alpha + \delta)\Delta_0(\zeta_0^D)}, \tag{23}$$

$$d^C(m) = \beta^C(\zeta_1^C, \zeta_0^C)\mathbb{E}(\theta_1|m), \quad \text{where } \beta^C(\zeta_1^C, \zeta_0^C) = \frac{\Delta_1(\zeta_1^C)}{\Delta_1(\zeta_1^C) + (1 - \lambda\delta)\Delta_0(\zeta_0^C)}. \tag{24}$$

[21] 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 9) 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.

From these expressions, note that the conflict is fully eliminated when $\delta = \bar{\delta}$, with $\bar{\delta} \equiv \frac{1-\alpha}{1+\lambda}$. Therefore, $\bar{\delta}$ corresponds to the maximum degree of further alignment that the principal is willing to bear.

Following analogous steps to those in the baseline model, we characterize the equilibrium under both organizational structures as a function of δ, ζ_1, and ζ_0. Then, for any value of $\delta \in [0, \bar{\delta}]$, the payoffs under decentralization and centralization become, respectively:

$$\mathcal{V}^D\left(\delta^D, \zeta_1^D, \zeta_0^D\right) = \pi_{1h}(\zeta_1^D) + (1-\lambda\delta^D)\pi_{0h}(\zeta_0^D) - \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[(1-\lambda\delta^D)\Delta_1(\zeta_1^D) + (\alpha+\delta^D)^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + (\alpha+\delta^D)\Delta_0(\zeta_0^D)\right]^2}, \tag{25}$$

$$\mathcal{V}^C\left(\delta^C, \zeta_1^C, \zeta_0^C\right) = \pi_{1h}(\zeta_1^C) + (1-\lambda\delta^C)\pi_{0h}(\zeta_0^C) - \frac{\left(4(1-\lambda\delta^C) - \left(\alpha+\delta^C\right)\right)\Delta_1(\zeta_1^C)\Delta_0(\zeta_0^C)}{3\left[3\Delta_1(\zeta_1^C) + \left(4(1-\lambda\delta^C) - (\alpha+\delta^C)\right)\Delta_0(\zeta_0^C)\right]}. \tag{26}$$

The principal optimizes the value of 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 payoff levels under the optimal values of δ, ζ_1 and ζ_0 for decentralization and centralization.

Proposition 9. *Under decentralization, it is never optimal to fully eliminate the residual conflict, i.e., $\delta^C < \bar{\delta}$. As λ increases, δ^D strictly decreases until we reach a cutoff $\bar{\lambda}^D$. When $\lambda > \bar{\lambda}^D$, the principal does not use monetary incentives for further alignment, i.e., $\delta^D = 0$.*

Proposition 9 shows that, under decentralization, the principal never fully eliminates residual conflict—even when the cost of monetary incentives is very small. Moreover, when λ is larger than a certain threshold, she stops using monetary incentives altogether.

Proposition 10. *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, i.e., $\delta^C = 0$.*

Proposition 10 specifies the equilibrium contract use for centralization and provides a similar picture to Proposition 9 in that, when the cost of providing monetary incentives is high, the principal chooses not to use them. However, if the cost is low, in this case, the principal can use them and fully eliminate the residual conflict.

Corollary 5. *When using monetary incentives is sufficiently costly (i.e., λ is high), the principal does not use them ($\delta = 0$) and all results in the baseline model remain unchanged.*

Corollary 5 is a robustness result, stating our key insight: when the cost of conflict mitigation 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. Stated differently, our baseline model, which assumes a residual exogenous conflict, provides a good approximation of this more general model.

In the remainder of this section, we provide additional insights about the role of monetary contracts and automation. Figure 9 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 $\delta = 0$ (no monetary contract) and $\delta = \bar{\delta}$ (no residual conflict).

Remark 1. *Automation capacity and monetary contracts serve as strategic substitutes for the principal to manage conflict.*

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 that implies that the strategic use of technology deployment can substitute for conventional methods of managing subordinates. Investment into a higher automation capacity, when automation is utilized alongside contracts, can make such contracts less costly. The return on investment for automated technologies should therefore not be calculated by considering the cost of production alone, but also by considering the savings from the costs of incentive alignment.

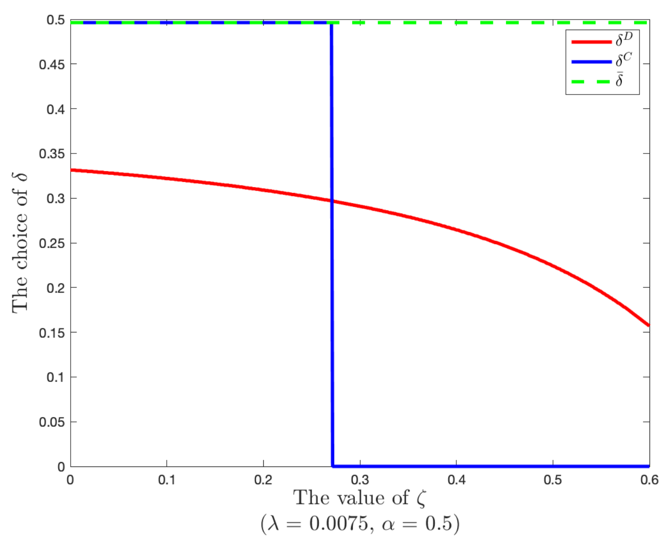
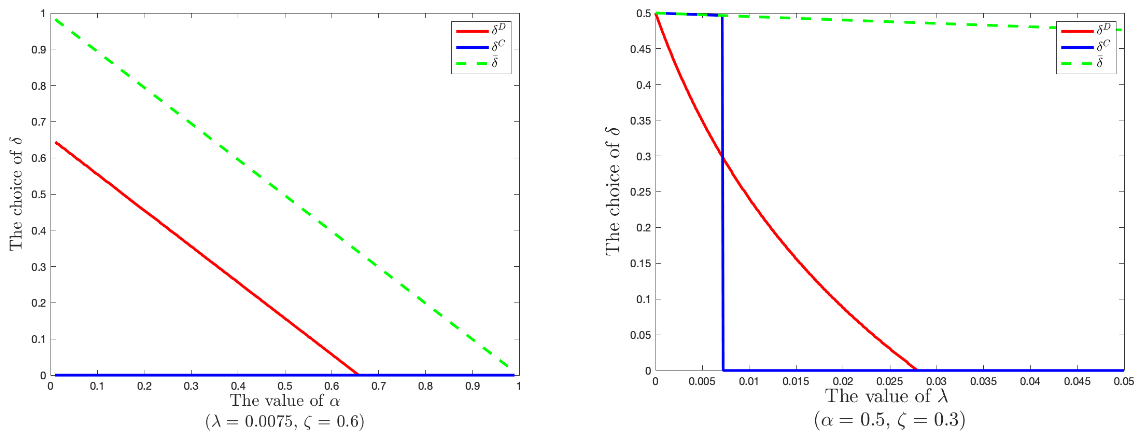


Figure 9: Degree of further alignment (δ^D, δ^C) vs. automation capacity (ζ).

Figure 10a illustrates the degree of further alignment under decentralization and centralization (δ^D and δ^C) depending on the conflict (α) for fixed values of cost of alignment (λ) and automation capacity (ζ). In the figure, as conflict increases (lower α), the principal allocates a higher share of Division 0's profit for further alignment (higher δ). Figure 10b illustrates the dependency of δ^D and δ^C on λ for fixed levels of residual conflict and automation capacity.



(a) Depending on the value of α.

(b) Depending on the value of λ.

Figure 10: The dependency of δ^D, δ^C on α and λ.

The main observations are threefold. First, there is no uniform relationship between δ^D and δ^C. Second, under the centralized organizational regime, the principal's use of monetary contracts features a bang-bang structure, in that she either completely eliminates the conflict or does not use monetary contract at all (Proposition 10). This is not the case for decentralized organizations and the principal never fully eliminates the conflict (Proposition 9). Last, the use of monetary contracts decreases with its cost λ. This is rather intuitive, as the cost of further alignment increases, using monetary contracts becomes less attractive for the principal.

Finally, Figure 11 reproduces Figure 6 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 decentralization more likely. This indicates once again that our reduced-form baseline model captures the relationships revealed by the more general model of this section.

5.3 Discussion on Additional Considerations

Note that our model left a number of additional factors out of scope. We briefly discuss them below.

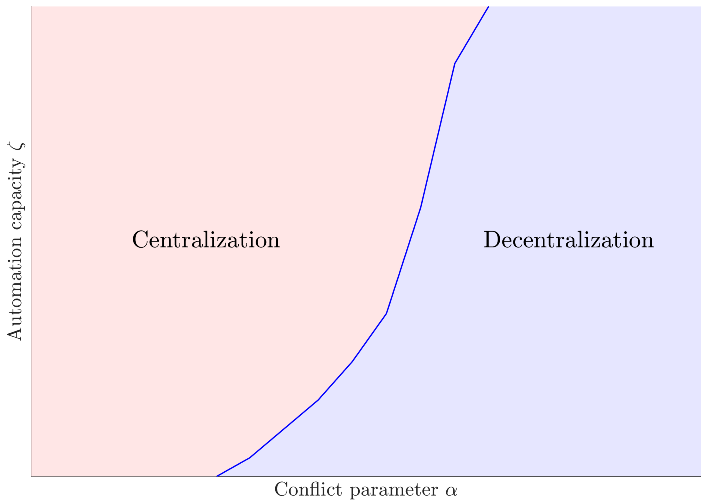


Figure 11: The optimal regime depending on the automation capacity in the presence of monetary contracts.

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. less-informed 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 information of 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) acts 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 that, 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, we could consider the case where the worker effort is not observed by the principal, creating a moral hazard problem. Specifically, we would assume that each task results in either "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 in 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, the optimal automation deployment strategy, and the equilibrium communication 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 adoption of a higher automation capacity (Section 5.1). In this sense, moral hazard acts similarly to a higher productivity of automated tasks (larger ρ) and a lower cost of automation adoption (lower τ).

6 Conclusion

The exponential growth in computing technology has improved robotics and artificial intelligence dramatically since the 1960s, and these technologies are transforming today's organizations. Machines and software are integral parts of all marketing and management operations today, in industries ranging from manufacturing, retail, law, medicine, geology, to engineering. With the growing scope and scale of automation, not surprisingly, the interest from scholars in understanding the implications of automation in workplaces has grown. However, a great majority of these studies to date focused on the immediate impact of automation on labor market outcomes such as employment and wages (Acemoglu and Restrepo, 2019, 2020) and reallocation of labor from low-skill to high-skill tasks (Acemoglu and Restrepo, 2018). Automation's impact in organizations, however, goes beyond these labor market effects. To our knowledge, this is the first study to document broader impacts of automation with a focus on the organizational structure and decision-making.

Our analysis yielded four key findings. First, we show that one must anticipate heterogeneity among firms in how they utilize an identical automation technology. More specifically, in firms in which the decision-making authority is reinforced at the top, tasks in divisions with more uncertainty are automated. This pattern is reversed in firms where decision-making authority is distributed within the firm, and tasks in less uncertain divisions face automation. The mechanisms which drive automation adoption and utilization in each of the two described cases are different. In the former case, automation helps a principal to reduce her reliance on her subordinate's private information, while in the latter case it helps a principal to shield the business-as-usual division from biased decision-making.

Second, when the overall automation capacity increases, firms in marketplace follow distinctly different strategies of adaptation to changing market conditions. Centralized firms lean more towards a continuation strategy relative to decentralized firms, which lean more towards an adaptation strategy. Moreover, with higher investment into automation, the difference between the two strategies increases—forming further differentiation between firms, as the former becomes more stale and the latter becomes more agile.

Third, we offer three new insights about the changes that a firm may anticipate with regards to its human resources and decision-making. First, unlike the conventional thinking in labor markets which assumes that firms will automate low-skilled tasks first (Autor et al., 2003), our results suggest that the opposite may hold for some firms, if the uncertain divisions house higher-skilled tasks on average. Second, automation may reduce the strategic role of mid-level managers and re-appropriate them towards more operational tasks. Importantly, the changes to the scope of a manager's duties are not because *his* job is automated—it is the automation of lower level tasks what changes the nature of his responsibilities. Third, as automated technologies become less costly over time, and can be adopted more easily by firms, the increased automation capacity, in turn, will result in further centralization in organizations, where the decision-making authority is reinforced at the top. This finding reverses the predictions from earlier literature (Acemoglu et al., 2007) which claim that new technologies are more likely to result in decentralized, more democratic organizations.

Last, but perhaps most importantly, we show that automated technologies offer executives a substitute to monetary contracts to manage conflict. In Extension 5.2, we show that an executive does not always choose to use a monetary contract to manage the conflict with the manager, and when she does, she may choose not to eliminate the conflict completely. When she is endowed with a higher technology capacity, she can further forego the use of contracts. This is a striking finding, as to our knowledge, this is the first paper to offer insights about how new technologies (possibly including those other than automation) interact with contracts—therefore, payment and management of subordinates—and reduce an executive's reliance on them in a firm.

Table 1 summarizes our findings as questions and guidelines for managers and technology consultants who are thinking about the possible implications of automating organizations. We list a number of strategic questions in each row, and next, we describe our prescription to address them depending on the structure of the firm.

Managerial Problem	Organizational Structure: Centralized	Organizational Structure: Decentralized
Q1. Which tasks should be automated?	Repetitive, Low-uncertainty	Cognitive, High-uncertainty
Q2. How should adaptation strategy look?	Focus more on continuity, use existing strategies	Focus more on adaptation, embrace new market conditions
Q3. How does increasing automation resources affect firm strategy?	Increasing continuity, becoming more stale	Increasing adaptation, becoming more agile
Q4. How does automation strategy change consensus among managers?	Increased consensus between top- and mid-managers	Decreased consensus between top- and mid-managers
Q5. How does increasing automation impact the likelihood of organizational structure?	Becomes more likely	Becomes less likely

Table 1: Managerial Questions about Automation & Prescriptions

Implications for Marketing Managers

Automation of marketing tasks is happening at a rapid pace. Therefore marketing managers naturally wonder how automating tasks will change their organizations, and what kind of tasks they should automate.

For managers, we have six recommendations. First, before they choose to automate tasks, they should keep in mind that, even the automation of simple, routine, low-level tasks can influence the interactions between mid- and higher-levels of management. For instance, a marketing executive of a grocery chain may assume that automating checkout (i.e., removing human cashiers and adopting self-checkout kiosks) may not have an impact on the behaviors of the floor-manager. However, our study suggests, automating seemingly simple tasks may influence the reporting of a mid-level manager, therefore, may impact a principal's reliance on the manager and his decision-making role, too.

Second, marketing tasks vary widely in terms of the required cognitive skills and the degree of uncertainty involved. If a marketing executive must choose between automating between two tasks, which one should she pick? Some tasks such as setting prices for products, deciding on levels of inventory to stock, or choosing product design attributes are decisions involving higher degrees of uncertainty, and may require higher levels of judgement and reasoning. Other tasks such as checkouts, service and repair of products, and product shipment are routine tasks relying on manual and less-cognitive skills. While it is possible to automate all of the above mentioned marketing tasks today, our paper suggests that marketing managers do not necessarily need to rush to do so. Our study shows that considerations such as the structure of an organization, beyond technological advances and cost of technology, may affect the choice of which task to automate. While there is no one-size-fits-all answer, in Table 1, we provide guidelines. The decision to automate checkouts may look very different for two grocery store chains, e.g., for Walmart and Wegmans, if they differ in organizational structure. So, an identical and accessible technology such as self-checkouts may not be advisable to adopt for grocery stores. If Walmart has a centralized structure, then it is advisable to automate checkout. If not, automating divisions with higher uncertainty or higher-skill tasks (e.g., automation of pricing decisions, product design) is a better fit to the company.

Third, our findings suggest that as firms adopt higher levels of automation and use it optimally, their adaptation strategies will start to differentiate. A higher adaptation or a higher continuation strategy has direct implications on marketing outcomes. For instance, a higher adaptation requires a firm to be more agile, i.e., adapt to changing market conditions. Some examples of changing market conditions in marketing are, changing customer preferences for the features they would like to see in a product, changing macroeconomic conditions, or changing levels of competitive advertising. A more agile firm modifies product offerings, prices, and competitive advertising strategy, respectively, in response to each of these mentioned conditions. A more stale firm follows a continuation strategy, e.g., responds to changing market conditions at a lesser extent. Our findings suggest that, automation can change how much a company alters these strategies based on the changing conditions. In other words, the dynamics of marketing strategy is influenced by the automation strategy of a firm.

Fourth, with higher levels of automation there will be higher differentiation across firms in terms of their adaptation strategies. This would imply, for instance that one company, e.g. Apple, may increase the frequency with which it upgrades the IPhone, while another, e.g. Samsung, may reduce the frequency with which it upgrades the Galaxy, if they have different organizational structures. Similarly, the frequency of price changes may show a greater gap between brands with higher automation levels, if they have different organizational structures. One brand would update prices more frequently (raising or decreasing them based on market conditions), and the other would smooth them over time.

Fifth, our study predicts higher degree of centralization as automation becomes cheaper and more accessible. The shift towards centralization may indicate a more radical organizational change for decentralized organizations relative to those who are already centralized. 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 better prepared for the changes that may come with automation. Failing to adjust organizational structure can have costly repercussions because it calls for higher—and therefore more costly—automation investment.

Finally, we deliver insights to marketers of automated technologies. Our study is a testament to the importance of organizational structure and conflict in deciding whether and how much to adopt automation. Therefore, we recommend salespeople trying to market automated technologies not to use blanket targeting strategies, but to offer the right technology to the right customer. Automation offers benefits such as reducing the reliance on financial contracts and reducing variability, which are little emphasized in practice, when automation firms are marketing these technologies to other firms. Marketers offering such technologies may want to focus more on these features in their promotional materials.

6.1 Future Research and Limitations

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 hopes that they will spur ideas for further examination of the timely and important topics of organizational design and technology.

1. For managers, above and beyond the benefits of increasing the efficiency with which a task is carried out, automation offers a strategic tool to manage the organization.

2. For any type of automation technology, there exists substantial heterogeneity among organizations in how they utilize it. Specifically, while organizations with decentralized decision-making structures are more likely to use automation in divisions where conditions are more certain, centralized firms automate tasks in divisions facing uncertainty.

3. For a given automation level, decentralized firms are better at adapting to new market conditions. For instance, these firms may more frequently update their products and services in line with the changing consumer demand. Moreover, as automation capacity increases for both centralized and decentralized firms, the gap between them in adaptation to the new conditions increases.

4. Firms with greater conflict or ill-managed organizational structures are more likely to invest into higher automation capacity relative to firms with lower conflict. From this perspective, a higher automation capacity may be a mask for ill-management of the organization.

5. As costs of automation decline, decision-making in organizations is more likely to be centralized, where higher-ranked managers are in charge of strategic decisions.

6. Firms are heterogeneous with respect to their automation of divisions that house low- vs. high-skilled tasks.

7. Use of contracts with mid-managers for incentive alignment may decline as a firm invests more into higher automation capacity.

Limitations

Our findings are limited in a number of ways. We used a stylized model of a firm focusing on a particular divisional structure in order to deliver sharp insights without further mathematical complications. There would be little change to the current insights if we introduced uncertainty in Division 0 as well, but at a lesser extent than what Division 1 faces. Moreover, we also kept the definition of automation purposefully simple and did not make stylized assumptions about its functions. This allows us to produce more generalizable findings. We leave these as examinations for future research.

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7 Proof of 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:

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

This completes the proof.

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:

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

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 7), we reach to:

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

This completes the proof.

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:

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

This completes the proof.

Proof of Proposition 2:

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 and Δ_0 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:

$$\left(1-(\theta_c-\beta^C e_{m'})^2\right)\pi_{1h}(\zeta_1^C)+(\theta_c-\beta^C e_{m'})^2\pi_{1l}(\zeta_1^C)+\alpha\left\{\left(1-(\theta_0-\beta^C e_{m'})^2\right)\pi_{0h}(\zeta_0^C)+(\theta_0-\beta^C e_{m'})^2\pi_{0l}(\zeta_0^C\right.$$
$$> \left(1-(\theta_c-\beta^C e_m)^2\right)\pi_{1h}(\zeta_1^C)+(\theta_c-\beta^C e_m)^2\pi_{1l}(\zeta_1^C)+\alpha\{(1-(\theta_0-\beta^C e_m)^2\pi_{0h}(\zeta_0^C$$
$$+(\theta_0-\beta^C e_m)^2\pi_{0l}($$

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:

$$(1-(\psi_k - d^C(m_k))^2)\pi_{1h}(\zeta_1^C) + (\psi_k - d^C(m_k))^2\pi_{1l}(\zeta_1^C) + \alpha\left((1-(d^C(m_k))^2)\pi_{0h}(\zeta_0^C) + (d^C(m_k))^2\pi_{0l}(\zeta_0^C)\right).$$

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

$$(1-(\psi_k - d^C(m_{k-1}))^2)\pi_{1h}(\zeta_1^C) + (\psi_k - d^C(m_{k-1}))^2\pi_{1l}(\zeta_1^C) + \alpha\left((1-(d^C(m_{k-1}))^2)\pi_{0h}(\zeta_0^C) + (d^C(m_{k-1}))^2\pi$$

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:

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

After some algebra, we obtain:

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

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

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

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:

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

This completes the proof.

Proof of Proposition 3:

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.

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

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

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 2). 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:

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

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

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

This completes the proof.

Proof of Corollary 1:

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). This completes the proof.

Proof of Corollary 2:

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

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

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

Proof of Corollary 3:

We first identify the firm's profit under no information. The decision $d^C(m)|_{m=\emptyset}$ is equal to 0—which directly results from Equation (10) and from the fact that $E(\theta_1) = 0$. Then, the firm's profit is given by:

$$\begin{aligned} \underline{\Pi}(\zeta_1, \zeta_0) &= \mathbb{E}\left[\bar{\pi}_0\left(\zeta_0, 0, \theta_0\right)\right] + \mathbb{E}\left[\bar{\pi}_1\left(\zeta_1, 0, \theta_1\right)\right] \\ &= \pi_{0h}(\zeta_0) + \pi_{1h}(\zeta_1)\int_{-1}^{1}\left(1 - \theta_1^2\right)\frac{d\theta_1}{2} + \pi_{1l}(\zeta_1)\int_{-1}^{1}\theta_1^2\frac{d\theta_1}{2} \\ &= \pi_{0h}(\zeta_0) + \frac{2}{3}\pi_{1h}(\zeta_1) + \frac{1}{3}\pi_{1l}(\zeta_1) \end{aligned}$$

We now turn to the firm's profit under perfect information. We can directly use Equation (14) with $\alpha = 1$. This yields:

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

We obtain:

$$\begin{aligned} VOI(\zeta_1, \zeta_0) &= \overline{\Pi}(\zeta_1, \zeta_0) - \underline{\Pi}(\zeta_1, \zeta_0) \\ &= \frac{\Delta_1(\zeta_1)^2}{3(\Delta_1(\zeta_1) + \Delta_0(\zeta_0))} \\ &= \frac{(1 - \zeta_1)^2}{3(2 - \zeta_1 - \zeta_0)}\frac{h^2 - l^2}{4c} \end{aligned}$$

One can easily check that this expression decreases with ζ_1 and increases with ζ_0. This completes the proof.

8 Proof of Statements from Section 4

Proof of Proposition 4:

From Equations (19) and (20), we know that, conditional on symmetric automation allocation, the centralized structure is optimal if and only if:

$$\frac{1+\alpha^2}{3(1+\alpha)^2}\Delta_S \geq \frac{4-\alpha}{3(7-\alpha)}\Delta_S.$$

After some algebra, we find that it is equivalent to:

$$3 + 5\alpha^2 - 8\alpha \geq 0.$$

Since $\alpha \in [0,1]$, this is equivalent to $\alpha \leq 0.6$. This completes the proof.

Proof of Proposition 5:

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 (4) 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:

$$\min_{\zeta_1^D,\zeta_0^D \in [0,1]} \frac{\Delta_1(\zeta_1^D)\Delta_0(\zeta_0^D)\left[\Delta_1(\zeta_1^D) + \alpha^2\Delta_0(\zeta_0^D)\right]}{3\left[\Delta_1(\zeta_1^D) + \alpha\Delta_0(\zeta_0^D)\right]^2,} \quad \text{s.t.} \;\; \zeta_1^D + \zeta_0^D = \zeta.$$

Moreover, we write in the remainder of this proof (Equation (5)):

$$\Delta_i(\zeta_i, w^*) = (1-\zeta_i)\kappa \quad \text{with } \kappa = \frac{h^2 - l^2}{4c}. \tag{27}$$

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 equivalent to:

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

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

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

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

As before, we know from Equation (4) 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:

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

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 $\zeta_1 \in [0, \zeta]$:

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

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

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

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.

This completes the proof.

Proof of Proposition 6:

By using the result of Proposition 5, 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:

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

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

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

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

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

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

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

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. This completes the proof.

9 Proof of Statements from Section 5

Proof of Proposition 7:

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 $\kappa = \frac{h^2-l^2}{4c}$:

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

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.

$$
\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{1-(1-\zeta_D^*)(\alpha-2\alpha^2)}{(1+\alpha(1-\zeta_D^*))^3}\right) - 2\tau\zeta_D^* = 0 \tag{28}
$$

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:

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

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.

$$\rho - \frac{h^2}{4c} + \frac{\kappa}{3}\left(\frac{(4-\alpha)^2}{\left(3(1-\zeta_C^*)+(4-\alpha)\right)^2}\right) - 2\tau\zeta_C^* = 0 \tag{29}$$

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 8:

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:

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

Moreover we have

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

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. This completes the proof.

10 Proof of Statements from Section 5.2

In this section, we first characterize the principal's payoff under each organizational structure, for given values of $\lambda > 0$, and $\delta \in [0, \bar{\delta}]$, in Proposition 11, and then prove it. Then we proceed to the proofs of Propositions 9 and 10 and Corollary 5 presented in Section 5.2.

Proposition 11. *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:*

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

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

Proof of Proposition 11

Under decentralization, we have:

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

Then by using the definition of $\beta^D(\zeta_1^D, \zeta_0^D) = \frac{\Delta_1(\zeta_1^D)}{\Delta_1(\zeta_1^D)+(\alpha+\delta)\Delta_0(\zeta_0^D)}$ gives us the principal's payoff under decentralization (Equation 25).

Under centralization, following the same steps with the proof of Proposition 2, 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

$\psi_k = r^{k-1}$:

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

Similarly:

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

Therefore, we obtain:

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

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

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

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:

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

Proof of Proposition 9

The optimal degree of further alignment under decentralization 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:

$$\begin{aligned}
&\frac{\partial \mathcal{V}^D\left(\delta, \zeta_1^D, \zeta_0^D\right)}{\partial \delta} \\
&= -\lambda\pi_{0h} - \frac{\Delta_1\Delta_0}{3}\frac{\left[-\lambda\Delta_1 + 2(\alpha+\delta)\Delta_0\right]\left[\Delta_1 + (\alpha+\delta)\Delta_0\right] - 2\Delta_0\left[(1-\lambda\delta)\Delta_1 + (\alpha+\delta)^2\Delta_0\right]}{\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3} \\
&= -\lambda\pi_{0h} + \frac{\Delta_1\Delta_0}{3}\left[\frac{\lambda\Delta_1^2 + \Delta_0\Delta_1\left[2(1-(\alpha+\delta)) + \lambda(\alpha-\delta)\right]}{\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3}\right] \\
&= -\lambda\underbrace{\left[\pi_{0h} - \frac{\Delta_0\Delta_1^2\left[\Delta_1 + (\alpha-\delta)\Delta_0\right]}{3\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3}\right]}_{>0} + \frac{2\left[1-(\alpha+\delta)\right]\Delta_0^2\Delta_1^2}{3\left[\Delta_1 + (\alpha+\delta)\Delta_0\right]^3} \qquad (30)
\end{aligned}$$

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 (30) is negative. This implies that when λ is large enough, the partial derivative $\frac{\mathcal{V}^D\left(\delta,\zeta_1^D,\zeta_0^D\right)}{\partial\delta}$ 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:

$$\left.\frac{\partial \mathcal{V}^D\left(\delta, \zeta_1^D, \zeta_0^D\right)}{\partial \delta}\right|_{\delta=\bar{\delta}} = \lambda\left(-\pi_{0h} + \frac{\Delta_1^2\Delta_0}{3(\Delta_1 + M\Delta_0)^2}\right) \qquad (31)$$

It is clear to see that, $\frac{\partial\mathcal{V}^D\left(\delta,\zeta_1^D,\zeta_0^D\right)}{\partial\delta} < 0$ 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 (30) that $\frac{\partial^2\mathcal{V}^D\left(\delta,\zeta_1^D,\zeta_0^D\right)}{\partial\delta^2} < 0$ 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 $\frac{\partial\text{FOC}}{\partial\delta^D}<0$.

Proof of Proposition 10

Recall that, 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:

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

We now complete the proof of Proposition 10 in a number of steps.
Step 1. 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:

$$\frac{\partial\mathcal{V}^C\left(\delta,\zeta_1^C,\zeta_0^C\right)}{\partial\delta}=-\lambda\pi_{0h}+\frac{\Delta_1^2\Delta_0(4\lambda+1)}{\left[3\Delta_1+\left(4(1-\lambda\delta)-(\alpha+\delta)\right)\Delta_0\right]^2}\tag{32}$$

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.
Step 2. 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.
Step 3. 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 (4) and (5)), 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 $\bar{\lambda}^C$ and completes the proof.

Proof of Corollary 5

Defining $\bar{\lambda} = \max\{\bar{\lambda}^D, \bar{\lambda}^C\}$, and $\underline{\lambda} = \underline{\lambda}^C$ completes the proof.