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Abstract

We consider an organization with two projects which have productive spillovers. Three agents are active in this organization: two agents, each specialized in one project, and the CEO, who is a generalist. The organization owner first allocates authority over each project to these three individuals. When an individual has authority over one project, which is not necessarily the one he is specialized in, he decides between prioritizing this project or the spillover it generates on the other project. Next, every individual decides which level of effort to exert; each agent chooses the effort in the project he specializes in, and the CEO chooses the effort impacting both projects. Each individual receives a share of the project's profits he puts effort in and a share of the project's profit for which he has authority. This creates a double moral hazard problem as none of these two decisions are contractible. Under two conditions, we show the optimality of hierarchical delegation, that is, an internal organization in which the CEO has authority over one project and one agent has authority over the project he is not specialized in. The first condition is that the CEO is more productive in exerting effort than the agents. The second condition is that prioritizing spillovers is moderately more profitable than prioritizing the profits in the project on which one has authority. We illustrate the emergence of hierarchical delegation by studying the significant reorganization that took place at Facebook in 2018.

JEL Classification: C70, D23, L22.

Keywords: decision rights, authority, moral hazard, hierarchies, incentives.

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I Introduction

Hierarchies are ubiquitous in modern corporations even though there is a clear tendency in companies to reduce the layers of these organizations. However, as mentioned by Foss and Klein (2023) the challenge for the companies is to *rethink hierarchies* since they represent a useful way to balance two opposing forces: autonomy to mobilize employees' and managerial authority to coordinate an organization in a large scale. Although hierarchies are present in almost every current organization, the main results in economics rely generally on simple two-layers organizations, where prescriptions are either to centralize or to decentralize decision rights. We focus on an organization that choose the number of layers of its organizational design, allowing for more than two layers of hierarchy, in order to balance projects coordination and individual self-motivation. What is the optimal organizational design under these conditions? Under what circumstances do *more than two-layer* hierarchies perform better than alternative forms of organization?

We study the organizational design of a two-project organization with productive spillovers among projects. Similar to Choe and Ishiguro (2012), there are three active individuals in this organization: two agents (Ari and Bob), each specialized in one project (A and B, respectively), and a CEO, who is a generalist, involved in both projects. By organizational design we mean the owner's allocation of authority over each project to one of the three individuals. When an individual has authority over one project, he decides to prioritize either this project or the spillovers it generates on the other project. We also define the former as a motivational or selfish decision and the latter as a cooperative decision. After that, each individual decides the level of effort to exert affecting the probability of project success; a specialized effort by each agent or a general effort affecting both projects by the CEO. Each individual perceives a share of the project's profits where he puts effort in and a share of the project for which he has authority. These self-interested individuals have no commitment either to the project's decision or to the costly effort to exert, revealing a double moral hazard problem. In this context, a hierarchical delegation design is optimal under two conditions: (1) the CEO's effort is more productive than the sum of the two agents' efforts; and, (2) prioritizing spillovers is moderately more profitable than prioritizing the project on which he has authority. By hierarchical delegation, we refer to an organization with three layers of hierarchy where the CEO has the authority over one project while the agent specialized in that project has the authority over the other project.

In our model the two elements that relate to both projects are the general effort that the CEO makes, and the spillovers that each project has on the other one. The decision-making affects the payoffs of each project, and because of that, also the optimal effort decision. In this scenario, when spillovers are substantial and the CEO is more productive than the agents, a hierarchical delegation design results in a good balance to implement cooperation in projects decisions and to motivate the CEO to exert effort. In a hierarchical delegation design, the organization focuses on one project (say project A) as a consequence of three main reasons. First, the CEO's decision prioritizes the intrinsic profits of project A, relegating the spillovers this project could have generated but motivating Ari to exert effort. Second, it capitalizes the spillovers that project B generates in project A since Ari's makes a cooperative decision in project B. Third, the CEO has high incentives to exert effort, increasing the probability that both projects are successful and increasing the expected profits in project A (due to motivation and project B spillovers). We contribute to the literature by showing that this structure emerges as a response to the lack of commitment that the CEO has to make optimal decisions in a double moral hazard setting.

We study the optimal organization by comparing every possible organizational design. The main organizational designs are centralization (the CEO has the authority over both projects), decentralization (each agent has the authority over his own project), cross-authority (each agent has the authority over the other project), and hierarchical delegation (the CEO has the authority over one project, say A, and Ari has the authority over project B). The optimal organizational design balances the trade-off between the relative profits of spillovers with respect to the intrinsic profit that a project has itself and the relative productivity of the CEO with respect to the agents.

We define two scenarios that we use as reference points. First, a *first best scenario* where a social planner maximizes a welfare function or, in other words, a case where the owner can observe and enforce decisions and efforts. In this case, the social planner prioritizes spillovers when they are more profitable than the intrinsic value of a project, complementing the project decision with optimal levels of effort. Importantly, decision-making is not affected by the relative productivity of the CEO with respect to the agents.

Second, a *benchmark scenario* in which the owner not only chooses an organizational design but also is in charge of the decision-making. However, the owner faces moral hazard problems in agents and CEO effort provision. The moral hazard problem is more severe when spillovers are pursued with cooperative decisions. The spillover profits must be high enough to compensate for the severe moral hazard problem on efforts; otherwise, selfish decisions to prioritize the project in which the individual has the authority are preferred. In terms of the organizational design, the owner anticipates that the authority provides additional incentives to exert effort. Consequently, when the CEO is more productive than the agents, centralization is the best organizational design. When the CEO is less productive than the agents, agents are in charge of making project decisions: either under decentralization or cross-authority, depending on whether spillovers are low or high, respectively. In any case, the decision is always made by the owner no matter who is in charge of implementing it.

In the main modelthe owner allocates authority but is not able to control the decision to be made. As a consequence, when incentives between the owner and the decision-maker (CEO, Ari, and/or Bob) are not aligned some additional conflict of interest arises. When the CEO is less productive than the agents the results of the *benchmark* and the *model* remain equal, as incentives are aligned. However, when the CEO is more productive than the agents emerges the main result. If the profits of the spillovers are moderate, centralization may no longer be the best organizational design (recall that in the *benchmark* it is always preferred). Instead, cross authority or hierarchical delegation are the second best organizational designs chosen by the owner. The conflict arises because the CEO knows that spillovers are important but she also bears the main cost of efforts for the projects to be successful. The CEO prefers instead to prioritize the profits of the projects in which she has the authority to encourage agents' effort. Consequently, the owner chooses another organizational design delegating at least partially on the agents. When the CEO is slightly more productive than the agents, cross authority is the best design to balance the level of efforts with cooperative decisions. When the CEO is considerably more productive than the agents, hierarchical delegation is the best organizational design to balance high effort (by the CEO) with partial cooperation (and partial motivation).

Since we consider a fixed payment scheme, we make a comparative statics analysis in which we consider different values for participation share and authority share of the profits to understand their impact on the implementation of constrained-optimal organizations (hierarchical delegation and cross-authority). Thus, we show that hierarchical delegation and cross-authority are more likely to arise with an increase in the share of profits allocated to the intrinsic motivation (in both projects). In other words, the more important the moral hazard problem in the effort choice, the more likely the organization relies on a hierarchical delegation design.

Our results are useful to understand the restructuring of Facebook in 2018. There is ample evidence of structure reorganization, with companies like *Google (2015)*, *Tesla (2018)*, and *Disney (2018)* undergoing such changes.[1,2] Additionally, reorganizations in companies like P&G, Sony, and IBM were previously highlighted in Choe and Ishiguro (2012). Every reorganization seeks to find the right balance between project coordination and managerial motivation. In this paper, we focus on Facebook's reorganization, for which we have collected valuable anecdotal information that has not been previously discussed.

Facebook underwent a structural shift, transitioning from a more decentralized organizational model to a more hierarchical one in 2018. We interpret that this change aimed to improve coordination from the other apps with the Facebook app without renouncing considerably to some self-motivation in the Facebook app. We study the case from the acquisition of Instagram in 2012 and WhatsApp in 2014 to the reorganization in 2018. Both acquisitions were driven by the recognition of strong synergies among these apps. However, despite the complementarities, Instagram and WhatsApp were led by their founders and independently from the Facebook app until 2018. After the reorganization, the Facebook app took special centrality. The CEO (Zuckerberg) supervises strategic decisions on the main app and develops the ad technology (e.g., algorithms) to monetize every app. However, the manager in charge of the Facebook app started to control both apps which is evident in three different features. First, Instagram and WhatsApp's leaders were replaced by former Facebook veterans and all apps were unified in one big unit, facilitating enhanced coordination and granting the Facebook app greater control. Second, at this point, the Facebook app was the most effective platform for monetizing advertising, owing to its inherent social network characteristics and its traffic volume.[3] Finally, Facebook took over the main product of WhatsApp, its messaging system, and substantially increased coordination between Instagram and Facebook through a one-way cross-posting policy.[4] By aligning all these apps under the umbrella of the Facebook app, the company's board ensured seamless coordination and retained the leadership of the Facebook app under the orbit of the company's CEO. The reorganization materialized in continuous profit growth for the company, primarily driven by the success of the Facebook app and the spillovers the Facebook app received from the other apps.

This paper provides the following contributions. First, it contributes to the literature showing that hierarchical delegation is the optimal organization to deal with a double moral hazard problem in effort and decision making when spillovers are important. Even when previous papers have already shown that this organization may arise, we provide that these results are robust to different setup extensions. Second, and maybe more important, we identify that the lack of commitment of the CEO to make the owner's most preferred decision motivates the emergence of the hierarchical delegation design as the optimal structure and we conduct a sensitivity analysis to show the robustness of the results. Third, it applies the theoretical framework to understand 2018 Facebook's reorganization, contributing with new relevant evidence in an important and dynamic industry.

[1]In Google's case, in his announcement, Page stated that the planned holding company would allow for '... more management scale, as we can run things independently that aren't very related'. Available at `https://www.cnet.com/tech/tech-industry/googles-larry-page-explains-the-new-alphabet/`.

[2]In Disney's case, "The new structure consolidates the company's direct-to-consumer services, technology and international media operations into a single business to coordinate and capitalize opportunities. Additionally, the before separated parks and resorts, and consumer products operations are combined to increase the visibility of Disneys' characters." All the information availble at `https://disneyconnect.com/dpep/the-walt-disney-company-announces-strategic-reorganization/`.

[3]Monetizing in WhatsApp posed challenges due to its nature of messaging app and Instagram had considerably less traffic than Facebook at the time.

[4]This policy allowed content posted on one app, particularly Instagram, to be instantly mirrored on the other, specifically Facebook.

The remainder of the paper is organized as follows. Section II summarizes the related literature. Section III introduces the model as well as the first best and benchmark scenarios. Section IV describes all possible organizational designs. Section V shows the optimal organizational structures in benchmark and model scenarios. Section VI shows a comparative static analysis for the payment scheme. Section VII discuss the main assumptions. Section VIII shows a case of study. Finally, Section IX concludes.

II Related literature

Organizational design and firm's hierarchies have long traditions in the literature of economics (Coase, 1937; Williamson, 1975; Grossman and Hart, 1986). Traditionally, the literature considers two different kinds of hierarchies: *simple* or *two-tier* hierarchies and *multi-tier hierarchies.* The study of *multi-tier hierarchies* have different approaches: an incentive approach, communication problems and information flows, and heterogeneous agents with different abilities. This paper is strongly related to the literature of hierarchies from an incentive perspective. A thorough survey of these results can be consulted on Gibbons et al. (2013) and in Mookherjee (2006). Some seminal papers like Aghion and Tirole (1997); Baker et al. (1999) analyze the decision to either delegate authority or not given that the information in the hands of individuals at the bottom and at the top differ.[5] Several other papers pursue this research as well.[6] Among the second approach three important papers related to ours are Dessein (2002), Rantakari (2008) and Alonso et al. (2008).[7] The overall conclusion of all this literature is that (more) centralized organizations show up as a need of more coordination (span of control, task allocations, etc.) while decentralized organizations appear as a promotion of individual actions (exploit abilities, extract information, etc.).

As above mentioned, we focus on the existence of more than two tiers in hierarchies from an incentive perspective. In particular, this paper is strongly related and complementary to Choe and Ishiguro (2012); Kräkel (2017); Choe and Park (2011); Choe and Ishiguro (2022). Our paper is closer to the first two references than the last two. First, Choe and Ishiguro (2022) analyzes the existence of hierarchies in a dynamic setting, while in our paper we consider a static setting. Additionally, hierarchy in their work is defined as a chain of command between one principal and two agents. Thus, the principal is not only the designer, but if he retains the authority for one project, he is involved in the decision-making process.[8] Second, Choe and Park (2011) analyzes the existence of hierarchies in an organization with three individuals, a principal and two heterogeneous agents, one of these agents is a worker who provides effort and the other one is a manager who

[5] While Aghion and Tirole (1997) states that delegation is optimal given that the *real* authority relies on the individual who has better information, Baker et al. (1999) states that there might be commitment problems inherent to delegation. Even when it might be optimal ex-ante, the individual with the formal authority (the one who is entitled with the authority) will renege from the commitment ex-post.

[6] Bester and Krähmer (2008) and Harris and Raviv (2005) consider the case where a principal decides to either delegate decision-making authority or to keep it. In the first paper, they consider a moral hazard problem whereas in the second one the principal deals with an adverse selection problem. Others papers, such as, Ishihara (2021) analyzes the effect of delegating in a dynamic single agent problem.

[7] The main contributions of this last strand of the literature are surveyed in Garicano and Van Zandt (2012). Some important papers, after this previous revision are Dequiedt and Martimort (2015); Celik et al. (2023). Other important papers like Rajan and Zingales (2001) show the way in which a hierarchical structure implies individual interactions within the firm. Harris and Raviv (2002) analyze organization design according to an optimal coordination of interaction among activities. For their part, Hart and Moore (2005) state a problem-solver perspective of hierarchies differentiating between general and specialized tasks, in which those agents at the top of the organization are in charge of general tasks and these ones at the bottom deal with specialized tasks.

[8] Choe and Ishiguro (2022) analyzes conditions under which hierarchy is implemented in an organization when agents interact in long-term contracts. In this environment, hierarchy shows up as optimal when agents are sufficiently patient and the business conditions are favorable (the outcomes are not extremely sensitive to effort).

can acquire valuable information for the principal.[9] Differently from this paper, we consider two identical agents and a CEO that makes general effort. Even with these differences we recover hierarchical delegation as an optimal structure as well.

Moreover, we take a similar approach as Choe and Ishiguro (2012) but considering a sequential timing between decisions and effort instead a simultaneous environment. This provides two new insights. In our setup the optimal organizations differ: first, concentrated delegation and partial delegation disappear as optimal. This means that we limit the number of optimal organizational designs. However, we maintain cross authority and hierarchical delegation as optimal designs when efforts and projects decisions are not contractible. Secondly, we are able to characterize the mechanism that drives these results. Finally, Kräkel (2017) takes a similar approach as Choe and Ishiguro (2012) but considers a complete contracting environment where payments are conditional on efforts' signals and an additional share of profits for authority unconditional on the decision implemented. The introduction of these complete contracts on efforts' signals vanishes the possibility that hierarchical delegation appears as an optimal organizational design. Unlike Kräkel (2017) we keep the assumption of incomplete contracts over efforts' signals and decisions made.

III The model

In this section we state the model. We consider a similar framework to Choe and Ishiguro (2012). We define (A) the basics of the technology, describing the individuals and the productive activities developed at the organization that generate rents. (B) The utilities of each individual and the organization; we explain the distribution of rents among agents and how utilities are related to the decision making process that leads to different organizational designs. (C) The timing and the problem of each individual. Additionally, we introduce two reference points: the first best and a benchmark case.

Technology

We consider an organization with two divisions where each division $j \in \{A, B\}$ has one project j.[10] There are four relevant parties, the owner, a CEO (named M from Manager), and two agents, Ari and Bob (named A and B).[11] The owner can be considered a representative shareholder who is interested in maximizing profits of the overall organization.[12] By contrast, the other members of the organization perceive monetary concerns about the projects through their own utility.

Each project j may or may not be successful, and the probability of success of each of them depends on the effort of both the agent involved in it (a specialist) and the CEO (general manager). Given the effort choice $e := (e_A, e_B, e_M)$, project j succeeds with probability $P_j = P(e_M, e_j) \in (0, 1)$. Each effort $e_i \in \{e_A, e_B, e_M\}$ has an associated cost given by $g(e_i) = \frac{1}{2c_i} e_i^2$, where $c_i > 0$ and $e_i \in [0, 1]$. We assume $c_M = k$ and $c_A = c_B = c$, where the manager may be more or less efficient in exerting effort than the (symmetric) agents, i.e., $k \gtreqless c$. Note that the CEO's effort

[9] A hierarchical organization shows up when there is incomplete contracting and the allocation of decision rights to the manager motivates him to acquire information; with complete contracting centralization can make a better job. Also, Laffont and Martimort (1998) shows that hierarchies can be implemented to solve collusion problems in an organization with two agents with hidden information.

[10] long the paper we use organization and firm indistinctly, and we emphasize the results in a firm context. However, the analysis applies to every organization that fulfils the assumptions.

[11] For simplicity, throughout the paper we refer directly to 'projects' instead of 'divisions'.

[12] In a more complex organization, the owner could also be interpreted as a General Manager that delegates a task to a Regional Manager, M and two divisional managers A and B.

denoted by $e_M \in [0,1]$ has an impact in both projects, representing a general effort or an extreme case where the efforts of the CEO in both projects are perfect complements.

The success of a project affects the profits of both projects. It has an impact on its project while simultaneously creating a spillover effect on the other project. However, the magnitude of each effect depends on the decision made. For example, a project can prioritize its own project's benefits or spillovers to the other project. To simplify we are going to assume that there are two types of possible decisions for each project: a "Selfish" one (S) which has a stronger impact on its own profits and a "Cooperative" one (C) which generates more spillovers. Decisions in project j are denoted by d_j where $d_j \in \{S, C\}$. We assume that there are no direct costs to make any decision and that an unsuccessful project has no profits.

Let's denote an intrinsic concern for a project or, in other words, its own profit as h and the spillover or cooperative return as q. As mentioned, the profit generated by a successful project j has two parts which depend on the decision made d_j, its own profit denoted by $h(d_j)$, and an external or cooperative profit to the other project j' defined as $q(d_j)$, with $j \neq j'$. Projects are symmetric in their benefits for the same decision, then there are four values to be defined $\{(h(S), q(S)), (h(C), q(C))\}$; we require that $h(S) > h(C)$ and $q(S) < q(C)$, a selfish decision increases h but reduces q compared to a cooperative decision. Hence, given a pair of decisions $d := (d_A, d_B)$, a certain (or ex-post) profit of two successful projects A and B are:

$$\pi_A(d) = h(d_A) + q(d_B), \quad \pi_B(d) = h(d_B) + q(d_A). \tag{1}$$

In the case that only project A has succeed, the certain benefits for project A and B are:

$$\pi_A(d) = h(d_A), \quad \pi_B(d) = q(d_A). \tag{2}$$

An analogous situation is derived when only the project B succeeds. Finally, if both projects fail both projects certain benefits become zero.

To summarize, the expected profits of each project depend on the efforts and types of decisions made. The expected profits are built up of two aspects, the ex-post profit and the probability of success. Given the pair of decisions d and the triple of effort choices e, the expected profits of projects A and B are:

$$\begin{aligned} E(\pi_A(d)|e) &= P_A(e_M, e_A)\, h(d_A) + P_B(e_M, e_B)\, q(d_B), \\ E(\pi_B(d)|e) &= P_B(e_M, e_B)\, h(d_B) + P_A(e_M, e_A)\, q(d_A). \end{aligned}$$

For simplicity, we write $E(\pi_A) = E(\pi_A(d)|e)$ and $E(\pi_B) = E(\pi_B(d)|e)$. So far, we assume:

(a) $h(S) = h > h(C) = 0, q(C) = q > q(S) = 0$.

(b) Probabilities of success are linear on efforts, $P(e_M, e_j) = e_M + e_j$.

The first assumption simplifies the consequences of the decision into a discrete binary option for each type of payoff. If a selfish decision is made $h(S) = h$ while $q(S) = 0$; but if a cooperative decision is made $q(C) = q$ and $h(C) = 0$. One may interpret these parameters (h, q) as the incremental benefit of a successful project (for a given decision). The second assumption helps to simplify the analysis by ruling out complementarities between efforts. Later, assumption (c) establishes boundaries that ensure a closed form solution for equilibrium in each organizational design.

First Best

In the First Best scenario, a social planner chooses efforts and decisions that maximize the total surplus; i.e., expected profits minus effort costs. As a consequence, the social planner problem is:

$$\max_{d,e} \; W(d,e) = E(\pi_A) + \; E(\pi_B) - g(e_M) - g(e_A) - g(e_B) \tag{3}$$

where $d = (d_A, d_B) \in \{(S,S),(S,C),(C,S),(C,C)\}$ and $e = (e_A, e_B, e_M) \in [0,1]^3$. We will incorporate assumptions that guarantee probabilities of success to be in $(0,1)$; for simplicity, we assume that probabilities never exceed one.

Proposition 1: When $q < h$ the social planner chooses both decisions $d^{FB} = (S,S)$ and efforts level are $e^{FB} = (ch, ch, 2kh)$. Otherwise, a social planner chooses both decisions $d^{FB} = (C,C)$ and effort levels are $e^{FB} = (cq, cq, 2kq)$. Hence, the social surplus is:

$$W(d^{FB}, e^{FB}) = \begin{cases} 2(2k+c)\; h^2 \text{ if } q < h, \\ 2(2k+c)\; q^2 \text{ if } q \geq h. \end{cases} \tag{4}$$

To maximize the overall surplus, the social planner opts for cooperative decisions when they prove to be more profitable than self-motivated decisions, and self-motivated decisions otherwise. Given decisions, the social planner then determines the optimal efforts for the CEO and agents.[13]

Utilities and Organization

The payment scheme defines how the profits of project j are shared among individuals. An exogenous share $\alpha > 0$ is delivered to each individual that exerts an effort on project j. This means that individual j and M each receive a share $\alpha > 0$ of the profit π_j. Additionally, the individual in charge of making a decision in project j receives an exogenous share $\lambda > 0$ of the realized profit π_j, representing the value for authority. As mentioned next, this decision right is endogenous. The remaining share, i.e., $1 - 2\alpha - \lambda$, goes to the owner.

The only contractible variable is the decision right over each project j, defining the structure (i.e., organizational design) of the organization and the number of tiers of the hierarchy. We describe an allocation of decision rights for project A by $Y_A := (X_{MA}, X_{AA}, X_{BA}) \subset \{0,1\}^3$ where the first subindex describes who makes the decision for project A. For example, if $(X_{MA}, X_{AA}, X_{BA}) = (1,0,0)$, the CEO is in charge of making decisions regarding project A or, in other words, the owner centralizes the decision of project A in the manager M; if $(X_{MA}, X_{AA}, X_{BA}) = (0,1,0)$, Ari is in charge of making decisions regarding project A (the owner decentralizes project A to Ari); finally, if $(X_{MA}, X_{AA}, X_{BA}) = (0,0,1)$, Bob is in charge of making decisions regarding project A (the owner decentralizes project A to Bob like a cross-delegation). Similarly for project B, $Y_B := (X_{MB}, X_{AB}, X_{BB})$, where the second subindex is changed to B. Let $Y = (Y_A, Y_B) \in \mathcal{Y}$ define the organizational design, and $\mathcal{Y}$ be the set that defines the organizational design, which comprises the allocation of two decision rights over both projects to three individuals. Therefore, there are nine possible organizational designs, $\#\mathcal{Y} = 9$.

The owner chooses Y to maximize the total expected profits of the organization. That is, her objective function is $V(d,e) = E(\pi_A) \; + \; E(\pi_B)$.[14] Next, we introduce manager M and agent j's

[13] Alternatively, the owner maximizes total profits subject to participation constraints. I.e., in order to participate, each agent (agents and CEO) receives a fixed payment equal to the effort cost implemented after a given decision.

[14] Actually, it is appropriate to define the objective function as $V(d,e) = (1 - 2\alpha - \lambda)\,(E(\pi_A) \; + \; E(\pi_B))$. Given that (α, λ) are fixed parameters, we find it more convenient to write V as his gross profits rather than his net profits.

utility functions. First, the manager utility function is:

$$U_M^Y(d,e) = \alpha\Big(E(\pi_A) + E(\pi_B)\Big) + \lambda\Big(X_{MA}E(\pi_A) + X_{MB}E(\pi_B)\Big) - g(e_M). \tag{5}$$

The first term indicates the profits due to the effort exerted; as the manager makes an effort for both projects her intrinsic concerns depend on the sum of the expected profits of both projects. The second term presents the benefits of decision making which depends on the allocation of the decision rights chosen by the owner. Finally, the last term is the cost of effort for the manager. Similarly, the agent j's utility function is:

$$U_j^Y(d,e) = \alpha E(\pi_j) + \lambda\Big(X_{jA}E(\pi_A) + X_{jB}E(\pi_B)\Big) - g(e_j). \tag{6}$$

Again, the first term indicates the profits due to the effort exerted in project j. As each agent could be considered a specialist, they make effort just for one project, so their effort's profits come from only one project. The second term considers the benefits of decision making and works exactly in the same way as for the manager. The last term is the effort cost.

Timing

The timing for the model is as follows (represented in the line below). At date 0, the owner chooses a specific organizational design or governance structure $Y := \{Y_A, Y_B\}$. At date 1, the individual with the decision right j makes the decision for that project j, defining $d = (d_A, d_B)$. At date 2, observing d both agents and the manager choose their efforts, defining $e = (e_A, e_B, e_M)$. Finally, at date 3 nature defines which projects are successful and payoffs are delivered.[15]

Organizational design problem

The model described above considers the owner's problem of selecting an organizational design Y that maximizes the overall organization value (his own payoff) but considering that the only contractible variable is the decision right over each project, without being able to enforce a cooperative or selfish decision nor an effort choice. The participation constraints are guaranteed by the assumptions.[16] To put it bluntly, the owner's problem is to maximize the organization's value V subject to agents' and CEO's incentive compatible constraints on efforts and decisions. So, the owner's maximization problem is: [17]

[15] The timing of the model is different from Choe and Ishiguro (2011). We are considering that efforts' choices are taken after observing decision making over the projects - in a sequential game (instead of considering a bayesian game). We are considering those cases where important decisions in an organization are chosen before each worker decides the amount of effort exerted.

[16] Note that participation constraints are guaranteed by $e_i = 0$ for $i = A, B, M$; e.g., given $e' := (e_M, 0, e_B) \in [0,1]^2$, $U_A^Y(d, e') \geq 0 \ \forall d, Y, e'$.

[17] We consider the case where $2\alpha + \lambda = 1$ since the solutions of both problems are the same, but it simplifies the algebra for some steps of the proofs.

$$\begin{aligned}
\max_{Y \in \mathcal{Y}} \quad & V(d,e) = E(\pi_A) \; + \; E(\pi_B); \\
s.t: IC_d: \quad & d_j^*(Y) := \arg \max_{d_j} \; U_i^Y(d_j, d_{-j}, e^*(d,Y)) \, \forall (i,j) \in \{(i,j) \,|\, X_{ij} = 1, X_{iA} \neq X_{iB}\}, \\
& d^*(Y) := \arg \max_{d} \; U_i^Y(d, e^*(d,Y)) \; \forall i \in \{i \,|\, X_{iA} = X_{iB} = 1\}, \\
IC_e: \quad & e_i^*(d,Y) := \arg \max_{e_i} \; U_i^Y(d, e_i, e_{-i}), \; \forall i = A, B, M.
\end{aligned} \tag{7}$$

While IC_e is relevant for the CEO and both agents, IC_d is only relevant for the decision maker in project j, i.e., $X_{ij} = 1$. Notice that IC_d represents structures where projects' decisions are allocated to different individuals, in the second line of problem (7) (e.g., decentralization), or to the same individual, in the third line of problem (7) (e.g., centralization).

Assumptions

For tractability, we require that parameters c, k, h are small. Additionally to Assumption (a) and (b) throughout this article we assume:

(c) $q < Z := \frac{1}{2k\alpha + max\{2k\lambda, (k+c)\lambda\}}$.

(d) The only contractible variable is the decision over a project due to incomplete contracts.

Assumption (c) complements assumption (b)[18]. Assumption (c) enables the model to have a closed form solution for equilibrium in each organizational design. It is a sufficient condition under which equilibrium effort satisfies $e_M + e_j = P_j < 1, \; j = A, B$ (no corner solution). The incomplete contracts assumption states that it is impossible to build a contingent contract for each possible combination of states of nature in the organization.

Now in order to compare our results we develop a specific benchmark analysis.

Benchmark

In the *Benchmark case* we assume that the owner is in charge of decision-making but he cannot neither observe nor, evidently, contract on individual efforts. That is, the owner selects the organizational design and makes decisions (or enforceable recommendations) with the aim of maximizing the firm's expected profits, subject to an incentive compatibility constraint on each individual effort choice.

Formally, in the benchmark analysis the owner chooses the organizational design and decisions (Y, d) that maximizes the overall organization value (his own payoff) subject to both participation and incentive compatibility constraints of the CEO and agents. Since the problem is defined in a way that guarantees the participation constraint of the CEO and agents, the owner can ignore them. To put it simply, the owner's problem is to choose (Y, d) in order to maximize the organization's value V_B subject to agents' and CEO's incentive compatible effort choice.[19] So, the owner's maximization problem is:

$$\begin{aligned}
& \max_{Y,d} \; V_B(d,e) = E(\pi_A) \; + \; E(\pi_B), \\
& s.t: \; IC_e: \quad e_i^B(d,Y) := \arg \max_{e_i} \; U_i^Y(d, e_i, e_{-i}), \; \forall i = A, B, M.
\end{aligned} \tag{8}$$

[18] For the case of the first best problem the condition is the following c, k, h small enough and $q < Z' := \frac{1}{2k+c}$.

[19] Subscript B indicates that this value is computed under the benchmark framework.

One can think this problem as the owner suggesting d that is contractible or easy to monitor. Regardless of d, Y matters because the value of authority provides additional incentives to exert effort. We postpone the solution of this maximization problem until we explain the optimal organizational design. We decide to put off the solution because the comparison between the benchmark and the model framework is essential to understand the mechanisms that explain our results.

IV Organizational design

In this section we present and organize each of the organizational designs. For the sake of clarity in explaining the possible structures, we provide a name to each organizational design that later on is defined in terms of $\mathcal{Y}$. Even when there are nine possible organizational designs, we reduce it to six due to symmetry. We classify them in centralization (CE), decentralization (DE), cross authority (CA), partial delegation (PD), hierarchical delegation (HD), and concentrated delegation (CD). The last three are consistent with two possible symmetric organizational designs. Hence, the set $\mathcal{Y}$ can also be summarized in $\mathcal{Y} := \{CE, DE, CA, PD, HD, CD\}$.

Partial Delegation implies that the manager has the decision authority over one project, say project A, whereas Bob has decision authority over project B. This is different from what we call hierarchical delegation, which will be described in one of the next subsections. *Concentrated Delegation* consists of delegating the decision rights over both projects to one agent, Ari or Bob. These two organizational designs, *Partial Delegation* and *Concentrated delegation*, are discarded in the main analysis because they are always dominated by other organizational designs (for the proof see the *Appendix A*). Therefore, the relevant set is $\mathcal{Y} := \{CE, DE, CA, HD\}$.

Centralization

In centralization the organizational design is $Y = \{CE\} = \{(1, 0, 0), (1, 0, 0)\}$, where the manager has the decision authority over both projects; that is, $X_{MA} = X_{MB} = 1$ and $X_{jj'} = 0$ for $j, j' = A, B$. Thus, the manager's expected payoff and agent j expected payoff become:

$$U_M^{CE}(d, e) = (\alpha + \lambda) \sum_{j=A,B} E(\pi_j) - g(e_M),$$
$$U_j^{CE}(d, e) = \alpha\ E(\pi_j) - g(e_j). \tag{9}$$

We add the upper index CE to indicate the organizational design.

Decentralization

Under Decentralization $Y = \{DE\} = \{(0, 1, 0), (0, 0, 1)\}$ where each agent has decision authority over his own project: $X_{ij} = 0$ and $X_{jj} = 1$ for $i \neq j$ where $i = A, B, M$ and $j = A, B$. Thus, the manager's expected payoff and agent j's expected payoff become:

$$U_M^{DE}(d, e) = \alpha \sum_{j=A,B} E(\pi_j) - g(e_M),$$
$$U_j^{DE}(d, e) = (\alpha + \lambda)\ E(\pi_j) - g(e_j). \tag{10}$$

Cross-Authority

Under Cross-Authority $Y = \{CA\} = \{(0,0,1),(0,1,0)\}$; i.e., each agent has decision authority over the other project: $X_{BA} = X_{AB} = 1$ and $X_{MA} = X_{BB} = X_{AA} = X_{MB} = 0$. In cross-authority delegation, the CEO's expected payoff is the same as that in decentralization and agent j's expected payoff incorporates a profit from the other project. Respectively, they are given by:

$$U_M^{CA}(d,e) = \alpha \sum_{j=A,B} E(\pi_j) - g(e_M),$$
$$U_j^{CA}(d,e) = \alpha\ E(\pi_j) + \lambda\ E(\pi_{j'}) - g(e_j). \tag{11}$$

Hierarchical Delegation (HD)

Under Hierarchical Delegation $Y = \{HD\} = \{(1,0,0),(0,1,0)\}$ (or $\{(0,0,1),(1,0,0)\}$); i.e., authority over one project, say project A, is allocated to the manager, whereas authority over the other project (B) is allocated to Ari: $X_{MA} = X_{AB} = 1$ and $X_{BA} = X_{BB} = X_{AA} = X_{MB} = 0$. We call this the $M - A - B$ hierarchy (a symmetric $M - B - A$ hierarchy can be defined). In this case, a three-tier hierarchy is characterized by successive allocation of decision authority where Ari plays the role of a "middleman." The three-tier hierarchy can be best understood as a chain of command where the party in the upper tier exercises authority over the party in the immediately lower tier. Hierarchical delegation is different from partial delegation in that the latter does not have such a chain of command. In partial delegation, one agent has authority over his own project, whereas the manager has authority over the other project; then, the link between the delegated agent and the other project is absent in partial delegation. In a $M - A - B$ hierarchical delegation, the manager's and agents' expected payoff are given by:

$$U_M^{HD}(d,e) = (\alpha + \lambda)\ E(\pi_A) + \alpha\ E(\pi_B) - g(e_M),$$
$$U_A^{HD}(d,e) = \alpha\ E(\pi_A) + \lambda\ E(\pi_B) - g(e_A), \tag{12}$$
$$U_B^{HD}(d,e) = \alpha\ E(\pi_B) - g(e_B).$$

V Optimal Organizational Design

In this section, we determine the optimal organizational design by analyzing the performance of each structure under the benchmark and the model cases, respectively. First, we present the total expected profit of the organization, the decision, and the effort choice for each individual. We then identify the optimal organization design based on the parameter values. In both cases, the optimal structure depends on two main factors: the relative importance of cooperative versus motivation decisions, measured by q/h, and the relative productivity of the CEO versus both agents in exerting effort, calculated by comparing k and $c/2$.[20]

The benchmark case is analyzed in Propositions 2 to 6, and the main model is analyzed in Propositions 7 to 12. To provide a clear presentation of the results, we present the proof of

[20] Note that while e/k is the CEO's marginal cost of effort and e/c represents the marginal cost of effort for each agent, we can compare $1/k$ and $1/c$ as the relative productivity of the manager and one agent for a given effort value e. Thus, we could interpret the condition $k = c/2$ as the CEO being as efficient as both agents. This is because the CEO's effort affects the probability of success of both projects, whereas each agent's effort affects the probability of success of his own project only. Therefore, if $k > c/2$, the effort cost for the manager is smaller than the cost of both agents combined given the same level of effort for all of them. Analogously, if $k < c/2$.

Proposition 2 for centralization under the benchmark case and the remaining proofs can be found in *Appendix B* (Propositions 3 to 6) and *C* (Propositions 7 to 11).

Benchmark case

In the benchmark case, the owner seeks to maximize V_B by choosing (Y, d), while taking into account the incentive compatibility constraint in the effort choice, as stated in (8). In other words, the owner must design the organization and make decisions to address the moral hazard problem in the individual's effort. Hence, the relation between CEO's and the agents' productivity is crucial in promoting the effort of (the most productive) individuals.

The moral hazard problem affects not only effort choice but also project decision-making. The impact of moral hazard is particularly severe in cooperative decision-making situations; then, the optimal decision may favor selfish choices even when the first-best solution would recommend cooperation. This occurs because agents are typically focused on their own project and do not fully internalize the benefits of cooperation. As a result, the disadvantages of cooperative decisions are present in all organizational designs, motivating the owner to make selfish decisions more often.

The game is solved by backward induction. Propositions 2 to 5 characterize the best decision making d subject to the incentive constraint in the effort choice for each organizational design. Finally, proposition 6 summarizes the solution to the owner's problem in equation (8).

Proposition 2: (Centralization) Assume $Y = \{(1,0,0),(1,0,0)\}$. Define a cutoff $\tilde{q}^{CE} := \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}$. When $q/h < \tilde{q}^{CE}$ both decisions are $d^B = (S,S)$ and the efforts are $e^B = (c\alpha h, c\alpha h, 2k(\alpha+\lambda)h)$. When $q/h \geq \tilde{q}^{CE}$ both decisions are $d^B = (C,C)$ and the efforts are $e^B = (0,0,2k(\alpha+\lambda)q)$. Hence the overall value of the firm is:

$$V_B^{CE}(d^B, e^B) = \begin{cases} \big(4k(\alpha+\lambda) + 2c\alpha\big)\ h^2 & \text{if } q/h < \tilde{q}^{CE}, \\ 4k(\alpha+\lambda)\ q^2 & \text{if } q/h \geq \tilde{q}^{CE}. \end{cases} \tag{13}$$

Proof

Solving by backward induction, at time 2 the CEO and each agent maximize their utility after observing the decisions $d = (d_A, d_B)$, i.e., $e^B(d)$. If $d = (C,C)$, then $e^B = (0,0,2k(\alpha+\lambda)q)$. If $d = (S,S)$, then $e^B = (c\alpha h, c\alpha h, 2k(\alpha+\lambda)h)$. If $d = (C,S)$ (analogous solution for $d = (S,C)$), $e^B = (0, c\alpha(h+q), k(\alpha+\lambda)(q+h))$.

Anticipating those efforts $e^B(d)$, the owner chooses $d \in \{(S,S),(S,C),(C,S),(C,C)\}$ to maximize $V_B^{CE}(d, e^B(d))$:

$$\begin{aligned} V_B^{CE}((C,C), e^B(C,C)) &= 4k(\alpha+\lambda)\ q^2, \\ V_B^{CE}((S,S), e^B(S,S)) &= (4k(\alpha+\lambda) + 2c\alpha)\ \ h^2, \\ V_B^{CE}((C,S), e^B(C,S)) &= k(\alpha+\lambda)\ (q+h)^2 + c\alpha h^2. \end{aligned}$$

Notice that $V_B^{CE}((C,S), e^B(C,S)) = V_B^{CE}((S,C), e^B(S,C))$. The key parameter that defines the best decision in any organizational design, in this case centralization, is the ratio of cooperative profits over motivation incentives of projects, i.e., q/h. We next define some relevant cutoff in this dimension q/h:

- First Case: $V_B^{CE}((C,C),e^B(C,C)) \geq V_B^{CE}((S,S),e^B(S,S)) \Leftrightarrow q/h \geq \tilde{q}_1 = \sqrt{1+\frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}$.

- Second Case: $V_B^{CE}((C,C),e^B(C,C)) \geq V_B^{CE}((C,S),e^B(C,S)) \Leftrightarrow q/h \geq \tilde{q}_2 = \frac{1+\sqrt{4+3\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}}{3}$, *considering only the positive root.*

- Last Case: $V_B^{CE}((C,S),e^B(C,S)) \geq V_B^{CE}((S,S),e^B(S,S)) \Leftrightarrow q/h \geq \tilde{q}_3 = -1+\sqrt{4+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$, *considering only the positive root.*

Notice that $\tilde{q}_1, \tilde{q}_2$ and $\tilde{q}_3$ are represented in the q/h dimension. Given our assumptions, it is not difficult (but it may take some time) to check that $\tilde{q}_2 \leq \tilde{q}_1 \leq \tilde{q}_3$. Consequently the main cutoff is $\tilde{q}_1$: if $q/h > \tilde{q}_1$, then $q/h > \tilde{q}_2$; consequently, $d = (C,C)$ is preferred to both $d = (S,S)$ and $d = (C,S)$ (and $d = (S,C)$ too). If $q/h < \tilde{q}_1$, then $q/h < \tilde{q}_3$; consequently, $d = (S,S)$ is preferred to both $d = (C,C)$ and $d = (C,S)$ (and $d = (S,C)$ too).

Finally, we can obtain equation (13), taking $\tilde{q}_1$ as the threshold $\tilde{q}^{CE}$ in q/h dimension.

□

Proposition 3: (Decentralization) Assume $Y = \{(0,1,0),(0,0,1)\}$. Define a cutoff $\tilde{q}^{DE} := \sqrt{\frac{1}{2}(1+\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha})}$. When $q/h < \tilde{q}^{DE}$ both decisions are $d^B = (S,S)$ and the efforts are $e^B = (c(\alpha+\lambda)h, c(\alpha+\lambda)h, 2k\alpha h)$. When $q/h \geq \tilde{q}^{DE}$ both decisions are $d^B = (C,C)$ and the efforts are $e^B = (0,0,2k\alpha q)$. Hence the overall value of the firm is:

$$V_B^{DE}(d^B,e^B) = \begin{cases} 2\big(c(\alpha+\lambda)+2k\alpha\big)h^2 & \text{if } q/h < \tilde{q}^{DE}, \\ 4k\alpha q^2 & \text{if } q/h \geq \tilde{q}^{DE}. \end{cases} \tag{14}$$

Proposition 4: (Cross-authority) Assume $Y = \{(0,0,1),(0,1,0)\}$. Define a cutoff $\tilde{q}^{CA} := \sqrt{\frac{2k\alpha+c\alpha}{2k\alpha+c\lambda}}$. When $q/h < \tilde{q}^{CA}$ both decisions are $d^B = (S,S)$ and the efforts are $e^B = (c\alpha h, c\alpha h, 2k\alpha h)$. When $q/h \geq \tilde{q}^{CA}$ both decisions are $d^B = (C,C)$ and the efforts are $e^B = (c\lambda q, c\lambda q, 2k\alpha q)$. Hence the overall value of the firm is:

$$V_B^{CA}(d^B,e^B) = \begin{cases} 2(2k\alpha+c\alpha)\ h^2 & \text{if } q/h < \tilde{q}^{CA}, \\ 2(2k\alpha+c\lambda)\ q^2 & \text{if } q/h \geq \tilde{q}^{CA}. \end{cases} \tag{15}$$

Proposition 5: (Hierarchical delegation) Assume $Y = \{(1,0,0),(0,1,0)\}$. Define cutoffs $\tilde{q}_1^{HD} := \frac{1}{k(1+\alpha)+c\lambda}\big((k(\alpha+\lambda)+\sqrt{k^2(\alpha+\lambda)^2+[k(\alpha+\lambda)+c\alpha][k(1+\alpha)+c\lambda]}\big)$ and $\tilde{q}_0^{HD} := -1+\sqrt{2+\frac{2\alpha}{\alpha+\lambda}+\frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$. When $q/h < \tilde{q}_0^{HD}$, both decisions are $d^B = (S,S)$ and efforts are $e^B = (c\alpha h, c\alpha h, k(2\alpha+\lambda)h)$. If $\tilde{q}_0^{HD} \leq q/h < \tilde{q}_1^{HD}$, decisions are $d^B = (S,C)$ and efforts are $e^B = (c\alpha h, 0, k(\alpha+\lambda)(h+q))$. Finally, when $q/h \geq \tilde{q}_1^{HD}$ both decisions are $d^B = (C,C)$ and efforts are $e^B = (c\lambda q, 0, k(2\alpha+\lambda)q)$. Hence the overall value of the firm is:

$$V_B^{HD}(d^B,e^B) = \begin{cases} (2k(2\alpha+\lambda)+2c\alpha)\,h^2 & \text{if } q/h < \tilde{q}_0^{HD}, \\ k(\alpha+\lambda)(h+q)^2+c\alpha h^2 & \text{if } \tilde{q}_0^{HD} < q/h \leq \tilde{q}_1^{HD}, \\ (2k(2\alpha+\lambda)+c\lambda)\,q^2 & \text{if } q/h > \tilde{q}_1^{HD}. \end{cases} \tag{16}$$

The Best Organization to the Benchmark Case

We now compare the results in propositions 2 to 5, obtaining the best organizational design for an owner that is in control of the decision making process but not on the effort exerted by the CEO or the agents. Recall, that each $\tilde{q}^Y$ represents the threshold that identifies the set of parameters q/h and k/c under which an optimal design Y implements a pair of decisions d. For every Y different from HD (i.e., CE, DE, CA), there is only one threshold $\tilde{q}^Y$ that splits the set where (S, S) and (C, C) are preferred. For HD, there are two values, q_0^{HD} and q_1^{HD}, that split the set for which (S, S) is preferred to (S, C) and (S, C) is preferred to (C, C). We denote in proposition 6, $\tilde{q}_{B1}$ and $\tilde{q}_{B2}$ as the thresholds that identify the set of parameters q/h and k/c where each organization design is optimal as stated in equation (8).

Proposition 6: When $k/c \geq 1/2$, that is the CEO is more productive than both agents, the organizational design is centralization, with $d = (S, S)$ if $q/h < \tilde{q}_{B1}$ and with $d = (C, C)$ if $q/h \geq \tilde{q}_{B1}$. When $k/c < 1/2$, the organizational design is decentralization with $d = (S, S)$ when $q/h < \tilde{q}_{B2}$ or cross-authority with $d = (C, C)$ $q/h \geq \tilde{q}_{B2}$. Thresholds $\tilde{q}_{B1}$ and $\tilde{q}_{B2}$ are values of q/h which depend on k, c, α and λ, the expression of these thresholds are in the proof.

In every organizational design (Y), every decision (d) in the benchmark case is susceptible to a moral hazard problem in the effort dimension, which can lead to lowered effort levels compared to the First Best scenario. Furthermore, cooperative decisions are associated with weaker incentives to exert effort compared to selfish decisions, exacerbating the moral hazard problem when cooperation is involved. This weakness of cooperative decisions can prompt the owner to opt for selfish decisions in situations where they would have otherwise chosen cooperative decisions in the optimal scenario. In figure 1b, this effect shows up in the areas of the following intervals, the blue area for the interval $1 < q/h < \tilde{q}_{B1}$ (when $k/c \geq 0.5$) or the yellow area for the interval $1 < q/h < \tilde{q}_{B2}$ (when $k/c < 0.5$). However, if the benefits of cooperation are significant ($q/h > \tilde{q}_{B1}$ or $q/h > \tilde{q}_{B2}$), the owner chooses cooperative decisions bearing the cost of smaller efforts.

To select the optimal organizational design, the owner considers the impact of decision rights on incentivizing effort. Note that centralization is the organizational design that provides more incentives to the manager; on the contrast, decentralization and cross-authority provides more incentives to the agents. If the CEO is more productive than the agents, centralization becomes the optimal organizational design, where decisions can be either selfish of cooperative depending on the relative returns and the incentives they generate for effort; i.e., (S, S) if $q/h < \tilde{q}_{B1}$ and (C, C) if $q/h \geq \tilde{q}_{B1}$.If the CEO is less productive than the agents, the agents are given decision-making authority, and the owner decides between decentralization with selfish decisions when cooperation is not very profitable, and cross-authority with cooperative decisions when the benefits of cooperation are substantial. Notice in Propositions 3 and 4 that cross-authority provides more incentives to exert effort than decentralization when decisions are cooperative.

We can illustrate these concepts with a numerical example, shown in Figures 1a and 1b. In the First Best scenario (shown in Figure 1a), the key choice is whether to make decisions in a selfish or cooperative manner. Since effort is contractible in this scenario, there is no moral hazard problem. Decisions are selfish when the coordinated effects are less than or equal to a threshold, which is represented by $q = 0.5$ $(= h)$ in the example, and are cooperative otherwise.

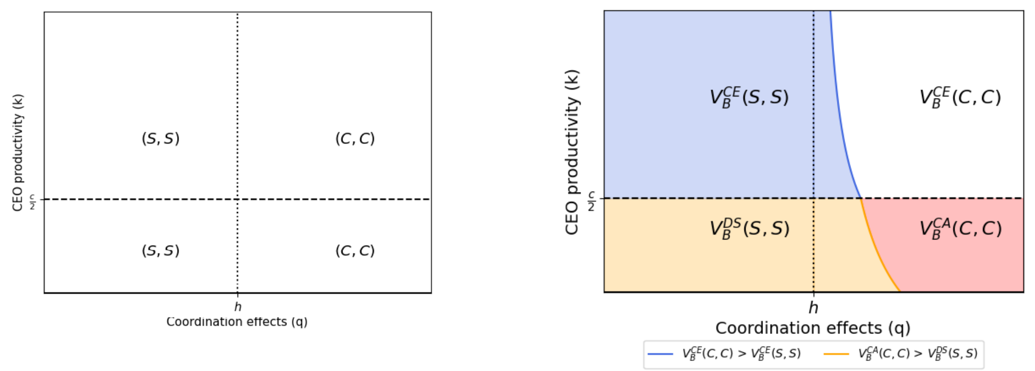
In the Benchmark case, where effort is not contractible, both the CEO and the agents have the incentive to reduce their level of effort. Payment schemes based on the project in which each individual is involved exerting effort and the project for which they have projects' decision rights serve as an incentive mechanism. As a result, selfish decisions provide greater incentives for effort than cooperative decisions, exacerbating the moral hazard problem in organizations with cooperative decisions. Therefore, as long as the profitability of cooperative decisions is moderate, selfish decisions are preferred. This preference for selfish decisions is represented by the blue area that depicts threshold $\tilde{q}_{B1}$ (in the case of centralization) and the yellow area that represents threshold $\tilde{q}_{B2}$ (in the case of decentralization) when $q > h$ in Figure 1b.

It is worth noting that in the blue line the owner centralizes the organization but he is indifferent between selfish decisions and cooperative decisions. Cooperative decisions motivates lesser effort from the agents that is partially compensated by an increase in CEO's effort who bears all the cost. The fewer total effort reduces the probability of projects' success, that is compensated by high spillovers of cooperation. This tension will be important in identifying the main result of the paper in proposition 11.

In summary, the moral hazard problem generates a cost to the owner, reducing the profitability of the firm in every organizational design and for all decisions. However, the moral hazard problem is relatively better handled with selfish decisions than with cooperative decisions, making organizational designs that complement selfish decisions more favorable. Nevertheless, if cooperation is crucial for the profitability of the organization, the owner may choose to tolerate the effects of the moral hazard problem.

Finally, the optimal organizational design depends on the relative efficiency of the CEO and the agents in exerting effort. When the CEO is more efficient than the agents, a centralized organizational design is preferred. On the other hand, if the agents are more efficient, some kind of delegation is implemented, either through decentralization with selfish decisions or cross-authority with cooperative decisions. The later is chosen when the benefits from cooperation are sufficiently high.

(a) First Best (b) Benchmark



Note: This figure considers that the parameters $\alpha = \lambda = 1/3$ and $h = c = \frac{1}{2}$ as an example.

The model case

In the main model, the owner chooses (Y) to maximize V subject to incentive compatibility constraints in the choice of effort and in decision making, as given in equation (7). In other words, the owner designs the organization to cope with the moral hazard problem in the choice of effort and decision making. Therefore, to increase the effort of the most productive person and motivate the best decisions, the owner allocates the project decision rights between the CEO and the agents depending on their relative productivity and their own incentives in decision making.

The sequential game is solved by backward induction, for each organizational design. That is, for each type of organizational design Y there is an incentive to make a decision $d = (d_A, d_B)$ in each project (by the person in charge in each project) that anticipates an effort choice by each individual $e = (e_A, e_B, e_M)$. The owner chooses the organizational design Y that maximizes V.

The only difference between the model and the Benchmark case lies in the commitment to decision making. In the Benchmark the owner can "suggest" a decision that is implemented by the person in charge. Now this suggestion is not binding; i.e., the person in charge of the authority makes the decision that maximizes his own expected utility anticipating the incentives on efforts. In other words, there is no commitment in decision-making. These differences are captured on the thresholds under which different decision pairs are implemented. In other words, the only difference that we see between benchmark equations (13) - (16) and model equations (17) - (20) are the values $\tilde{q}^Y$ and $\hat{q}^Y$. Briefly anticipating the results, these differences in thresholds reflect the moral hazard problem in decisions and make the owner anticipate and choose a sub-optimal organization (compared to the benchmark scenario) that better balances the trade-off between self-motivation and coordination. After propositions 7-10, we state the main result of the paper in proposition 11.

Proposition 7: (Centralization) Assume $Y = \{(1,0,0),(1,0,0)\}$. Define a cutoff $\hat{q}^{CE} := \sqrt{1 + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$ When $q/h < \hat{q}^{CE}$, the CEO makes both decisions $d = (S,S)$ and each agent chooses $e^* = (c\alpha h, c\alpha h, 2k(\alpha+\lambda)h)$. When $q/h \geq \hat{q}^{CE}$ the CEO makes both decisions $d = (C,C)$ and the efforts are $e^* = (0,0,2k(\alpha+\lambda)q)$. Hence the overall value of the firm is:

$$V^{CE}(d^*, e^*) = \begin{cases} \big(4k(\alpha+\lambda) + 2c\alpha\big)\ h^2 & \text{if} q/h < \hat{q}^{CE}, \\ 4k(\alpha+\lambda)\ q^2 & \text{if } q/h \geq \hat{q}^{CE}, \end{cases} \tag{17}$$

Proposition 8: (Decentralization) Assume $Y = \{(0,1,0),(0,0,1)\}$. Define a cutoff $\hat{q}^{DE} := \sqrt{1 + \frac{1}{4}\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha}}$. When $q/h < \hat{q}^{DE}$ each agent j chooses $d_j = S$, then $d^* = (S,S)$ and $e^* = (c(\alpha+\lambda)h, c(\alpha+\lambda)h, 2k\alpha h)$. When $q/h \geq \hat{q}^{DE}$ each agent decides both cooperative $d^* = (C,C)$ and the efforts are $e^* = (0,0,2k\alpha q)$. Hence the overall value of the firm is:

$$V^{DE}(d^*, e^*) = \begin{cases} 2\big(c(\alpha+\lambda) + 2k\alpha\big)h^2 & \text{if} q/h < \hat{q}^{DE}, \\ 4k\alpha q^2 & \text{if } q/h \geq \hat{q}^{DE}. \end{cases} \tag{18}$$

Proposition 9: (Cross-authority) Assume $Y = \{(0,0,1),(0,1,0)\}$. Let's define $\hat{q}^{CA} = \sqrt{\frac{(\alpha+\lambda)(2\alpha k + c\alpha) - \frac{c\alpha^2}{2}}{(\alpha+\lambda)(2\alpha k + c\lambda) - \frac{c\lambda^2}{2}}}$. When $q/h < \hat{q}^{CA}$, $d^* = (S,S)$ and $e^* = (c\alpha h, c\alpha h, 2k\alpha h)$. When $q/h \geq \hat{q}^{CA}$, $d^* = (C,C)$ and $e^* = (c\lambda q, c\lambda q, 2k\alpha q)$. Hence the overall value of the firm is:

$$V^{CA}(d^*, e^*) = \begin{cases} 2(2k\alpha + c\alpha)\ h^2 & \text{if} q/h < \hat{q}^{CA}, \\ 2(2k\alpha + c\lambda)\ q^2 & \text{if } q/h \geq \hat{q}^{CA}. \end{cases} \tag{19}$$

Proposition 10: (Hierarchical Delegation) Assume $Y = \{(1,0,0),(0,1,0)\}$. Let's define $\hat{q}_1^{HD} = \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \sqrt{\Big(\frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]}\Big)^2 + \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \frac{2c(\alpha+\lambda)}{k(3\alpha+2\lambda)+2c\lambda}}$ and $\hat{q}_0^{HD} =$

$\sqrt{2+\frac{\lambda}{\alpha}+\frac{c}{k}\frac{\alpha\lambda}{\alpha(\alpha+\lambda)}}-1$. When $q/h < \hat{q}_0^{HD}$, $d^* = (S,S)$ and $e^* = (c\alpha h, c\alpha h, k(2\alpha+\lambda)h)$. $\hat{q}_0^{HD} \leq q/h < \hat{q}_1^{HD}$, CEO makes a selfish decision while Ari a cooperative one, i.e., $d^* = (S,C)$ and efforts are $e^* = (c\alpha h, 0, k(\alpha+\lambda)(h+q))$. When $q/h \geq \hat{q}_1^{HD}$, $d^* = (C,C)$ and $e^* = (c\lambda q, 0, k(2\alpha+\lambda)q)$. Hence the overall value of the firm is:

$$V^{HD}(d^*,e^*) = \begin{cases} (2k(2\alpha+\lambda)+2c\alpha)\,h^2 & \text{if } q/h < \hat{q}_0^{HD}, \\ k(\alpha+\lambda)(h+q)^2 + c\alpha h^2 & \text{if } \hat{q}_0^{HD} \leq q/h < \hat{q}_1^{HD}, \\ (2k(2\alpha+\lambda)+c\lambda)\,q^2 & \text{if } \hat{q}_1^{HD} \leq q/h. \end{cases} \quad (20)$$

We now state the main result. In proposition 11 the thresholds $\hat{q}_{M1}, \hat{q}_{M1'}$ and $\hat{q}_{M2}$, represent the values that identify the set of parameters q/h and k/c where each organizational design is optimal design as stated in equation (7).

Proposition 11: We define some thresholds $\hat{q}_{M1}(k,c,\alpha,\lambda), \hat{q}_{M1'}(k,c,\alpha,\lambda)$ and $\hat{q}_{M2}(k,c,\alpha,\lambda)$, with $\hat{q}_{M1} < \hat{q}_{M1'} < \hat{q}_{M2}$; the expression of these thresholds are in the proof. When $k/c < 1/2$, the results of benchmark remain without modifications. When $k/c \geq 1/2$, the owner chooses centralization with $d = (S,S)$ when $q/h < \hat{q}_{M1}$. When $\hat{q}_{M1} < q/h < \hat{q}_{M2}$, he chooses either hierarchical delegation with $d = (S,C)$ if $q/h < \hat{q}_{M1'}$ or cross-authority with $d = (C,C)$ otherwise. Finally, when $q/h \geq \hat{q}_{M2}$ he chooses centralization with $d = (C,C)$.

Proposition 11 proposes an optimal organizational design for situations in which the CEO and agents have no commitment to decision-making, and the owner must allocate decision rights to address the resulting double moral hazard problem (effort choice and decision making). The model shows that the optimal design depends, as in the benchmark case, on the relative profitability of selfish *vs.* cooperative decisions, as well as the relative productivity of the CEO and agents in exerting effort. Surprisingly, hierarchical delegation may emerge as the optimal design in some cases.

The lack of commitment in project's decision generates an additional conflict between the owner and the persons in charge of making a decision. The owner allocates decision rights to the individuals, anticipating which decisions are going to be made. In many cases, there is no misalignment in the project's decision since the CEO or the agents implement the decision that is desired by the owner. Despite that, there are situations in which the interests of the CEO and the owner are in conflict. In such cases, the owner has incentives to modify the organizational design.

In particular, when the CEO is more productive than both agents (i.e., $k/c \geq 1/2$) hierarchical delegation or cross-authority may appear as the best organizational design of the firm. When the CEO is highly productive, centralization becomes the preferred organizational design, particularly when the level of cooperation required is very low. When the spillover effects of cooperation are low (i.e., $q/h < \hat{q}_{M1}$), the incentives to exert effort become more important and align better with selfish decisions. This provides high-powered incentives to the CEO and the agents. As a result, the CEO is more likely to select selfish decisions, which coincide ultimately with the owner's preferences.

When the benefits of cooperation are moderate (i.e., $\hat{q}_{M1} \leq q/h < \hat{q}_{M2}$) a conflict of interest arises between the owner and the CEO. The owner wants to appropriate the benefits of cooperative decisions that overcome the anticipated reduction in total efforts. However, the reduction in efforts is not evenly distributed between the CEO and the agents. The agents dramatically reduce their efforts, while the CEO increases his effort. In other words, the CEO bears the cost of this change from selfish to cooperative decisions. Instead, the CEO prefers selfish decisions that, while reducing his own incentives to exert effort, motivate Ari and Bob to exert effort. Consequently, the CEO's interests are not aligned with the owner's ones. This situation is what we define as the double moral hazard problem.

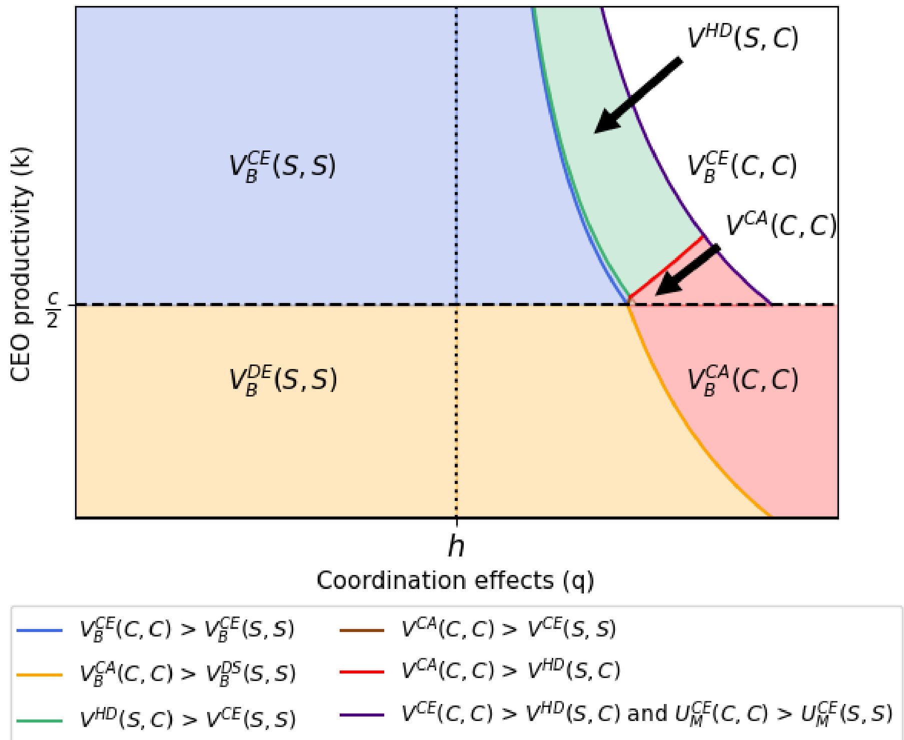
To address this double moral hazard issue, the owner may decide to modify the organizational design. If the CEO's productivity is only slightly higher than that of the agents, the second-best solution involves transitioning from a centralized design to a cross-authority design. By shifting decision-making authority from the CEO to the agents, the CEO's incentives to exert effort are reduced, but the cross-authority design promotes more cooperative decision-making, which partially offsets the reduction in effort. As a result, efforts may be somewhat diminished due to the lower productivity of the agents relative to the CEO, but the owner can still benefit from the spillover effects of cooperation. If the CEO is much more efficient than the agents, the second-best solution involves shifting to a hierarchical delegation design. In this design, the CEO retains decision-making authority over one project (say Project A), while the agent involved in that project (Ari) is granted decision-making authority over the other project (Project B). Similar to the previous scenario, the CEO still prefers selfish decisions to motivate effort from the agent. However, the agent chooses cooperative decisions in anticipation of substantial spillover effects that provide incentives for the CEO to exert effort. In summary, the agent with no decision-making authority has less incentive to exert effort, the agent with one decision-making right has some incentives to exert effort, and the CEO has high-powered incentives to exert effort. Consequently, the hierarchical delegation balances high-powered incentives to the most productive worker (the CEO) with some cooperative decisions that generate spillovers.

When the benefits from cooperation are extremely high (i.e., $q/h \geq \hat{q}_{M2}$) and the CEO is more productive than the agents, the CEO internalizes the high spillover effects of cooperation. In this scenario, a centralized structure does not create any conflict between the CEO and the owner. Cooperation can be effectively implemented, and the CEO is incentivized to exert effort. With low-powered incentives for the agents, the moral hazard problem in the agents' effort choice becomes an inevitable cost for the firm (and the CEO).

Notice that the new results are primarily driven by the fact that the agents are specialized in one project, having low-powered incentives to exert effort when cooperation is substantial. As the CEO works on both projects, he always preserves at least moderate incentives to exert effort. As agents are specialized in one project, the CEO and owner may differ when it may be worthy to motivate the agents to exert effort with selfish decisions, which ultimately motivates changes in the organizational design. By modifying the structure, the owner can reduce conflicts of interest and improve overall firm performance.

It is important to note that when the agents are more productive than the CEO, results on the optimal organizational design, decisions, and efforts in the model replicate those in the benchmark case. This implies that the incentives of the owner and the agents are aligned regarding the optimal organizational design. In this case, there is no double moral hazard problem. Overall, the alignment of incentives, in this case, simplifies the organizational design problem, as the optimal structure is the same as the benchmark case.

Figure 2: Model results



Note: This figure considers parameters $\alpha = \lambda = 1/3$ and $h = c = 1/2$ as an example.

Figure 2 provides an example to show the main result. The figure shows the results in figure 1b for the benchmark case but adds the thresholds computed in proposition 11. The thresholds define some areas: The blue area is the one where $V_B^{CE}(S,S)$ is the highest, to the left of threshold $\tilde{q}_{B1}$. This area expands until the green line, that is close the blue line, and depicts $\hat{q}_{M1}$. In this area, both the CEO and the owner prefer selfish decisions. The white area, to the right of threshold $\hat{q}_{M2}$, (when q is quite high) is the area where both the CEO and the owner prefer cooperative decisions and the organization profits are maximized with $V_B^{CE}(C,C)$, even under the moral hazard problem in efforts. The red curve represents $\hat{q}_{M1'}$ and the red area now is greater than in the benchmark case, showing that when the CEO is slightly more profitable than the agents, a design with cross authority may be preferred by the stockholder. This cross-authority guarantees cooperative decisions at the expense of a reduction in the effort level. The green area is the main new area of the figure. In this area, the CEO is quite productive, but cooperative decisions are also really profitable; then a hierarchical delegation is the best organizational design balancing the coordination in decision-making and the motivation of individuals to exert effort. That is, generating the spillovers of coordination in some decisions and providing high-powered incentives in the effort choice of the most productive person (the CEO). When the agents are more productive than the CEO, $k < c/2$ in figure 2, the results remain the same as in the benchmark case.

VI Comparative Static Analaysis

We have demonstrated that hierarchical delegation and cross-authority may replace centralization when the CEO is more productive than the agents, and the spillovers of cooperation are substantial. One may wonder how the results change with alternative payment scheme structures. That is, how results are modified by the impact of the importance of authority, represented by λ, and the share of profits allocated to each individual to motivate effort, represented by α.

First, centralization is more likely to be dominated as the motivation becomes more important. That is, our results are more relevant as α increases because the moral hazard problem in the effort choice is more relevant. In contrast, if $\alpha \to 0$, no individual has intrinsic motivation (incentives) to exert effort and λ is allocated to the most productive individual. Thus, the double moral hazard problem disappears which overrides the possibility of having hierarchical delegation or cross-authority. Centralization is always optimal as long as the CEO is more productive than agents (i.e., $k \geq c/2$). Consequently, motivation is crucial for our results to hold.

Second, the value of authority is relevant to understanding which organization, hierarchical delegation or cross-authority, is the best to replace centralization. Recall that the value of authority is important both in decision-making and also in the extra incentives to exert effort. Then, cross-authority provides better incentives to make good decisions at the cost of reducing the incentives to exert efforts due to authority. Hierarchical delegation provides better incentives to exert efforts relegating the accuracy of decisions over some projects. If $\lambda \to 0$, the value of authority reduces the incentives to exert extra effort. Then, cross-authority becomes more important.

Therefore, the incentives to replace centralization depend on the parameters λ and α. Graphical examples complement this analysis. Recall that picture Figure 2 illustrated the results for $(\alpha, \lambda) = (1/3, 1/3)$. Figures D1 and D2, available in Appendix D, show the results for $(\alpha, \lambda) = (2/5, 1/5)$, decreasing the share due to decision rights and increasing the share to the effort choice, and $(\alpha, \lambda) = (1/2, 1/4)$, increasing the share due to decision rights and reducing the share to the effort choice, respectively. These examples emphasize the importance of α, as the area where Hierarchical Delegation and Cross Authority have become optimal increases in this motivation parameter.

VII Discussion

We now discuss the three main assumptions: (1) the double moral hazard in efforts and decisions, (2) a general effort made by the CEO that affects both projects; and, (3) fixed payment schemes.

The first assumption relates to the fact that making decisions and exerting effort are both not contractible. Since individuals are inherently selfish, the organization must provide incentives to align objective functions as closely as possible in both dimensions. If either of these moral hazards is absent, hierarchical delegation is never optimal. If the owner can recommend decisions to the CEO, centralization can provide the best incentives to exert effort when there are substantial spillovers from cooperation. Similarly, if effort choices can be optimally enforced, centralization provides the right incentives to make optimal decisions for projects.

The second assumption states that the CEO makes a general effort that affects both projects simultaneously. This represents an extreme case of complementary efforts. The importance of this assumption lies in the fact that the incentives to exert efforts on different projects are closely interrelated; that is, improving one project becomes easier or more cost-effective when another project has been improved. Alternatively, the CEO may exert effort to successfully implement cross-sectional services that impact the entire organization, such as communication services and infrastructure design. It's essential to note that this serves as the unique link between projects. Without any link, the projects remain entirely independent, and, consequently, a hierarchical organization to connect both projects is never optimal

The third assumption implies that the payment scheme is related to the value of authority (λ) and the profit share from the project where each individual works (α), both of which we assume to be fixed. First, providing incentives for individuals to exert costly efforts is essential to address the moral hazard problem, and a share of project profits is the most direct payment scheme. While assuming that α is fixed might raise concerns, section VI shows that the scenarios where hierarchical delegation is optimal vary but do not disappear as α changes. In fact, the more the high-powered incentives (i.e., higher α), the more likely it is that a hierarchical organizational design is preferable. Assuming a fixed λ may also be subject to criticism. Although the value of authority can be modified by the owner, there are numerous arguments to justify that some value remains tied to the authority.

If these assumptions of fixed payment schemes are relaxed to the extent that the owner can offer complete contracts on effort signals, the results of hierarchical delegation vanish, as presented by Kräkel (2017).

VIII Case of study

In this section we describe how our theory can shed some light on some examples of reorganizations of companies. In particular, we discuss the case of Facebook when acquiring Instagram and Whatsapp, but several other cases have been pointed out in the literature before, such as the reorganization of IBM, Procter & Gamble and Sony.

Facebook

Facebook, renamed Meta in 2022, is a digital company whose main product is the Facebook app, a social network. In the Facebook app each user has a personal profile with a net of social contacts (friends, family, coworkers, etc.); users post stories with pictures and videos where friends can comment. With various configurations, the social media industry has experienced exponential growth since its appearance at the beginning of the twenty-first century. While several projects quickly gained traction, significant acquisitions also occurred early on.

Facebook acquired Instagram in 2012 for 1 billion dollars. Instagram, founded in 2010, was a rapidly emerging social network specializing in posting pictures; popular among young generations.[21] Despite both companies having significant profit complementarities, Facebook emphasized the importance of maintaining independent management for both firms.[22] Two years later, in 2014, Facebook acquired WhatsApp, another major big tech company, for nearly 20 billion dollars. WhatsApp was a messaging app that performed exceptionally well on cellphones and smartphones, with a strong global presence established by 2014. Similar to the Instagram acquisition, Facebook asserted that WhatsApp's management would remain independent. In fact, the CEO and co-founder of WhatsApp continued to lead the company and was appointed to Facebook's board.[23]

A common pattern in Facebook's acquisitions is the importance of strategic complementarities among Facebook, Instagram, Messenger, and WhatsApp. Many of these strategic complementarities became evident later on. On the supply or technological side, there are significant economies of scale in research and development, allowing them to coordinate the development of similar features across all platforms, such as instant messaging. The networks within each app also allow

[21] Instagram started as a minimalist app for photo sharing. As it grew, the platform added various features, such as stories and filters for these stories, which gained high adoption among younger generations.

[22] There could also be alternative and complementary reasons for the acquisition, such as the threat that another giant company could acquire Instagram. We abstract from this possible market strategy behind the acquisition.

[23] The fact that he was part of Facebook's board and the management of WhatsApp was seen as a positive aspect of the acquisition: in that way, Facebook was acquiring his capabilities and not only the company. https://www.theguardian.com/media-network/media-network-blog/2014/feb/21/zuckerberg-facebook-whatsapp-mobile.

for spillovers or economies of scope; for instance, the network of phone contacts in one application may enable the company to find people in others, generating a richer database. WhatsApp also brought to Facebook the potential to make messaging applications accessible on more affordable mobile phones with fewer technological requirements. Additionally, the acquisition increased the user base and helped to segment the market.[24] On the demand side, users often value the ability to seamlessly transition from one application to another when these apps are interconnected. For example, interconnecting the apps allows users to log in to one application using another app's account information. It also enables the interconnection of different devices, facilitating simpler and faster cross-linking between apps and devices. These conveniences reduce users' entry and usage costs.

In 2018, however, Facebook shifted away from its initial concept of having each app operate independently and transitioned to a more hierarchical organizational design. While Instagram and WhatsApp were experiencing growth in user traffic, Facebook's growth (in activity and incorporating new users) was slowing down. The Facebook app, however, was responsible for most of the company's revenues and profits. On a larger scale, the company restructured its apps, placing the Facebook App at the core of this new structure.[25] Formally, a new division called the 'Family of Social Networks' was established, encompassing Facebook, Instagram, WhatsApp, and Messenger. In practice, all apps collaborated with Facebook to enhance the activity and ensure the successful monetization of Facebook's potential through advertising. While the cooperation and coordination were more noticeable in the case of WhatsApp, the other apps were also collaborating to benefit Facebook. We will now describe several facts that validate this conclusion.

The leadership of the new sector is in the hands of experienced Facebook veterans.[26] Christopher Cox, a software engineer who joined Facebook in 2005, was named the new Chief Product Officer (CPO) of the Social Network Family division, overseeing Facebook, WhatsApp, Instagram, and Messenger. Simultaneously, Chris Daniels, a former Facebook executive, replaced Jan Koum, the former CEO and co-founder of WhatsApp. In the case of Instagram, Adam Mosseri, former Facebook executive who started as Product Designer in 2008, was named president of Instagram.[27] Some press articles suggested that this reorganization implied the Facebook app gaining more control over WhatsApp and Instagram.[28] The same press release provides an explanation for this decision: *'The reorg could prevent Facebook from haphazardly tripping over itself in an attempt to seize on emerging trends. As visual communication becomes the new Facebook mandate, the company could similarly align its efforts in augmented reality, ephemeral and encrypted messaging, and e-commerce tools. Mosseri and Daniels can implement the Facebook strategy and shield their apps*

[24]We checked different websites for the statistics of use of each application: Facebook, Instagram, and WhatsApp; we described this use in table 1. In 2018 Facebook was the most used application of the company and had control over three of the five most used social networks (Facebook, Facebook Messenger, and WhatsApp) and four over six (with Instagram in the 6th place).

[25]Other reasons also motivated the reorganization: (1) the fast rise of new product lines: Artificial Intelligence, Virtual Reality, and Blockchains. (2) the Cambridge Analytica scandal following Trump's presidential election in 2016. The reorganization of the company moved from five to three main areas shuffling completely the leadership of its products: 1) New platforms and infrastructure; 2) ads, personnel, security, and growth; and 3) the family of social networks. `https://techcrunch.com/2018/05/08/one-family-under-cox/`.

[26]This movement was particularly striking for Instagram. Kevin Systrom, founder and removed leader of Instagram, was offered a job from Facebook company before founding Instagram. Systrom did not take the offer at this point and founded Instagram. Facebook's acquisition of Instagram was viewed as the possibility not only to acquire the company but also the services provided by Systrom. The decision to remove him was a neat picture of the trade-off. To prioritize Facebook's benefits was necessary to remove the people pushing Instagram self profits.

[27]Adam Mosseri was first named vice-president of Instagram. After four months, he took over the lead of the app replacing Kevin Systrom, ex-CEO and co-founder of Instagram.

[28]"These changes could reduce the autonomy of Instagram and WhatsApp, at least in philosophy if not in formal hierarchy. That might make them less appealing places to work, after WhatsApp veterans like Nikesh Arora were passed over in favor of an installed Facebook exec." `https://techcrunch.com/2018/05/08/one-family-under-cox/`

from the same old pitfalls. Instagram and WhatsApp have instituted themselves in their respective markets, and now have the leaders to make them well-oiled cogs in the Facebook machine'.

Facebook App was the most effective at monetizing its traffic. WhatsApp has little tools to monetize its traffic and Instagram had significantly less traffic than Facebook. However, both apps were crucial tools for enhancing Facebook's potential benefits. This quote reveals that, as of 2023, WhatsApp still cannot monetize through ads, while the Facebook App remains the primary advertising channel: *"The latest numbers reported in Facebook's self-service tools indicate that the company's portfolio of platforms now enables advertisers to reach a combined potential audience of more than 3 billion distinct users. That might not sound like 'news', because Facebook Inc.'s investor earnings reports indicate that the company's Family Monthly Active People (FMAP) figure exceeded 3 billion in Q2 2020. However, that FMAP figure also includes WhatsApp's 2 billion-plus users, and WhatsApp doesn't currently offer advertising placements. Furthermore, our analysis suggests that total potential advertising reach on Facebook only equates to about 78 percent of the platform's monthly active users."* Note that this pertains specifically to the Facebook platform, not the company's entire portfolio of platforms.[29] In the case of Instagram, the situation is different. In 2018, Instagram reached 0.85 billion people through its ads. However, with more than 2 billion users, Facebook App accounted for approximately 80% of the company's total revenue. In 2018 each user, on average, makes one post, writes four comments, likes ten posts, and clicks eight times on Facebook Ads every month. These numbers positioned Facebook at the core of the organization.[30] Consequently, any coordination that helps to increase user activity would have an impact on Facebook App much bigger than on Instagram.

The other apps focused on increasing cooperation with Facebook app, while the same emphasis was not necessarily placed on the reverse.[31] WhatsApp ceded control of its primary product, the messaging system, which came under the management of Facebook within the Family of Apps unit and had a positive impact on Facebook's business model. Having access to the messaging systems of every app, including WhatsApp's primary product, enabled Facebook to enhance and better target consumers on its platform by feeding data into their algorithms. In that way, Facebook improved its consumer targeting which allowed it to exploit its two-sided benefits: i.e., offering more dedicated products for consumers, and selling better allocation advertisements for sellers. This reorganization also affected Instagram and Messenger, compelling these products to cooperate and coordinate certain features to address issues arising from product overlap.[32] For example, Instagram implemented a cross-posting feature for stories from Instagram to Facebook. If a user made a story post on Instagram, it could be posted automatically on Facebook instantaneously. However, the reverse was not allowed, at least not at that time.[33]

In summary, we interpret this restructuring as a shift from a decentralized organization, where each app operated independently, to a more hierarchical structure. This reorganization prominently positions the Facebook App at the forefront of the company. In alignment with our model, the Facebook App project, referred to as 'Project A,' received top priority. The board entrusted Chris

[29] Check `https://datareportal.com/essential-facebook-stats` for a more detailed analysis.

[30] By 2022, these numbers had increased to twelve clicks on Facebook ads per user per month.

[31] We claim that even though WhatsApp, Instagram and Messenger might have benefited from Facebook's cooperation as well we do not see any strategic decision that Facebook made, affecting its own business only to increase complementarities in the other apps.

[32] "Facebook was a mess. The independence it dangled to close acquisition deals with Instagram and WhatsApp turned the company into a tangle of overlapping products. Every app had its own messaging and Stories options. Economies of scale were squandered. Top innovators led mature products already bursting at the seams with features while new opportunities went unseized." `https://techcrunch.com/2018/05/08/one-family-under-cox/`.

[33] For more detail check `https://techcrunch.com/2017/10/04/instaface/`. These one-way developments, coupled with the decision to remove Systrom, illustrate the company's primary focus on the externalities of Instagram on the Facebook app.

Cox, the CPO of the new division, with orchestrating and executing this initiative. His primary objective was to enhance Facebook's engagement levels. To achieve this goal, Cox implemented effective decisions in the other apps, referred to as 'projects B,' ensuring their collaboration and coordination with the Facebook App. Meanwhile, Mark Zuckerberg, the CEO, directed his primary efforts toward improving the advertising business.

We believe that this reorganization is based on the idea that Zuckerberg would have faced challenges in realizing strategic synergies between WhatsApp and Instagram within the framework of a hypothetical centralized organization. Furthermore, this could explain the delay in reorganization, which occurred four years after the acquisition of WhatsApp. To address this challenge, the company decided to adopt a hierarchical design. Under this new structure, Zuckerberg retained decision-making authority for the Facebook App (putting it at the forefront), while Chris Cox assumed responsibility for decisions pertaining to all other apps.

IX Conclusion

One of the central issues in organizational design is to find the optimum way to coordinate organizational activities while motivating different parties within the organization. The literature has mainly relied on a binary centralization-decentralization design. This article finds that under circumstances, where coordination to exploit spillovers and motivation to make efforts are important, other organization designs can emerge as optimal. These optimal organization designs are cross authority and hierarchical delegation that comprises more than two levels of hierarchy.

The more surprising finding is that hierarchical delegation appears to be the best structure to deal with a double moral hazard. Decisions are not contractible, yet they impact the incentives for non-contractible effort. These findings shed light on the underlying factors driving these results.

The model presented in this study provides a framework to understand the Facebook reorganization in 2018. The company monetizes with ads the users' activity. The ads algorithm worked really well in the Facebook App. However, growth in the number of users on the Facebook App was slowing down. In order to foster growth and to improve the algorithm to target users, the company reorganized into a hierarchical delegation organization. The CEO was in charge of making sure that the Facebook App was at the front and center of the organization. The manager of the apps was in charge of guaranteeing the cooperation of WhatsApp and Instagram favoring the traffic in the Facebook App. This reorganization proved to be worthy for several years.

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Appendix

A. Auxiliary proofs

Propositions 1: First Best

In First Best analysis the owner maximizes the Welfare function W under each set of decisions in order to obtain the optimum efforts in each case. Solving by backward induction, at time 2 the CEO and each agent make an effort that maximizes the welfare after observing the decisions $d = (d_A, d_B)$, i.e., $e^{FB}(d)$. If $d = (C, C)$, then $e^{FB} = (cq, cq, 2kq)$. If both decisions are selfish $d = (S, S)$, then $e^{FB} = (ch, ch, 2kh)$. Finally, if $d = (C, S)$ (analogously for the other asymmetric case), then $e^{FB} = (cq, ch, k(h + q))$.

Anticipating those efforts $e^{FB}(d)$, the owner chooses $d \in \{(S, S), (S, C), (C, S), (C, C)\}$ to maximize $V_B^{CE}(d, e^*(d))$:

$$\begin{aligned} W((C,C), e^{FB}(C,C)) = &\quad (2k + c)q^2. \\ W((S,S), e^{FB}(S,S)) = &\quad (2k + c)h^2. \\ W((C,S), e^{FB}(C,S)) = &\quad \tfrac{k(h+q)^2 + c(h^2+q^2)}{2}. \end{aligned}$$

Notice that $W((C, S), e^{FB}(C, S)) = W((S, C), e^{FB}(S, C))$. As in *proposition 2* the key parameter that defines the best decision is the ratio of cooperative profits over motivation incentives of projects. We next define some relevant cutoff in this dimension q/h:

- First Case: $W((C, C), e^{FB}(C, C)) \geq W((S, S), e^{FB}(S, S)) \;\Leftrightarrow\; q/h \geq 1$.
- Second Case: $W((C, C), e^{FB}(C, C)) \geq W((C, S), e^{FB}(C, S)) \;\Leftrightarrow\; q/h \geq 1$.
- Last Case: $W((C, S), e^{FB}(C, S)) \geq W((S, S), e^{FB}(S, S)) \;\Leftrightarrow\; q/h \geq 1$.

As it can be seen, $W((C, S), e^{FB}(C, S))$ is never going to be implementable, because $W((C, S), e^{FB}(C, S))$ is greater than $W((S, S), e^{FB}(S, S))$ when $q/h \geq 1$, but at the same time when $q/h \geq 1$, $W((C, C), e^{FB}(C, C))$ is greater than $W((C, S), e^{FB}(C, S))$. As a consequence, the social planner implements $W((C, C), e^{FB}(C, C))$ when $q/h \geq 1$ and $W((S, S), e^{FB}(S, S))$ otherwise.

□

Partial Delegation

Under Partial Delegation (PD) $Y = \{PD\} = \{(1, 0, 0), (0, 0, 1)\}$ (or $\{(0, 1, 0), (1, 0, 0)\}$); i.e., the manager has the decision authority over one project, say project A, whereas Bob has decision authority over project B: $X_{MA} = X_{BB} = 1$. This is different from what we call hierarchical delegation, which will be described in the next subsection. In partial delegation, Bob has decision authority over his own project and, therefore, his expected payoff is the same as that in decentralization. The manager's and agents' expected payoff in partial delegation is given by:

$$\begin{aligned} U_M^{PD}(d, e) &= (\alpha + \lambda)\ E(\pi_A) + \alpha\ E(\pi_B) - g(e_M), \\ U_A^{PD}(d, e) &= \alpha\ E(\pi_A) - g(e_A), \qquad (21) \\ U_B^{PD}(d, e) &= (\alpha + \lambda)\ E(\pi_B) - g(e_B). \end{aligned}$$

Define a cutoff $\tilde{q}^{PD} := \sqrt{1+\frac{c}{2k}}$. When $q/h < \tilde{q}^{PD}$ the CEO and Bob make decisions $d^B = (S,S)$ and the efforts are $e^B = (c\alpha h, c(\lambda+\alpha)h, k(2\alpha+\lambda)h)$. When $q/h \geq \tilde{q}^{PD}$ the CEO and Bob make a cooperative decision $d^B = (C,C)$ and the efforts are $e^B = (0,0,k(2\alpha+\lambda)q)$. Hence the overall value of the firm is:[34]

$$V_B^{PD}(d^*, e^B) = \begin{cases} (2k(2\alpha+\lambda) + c(2\alpha+\lambda))\,h^2 & \text{if } q/h < \tilde{q}^{PD}, \\ 2k(2\alpha+\lambda)q^2 & \text{if } q/h \geq \tilde{q}^{PD}. \end{cases} \tag{22}$$

The main insights of the proof come as follows. When $k/c < 1/2$ partial delegation is strictly dominated by decentralization when q/h is sufficiently small and by cross-authority otherwise. Since when $k/c < 1/2$ there is no misalignment between the decision preferred by the owner and those chosen by any other decision maker this is enough to discard it. On the other hand, when $k/c > 1/2$ Partial Delegation is always dominated by either Decentralization or Centralization from the owner perspective:

$$V_B^{DE}((S,S), e^B(S,S)) \geq V_B^{PD}((S,S), e^B(S,S)) \;\Leftrightarrow\; 2c\lambda h^2 \geq 0, \text{ when } q/h \leq \tilde{q}^{PD},$$
$$V_B^{CE}((C,C), e^B(C,C)) \geq V_B^{PD}((C,C), e^B(C,C)) \;\Leftrightarrow\; 2k\lambda q^2 \geq 0, \text{ when } q/h > \tilde{q}^{PD}.$$

Therefore, we should check whether Partial Delegation may arise as optimal when decisions are not contractible. We focus on cases where $k/c > 1/2$ as mentioned before. It is simple to check that there are some values, $\lambda \geq c$, for which Partial Delegation with decisions (C,C) is higher than Cross Authority (C,C). Additionally, there are values PD (C,C) gives a higher payoff, V, than HD(S,S). Therefore, the owner could be interested to implement Partial Delegtion in this area. However, note that the CEO and the agent in charge of decision making will require considerably more cooperation to move from (S,S) to (C,C) even than Centralization.[35] Therefore, Partial Delegation is dominated.

□

Concentrated Delegation

Under Concentrated Delegation (CD) $Y = \{CD\} = \{(0,1,0),(0,1,0)\}$ (or $\{(0,0,1),(0,0,1)\}$); i.e., Ari has the decision authority over both projects. The manager's and agents' expected payoff in partial delegation is given by:

$$\begin{aligned} U_M^{CD}(d,e) &= \alpha\; E(\pi_A) + \alpha\; E(\pi_B) - g(e_M), \\ U_A^{CD}(d,e) &= (\alpha+\lambda)\; E(\pi_A) + \lambda\; E(\pi_B) - g(e_A), \\ U_B^{CD}(d,e) &= \alpha\; E(\pi_B) - g(e_B). \end{aligned} \tag{23}$$

Define a cutoff $\tilde{q}^{CD} := \sqrt{1+\frac{2c\alpha}{4k\alpha+c\lambda}}$. When $q/h < \tilde{q}^{CD}$ the CEO and Bob make decisions $d^B = (S,S)$ and the efforts are $e^B = (c(\alpha+\lambda)h, c\alpha h, 2k\alpha h)$. When $q/h \geq \tilde{q}^{CD}$ the CEO and Bob make a cooperative decision $d^B = (C,C)$ and the efforts are $e^B = (c\lambda q, 0, 2k\alpha q)$. Hence the overall

[34] The effort levels and optimal decisions are obtained in the same way as in propositions 2-5

[35] From the utility of the CEO and agent in charge of decision making we obtain the threshold $\hat{q}^{PD} := -1 + \sqrt{4 + \frac{2c}{\alpha k} + \frac{4\alpha\lambda+\alpha^2}{\alpha^2}}$ which is considerable higher than $\hat{q}^{CE}$.

value of the firm is:[36]

$$V_B^{CD}(d^B,e^B) = \begin{cases} \big(4k\alpha + c(2\alpha+\lambda)\big)h^2 & \text{if } q/h < \tilde{q}^{CD}, \\ \big(4k\alpha + c\lambda\big)q^2 & \text{if } q/h \geq \tilde{q}^{CD}. \end{cases} \tag{24}$$

The main insights of the proof come as follows. When $k/c \geq 1/2$ concentrated delegation as other forms of complete delegation (decentralization and cross authority) are dominated by other organizational designs that give higher incentives to the CEO. On the other hand, when $k/c < 1/2$ it is convenient to split the incentives into the two agents since their cost functions of effort are strictly convex. As a consequence, the joint effort is greater when it is split equally between both agents because the cost of effort does not increase as fast as if it were not so. The incentive value for the most motivated agent will not produce an effort increase capable to cover the other agent decrease of effort due to the shape of the cost effort function and, therefore, the joint effort will decrease.

Note that concentrated delegation is never preferred to other forms of dominated organization designs, so it is not a valuable alternative. Comparing with decentralization when $q/h < \sqrt{1+\frac{2c\alpha}{4k\alpha+c\lambda}}$ is small for all k/c:

$$V_B^{DE}((S,S),e^B(S,S)) \geq V_B^{CD}((S,S),e^B(S,S)) \;\Leftrightarrow\; 2c\lambda h^2 \geq 0.$$

Since c, λ and h are greater than 0, decentralization with $d=(S,S)$ always dominates concentrated delegation with the same decision set. Comparing also with cross-authority when $q/h \geq \sqrt{1+\frac{2c\alpha}{4k\alpha+c\lambda}}$ for all $k, c > 0$:

$$V_B^{CA}((C,C),e^{FB}(C,C)) \geq V_B^{CD}((C,C),e^{FB}(C,C)) \;\Leftrightarrow\; 2c\lambda q^2 \geq 0.$$

Since concentrated delegation is always dominated by alternative organizational designs and it does not appear in the relevant region where moral hazard in efforts and moral hazard in decisions coexist it is not considered in the analysis.

□

Lemma

Consider values of c, k and h small enough to ensure that none probability is higher than one when selfish decisions are made, then we consider a bound for $q > h$. From proposition 7, the equilibrium success probability in centralization is $P_j = 2k(\alpha+\lambda)q$ for $j = A, B$ if $q/h \geq \hat{q}^{CE}$ and $P_j = [c\alpha + 2k(\alpha+\lambda)]h$ for $j = A, B$ otherwise. The latter probability does not depend on q and can be made less than one by making c, k and h small enough. Also the former probability is less than one if:

$$q < \frac{1}{2k\alpha + 2k\lambda}. \tag{L1}$$

From proposition 8, the equilibrium success probability in decentralization, when it is optimal, is $P_j = [2k\alpha + c(\alpha+\lambda)]h$ for $j = A, B$. Again this can be made less than one by choosing small

[36] The effort levels and optimal decisions are obtained in the same way as in propositions 2-5

enough c and k.

In cross-authority delegation, proposition 9 shows that the equilibrium success probability is $P_j = (c\lambda + 2k\alpha)q$ for $j = A, B$ when $q/h \geq \hat{q}^{CA}$, and $P_j = (c\alpha + 2k\alpha)h$ for $j = A, B$ otherwise. For the latter which does not depend on q, the same argument applies as in the previous cases. Also, the former is less than one if $q < 1/(c\lambda + 2k\alpha)$, which is satisfied if L2 is.

$$q < \frac{1}{2k\alpha + c\lambda}. \tag{L2}$$

From Proposition 10, the equilibrium success probabilities in hierarchical delegation are such that $\max\{P_A; P_B\} = [k(2\alpha + \lambda) + c\lambda]q$ if $q/h \geq \hat{q}_1^{HD}$, $\max\{P_A; P_B\} = k(\alpha + \lambda)(h + q) + c\alpha h$ if $\hat{q}_0^{HD} \leq q/h < \hat{q}_1^{HD} = \overline{q}$, and $\max\{P_A; P_B\} = [k(2\alpha + \lambda) + c\alpha]h$ if $q/h < \hat{q}_0^{HD}$. The last probability can be made less than one for small values of c and k. Note that the second probability is automatically smaller than one if $q \leq \frac{\alpha}{\alpha+\lambda}h$, for h that fulfils the condition in the first probability. Therefore, we can consider the case where $q > \frac{\alpha}{\alpha+\lambda}h$. However, since q is intermediate, cannot be bigger than $h + \frac{\alpha}{\alpha+\lambda}\frac{c}{k}$. Hence, this probability again can be made less than one for small values of c, k and h. Finally, the first probability is less than one if

$$q < \frac{1}{2k\alpha + \lambda(c + k)}. \tag{L3}$$

Thus L1-L3 are sufficient conditions for equilibrium success probabilities to be less than one in any organization if k and c are small enough. Combining L1-L3 proves the Lemma.

□

B. Benchmark Framework Equilibria

Proposition 3: Decentralization

In decentralization, each agent has the decision right over his own project: $X_{MA} = X_{MB} = 0$ and $X_{AA} = X_{BB} = 1$. And the utility functions are those stated in Equation 10.

Solving by backward induction, at time 2 the CEO and each agent maximize their utility after observing the decisions $d = (d_A, d_B)$, i.e., $e^B(d)$. If $d = (C, C)$, then $e^B = (0, 0, 2k\alpha q)$. If $d = (S, S)$, then $e^B = (c(\alpha+\lambda)h, c(\alpha+\lambda)h, 2k\alpha h)$. If $d = (C, S)$ (analogous solution for $d = (S, C)$), $e^B = (0, c(\alpha + \lambda)h, e_M = k\alpha(q + h))$.

Anticipating those efforts $e^B(d)$, the owner chooses $d \in \{(S, S), (S, C), (C, S), (C, C)\}$ to maximize $V_B^{DE}(d, e^*(d))$:

$$\begin{aligned} V_B^{DE}((C, C), e^B(C, C)) = &\quad 4k\alpha q^2. \\ V_B^{DE}((S, S), e^B(S, S)) = &\quad 2\big(c(\alpha + \lambda) + 2k\alpha\big)h^2. \\ V_B^{DE}((C, S), e^B(C, S)) = &\quad k\alpha\ (q + h)^2 + c(\alpha + \lambda)h^2. \end{aligned}$$

Notice that $V_B^{DE}((C, S), e^B(C, S)) = V_B^{DE}((S, C), e^B(S, C))$. The key parameter that defines the best decision in any organizational design is the ratio of cooperative profits over motivation incentives of projects, i.e., q/h. We next define some relevant cutoff in this dimension q/h:

- First Case: $V_B^{DE}((C, C), e^B(C, C)) \geq V_B^{DE}((S, S), e^B(S, S)) \Leftrightarrow q/h \geq \tilde{q}_1 = \sqrt{\frac{1}{2}(2 + \frac{c}{k}\frac{(\alpha+\lambda)}{\alpha})}$.

- Second Case: $V_B^{DE}((C,C), e^B(C,C)) \geq V_B^{DE}((C,S), e^B(C,S)) \Leftrightarrow q/h \geq \tilde{q}_2 = \frac{1}{3} + \sqrt{\frac{1}{3}(\frac{1}{3} + \frac{c}{k}\frac{\alpha+\lambda}{\alpha})}$, *considering only the positive root.*

- Last Case: $V_B^{DE}((C,S), e^B(C,S)) \geq (S,S), e^B(S,S) \Leftrightarrow q/h \geq \tilde{q}_3 = -1 + \sqrt{4 + \frac{c}{k}\frac{\alpha+\lambda}{\alpha}}$, *considering only the positive root.*

Notice that $\tilde{q}_1, \tilde{q}_2$ and $\tilde{q}_3$ are represented in the q/h dimension. Given our assumptions, it is not difficult (but it may take some time) to check that $\tilde{q}_2 \leq \tilde{q}_1 \leq \tilde{q}_3$. Consequently the main cutoff is $\tilde{q}_1$: if $q/h > \tilde{q}_1$, then $q/h > \tilde{q}_2$; consequently, $d = (C,C)$ is preferred to both $d = (S,S)$ and $d = (C,S)$ (and $d = (S,C)$ too). If $q/h < \tilde{q}_1$, then $q/h < \tilde{q}_3$; consequently, $d = (S,S)$ is preferred to both $d = (C,C)$ and $d = (C,S)$ (and $d = (S,C)$ too).

Finally, we can obtain equation (14), taking $\tilde{q}_1$ as the threshold $\tilde{q}^{DE}$ in q/h dimension.

□

Proposition 4: Cross-authority

In cross-authority, each agent has the decision right over the other project: $X_{MA} = X_{MB} = 0$ and $X_{AB} = X_{BA} = 1$. And the utility functions are those stated in Equation 11.

Solving by backward induction, at time 2 the CEO and each agent maximize their utility after observing the decisions $d = (d_A, d_B)$, i.e., $e^B(d)$. If $d = (C,C)$, then $e^B = (c\lambda q, c\lambda q, 2k\alpha q)$. If $d = (S,S)$, then $e^B = (c\alpha h, c\alpha h, e_M = 2k\alpha h)$. If $d = (C,S)$ (analogous solution for $d = (S,C)$), $e^B = (c\lambda q, c\alpha h, k\alpha(q+h))$.

Anticipating those efforts $e^B(d)$, the owner chooses $d \in \{(S,S),(S,C),(C,S),(C,C)\}$ to maximize $V_B^{CA}(d, e^*(d))$:

$$\begin{aligned}
V_B^{CA}((C,C), e^B(C,C)) = &\quad 2(2k\alpha + c\lambda)\ q^2.\\
V_B^{CA}((S,S), e^B(S,S)) = &\quad 2(2k\alpha + c\alpha)\ h^2.\\
V_B^{CA}((C,S), e^B(C,S)) = &\quad k\alpha\ (h+q)^2 + c(\alpha h^2 + \lambda q^2).
\end{aligned}$$

- First Case: $V_B^{CA}((C,C), e^B(C,C)) \geq V_B^{CA}((S,S), e^B(S,S)) \Leftrightarrow q/h \geq \tilde{q}_1 = \sqrt{\frac{2k\alpha+c\alpha}{2k\alpha+c\lambda}}$.
- Second Case: $V_B^{CA}((C,C), e^B(C,C)) \geq V_B^{CA}((C,S), e^B(C,S)) \Leftrightarrow q/h \geq \tilde{q}_2 = \frac{1}{3k\alpha+c\lambda}\big(k\alpha + \sqrt{7k^2\alpha^2 + c^2\alpha\lambda + k\alpha c\lambda}\big)$, *considering only the positive root.*

- Last Case: $V_B^{CA}((C,S), e^B(C,S)) \geq V_B^{CA}((S,S), e^B(S,S)) \Leftrightarrow q/h \geq \tilde{q}_3 = -1 + \sqrt{\frac{1}{(k\alpha+c\lambda)^2} + \frac{3k\alpha+c\lambda}{k\alpha+c\lambda}}$, *considering only the positive root.*

Notice that $\tilde{q}_1, \tilde{q}_2$ and $\tilde{q}_3$ are represented in the q/h dimension. Given our assumptions, it is not difficult (but it may take some time) to check that $\tilde{q}_2 \leq \tilde{q}_1 \leq \tilde{q}_3$. Consequently the main cutoff is $\tilde{q}_1$: if $q/h > \tilde{q}_1$, then $q/h > \tilde{q}_2$; consequently, $d = (C,C)$ is preferred to both $d = (S,S)$ and $d = (C,S)$ (and $d = (S,C)$ too). If $q/h < \tilde{q}_1$, then $q/h < \tilde{q}_3$; consequently, $d = (S,S)$ is preferred to both $d = (C,C)$ and $d = (C,S)$ (and $d = (S,C)$ too).

Finally, we can obtain equation (15), taking $\tilde{q}_1$ as the threshold $\tilde{q}^{CA}$ in q/h dimension.

□

Proposition 5: Hierarchical Delegation

In hierarchical delegation, the CEO has the decision over project A and Ari over project B (it could be the other way around symmetrically): $X_{MA} = 1$, $X_{MB} = 0$ and $X_{AB} = 1$. And the utility functions are those stated in Equation 23.

Solving by backward induction, at time 2 the CEO and each agent maximize their utility after observing the decisions $d = (d_A, d_B)$, i.e., $e^B(d)$. If $d = (C, C)$, then $e^B = (c\lambda q, 0, k(2\alpha + \lambda)q)$. If $d = (C, C)$, then $e^B = (c\alpha h, c\alpha h, k(2\alpha+\lambda)h)$. If $d = (C, S)$, $e^B = (0, c\alpha h, k\alpha(h+q))$. If $d = (C, S)$, $e^B = (c\alpha h, 0, k(\alpha + \lambda)(h + q))$.

Anticipating those efforts $e^B(d)$, the owner chooses $d \in \{(S, S), (S, C), (C, S), (C, C)\}$ to maximize $V_B^{HD}(d, e^*(d))$:

$$\begin{aligned}
V_B^{HD}((C,C), e^B(C,C)) = &\quad \big(2k(2\alpha + \lambda) + c\lambda\big)q^2. \\
V_B^{HD}((C,S), e^B(C,S)) = &\quad k\alpha(h + q)^2 + c\alpha h^2 + c\lambda q^2. \\
V_B^{HD}((S,C), e^B(S,C)) = &\quad k(\alpha + \lambda)(h + q)^2 + c\alpha h^2. \\
V_B^{HD}((S,S), e^B(S,S)) = &\quad \big(2k(2\alpha + \lambda) + 2c\alpha\big)h^2.
\end{aligned}$$

- First Case: $V_B^{HD}((C,C), e^B(C,C)) \geq V_B^{HD}((S,S), e^B(S,S)) \;\Leftrightarrow\; q/h \geq \tilde{q}_1 = \sqrt{\frac{2k(2\alpha+\lambda)+2c\alpha}{2k(2\alpha+\lambda)+c\lambda}}$.
- Second Case: $V_B^{HD}((C,S), e^B(C,S)) \geq V_B^{HD}((S,S), e^B(S,S)) \;\Leftrightarrow\; q/h \geq \tilde{q}_2 = -\frac{-\alpha k}{k\alpha+c\lambda} + \sqrt{\left(\frac{\alpha k}{k\alpha+c\lambda}\right)^2 + \frac{k(3\alpha+\lambda+c\alpha)}{k\alpha+c\lambda}}$, *considering only the positive root.*
- Third Case: $V_B^{HD}((S,C), e^B(S,C)) \geq V_B^{HD}((S,S), e^B(S,S)) \;\Leftrightarrow\; q/h \geq \tilde{q}_3 = -1+\sqrt{2 + \frac{2\alpha}{\alpha+\lambda} + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$, *considering only the positive root.*
- Last Case: $V_B^{HD}((C,C), e^B(C,C)) \geq V_B^{HD}((S,C), e^B(S,C)) \;\Leftrightarrow q/h \geq \tilde{q}_4 =$
  $= \frac{1}{k(1+\alpha)+c\lambda}\Big((k(\alpha+\lambda)+\sqrt{k^2(\alpha + \lambda)^2 + [k(\alpha + \lambda) + c\alpha][k(1 + \alpha) + c\lambda]}\Big)$, *considering only the positive root.*

Notice that $\tilde{q}_1, \tilde{q}_2, \tilde{q}_3$ and $\tilde{q}_4$ are represented in the q/h dimension. Given our assumptions, it is not difficult (but it may take some time) to check that $\tilde{q}_3 \leq \tilde{q}_1 \leq \tilde{q}_4 \leq \tilde{q}_2$. Note that the two relevant thresholds are $\tilde{q}_3$ and $\tilde{q}_1$. In other words, $d = (S, C)$ are preferred to $d = (S, S)$ for $q/h \in (\tilde{q}_3, \tilde{q}_1)$, but $d = (C, C)$ is the optimal for $q/h > \tilde{q}_1$ which makes $\tilde{q}_4$ and $\tilde{q}_2$ irrelevant. $d = (S, S)$ is optimal for $q/h < \tilde{q}_3$.

Finally, we can obtain equation (16), taking $\tilde{q}_3$ and $\tilde{q}_1$ as the threshold $\tilde{q}_0^{HD}$ and $\tilde{q}_1^{HD}$ in q/h dimension.

□

Proposition 6

Before start, for the sake of simplicity let's put aside for a while the notation of the efforts in the value of the organization, i.e. $V_B^{CE}((C, C), e^B(C, C)$ we directly denote it as $V_B^{CE}(C, C)$ and equivalently for every organizational design. We partition the range of $q/h \in (0, Z/h)$ further into three regions: (i) $q/h \in [0, 1]$ where the cooperative returns are lower or equal to motivational returns, (ii) $q/h \in (1, \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}})$ where the upper limit is the threshold under which $V_B^{CE}(C, C) > V_B^{CE}(S, S)$, and (iii) $q/h \in [\sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}, Z)$.

Consider case (i) first. From the equilibrium total expected profits derived above, we have $V_B^{CE}(S,S) - V_B^{PD}(S,S) = V_B^{PD}(S,S) - V_B^{DE}(S,S) = (2k-c)\lambda h^2 > 0$ if and only if $k/c > 1/2$. It is also easy to see $V_B^{DE}(S,S) > V_B^{CA}(S,S)$ and $V_B^{PD}(S,S) > V_B^{HD}(S,S)$. It follows that centralization is optimal if $k > c/2$ and decentralization is optimal otherwise.

Consider next case (ii). The only organizational designs which change their decisions are hierarchical delegation and cross-authority, so they are the only ones that need to be compared with decentralization and centralization. Suppose first that $k/c \geq 1/2$, $V_B^{CE}(S,S) > V_B^{CA}(C,C)$ if and only if $q/h < \sqrt{\frac{2k(\alpha+\lambda)+c\alpha}{2k\alpha+c\lambda}}$, note that this ratio is greater than the limit of the case considered. Additionally, $V_B^{CE}(S,S) > V_B^{HD}(S,C)$ if and only if $q/h < -1 + \sqrt{4 + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$, that is greater than the limit also. As a consequence, $V_B^{CE}(S,S)$ still being optimum if $k/c \geq 1/2$. Now suppose that $k/c < 1/2$, $V_B^{CA}(C,C) > V_B^{DE}(S,S)$ if and only if $q/h \geq \sqrt{1 + \frac{c\alpha}{c\lambda+2k\alpha}}$ and $V_B^{HD}(S,C) > V_B^{DE}(S,S)$ if and only if $q/h \geq -1 + \sqrt{1 + \frac{c}{k}\frac{(\alpha+2\lambda)}{(\alpha+\lambda)} + \frac{(3\alpha-\lambda)}{(\alpha+\lambda)}}$. Notice that cross-authority needs less cooperative returns over motivational returns than hierarchical delegation. Finally, $V_B^{CA}(C,C) > V_B^{HD}(S,C)$ if and only if $q/h \geq \frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda} + \sqrt{\left(\frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda}\right)^2 + \frac{k(\alpha+\lambda)+c\alpha}{k(3\alpha-\lambda)+2c\lambda}}$, that is lower than the threshold q/h for $V_B^{HD}(S,C) > V_B^{DE}(S,S)$. As a consequence, decentralization is optimum if $q/h < \tilde{q}_{B2} := \sqrt{1 + \frac{c\alpha}{c\lambda+2k\alpha}}$ and cross-authority otherwise.

Finally, consider case (iii). The lower limit is the threshold under which $V_B^{CE}(S,S)$ change to $V_B^{CE}(C,C)$, we call this ratio $\tilde{q}_{B1} := \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}$. The other organizational designs in which decisions are changed are hierarchical delegation, partial delegation and decentralization, the three of them decide cooperative decisions for both projects. It is straightforward that $V_B^{HD}(C,C) > V_B^{PD}(C,C) > V_B^{DE}(C,C)$. Hence, partial delegation and decentralization with both cooperative decisions are dominated. Additionally, $V_B^{CE}(C,C) - V_B^{HD}(C,C) = V_B^{HD}(C,C) - V_B^{CA}(C,C) = (2k-c)\lambda q^2$. Then if $k/c \geq 1/2$, centralization with both decisions cooperative is optimum while cross authority with both decisions cooperative is optimum otherwise.

It follows that when $k/c \geq 1/2$, there is only one optimum organizational design: centralization (in which the CEO can choose $d = (C,C)$ when $q/h > \tilde{q}_{B1}$ or $d = (S,S)$ otherwise). When $k/c < 1/2$, decentralization with $d = (S,S)$ will be chosen when $q/h < \tilde{q}_{B2}$ or cross-authority with $d = (C,C)$ otherwise.

□

C. Model Framework Equilibria

In this subsection the only step that changes in comparison to each *benchmark* equilibrium is the step in t_1 in which the individual in charge of decision making decides to choose the decision that is convenient for him/her according to his/her utility. The effort levels are identical as those calculated for each organizational design in the *benchmark case.*

Proposition 7: Centralization

Anticipating those efforts $e^*(d)$, the CEO chooses $d \in \{(S,S),(S,C),(C,S),(C,C)\}$ to maximize $U_M^{CE}(d, e^*(d))$:

$$\begin{aligned} U_M^{CE}((C,C), e^*(C,C)) = &\ 2k(\alpha+\lambda)^2\ q^2. \\ U_M^{CE}((S,S), e^*(S,S)) = &\ 2k(\alpha+\lambda)^2\ h^2 + 2c\alpha(\alpha+\lambda)h^2. \\ U_M^{CE}((C,S), e^*(C,S)) = &\ \tfrac{k(\alpha+\lambda)^2\ (h+q)^2}{2} + c\alpha(\alpha+\lambda)h^2. \end{aligned}$$

- First Case: $U_M^{CE}(C,C|e^*) \geq U_M^{CE}(S,S|e^*) \ \Leftrightarrow\ q/h \geq \hat{q}_1 = \sqrt{1 + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$.
- Second Case: $U_M^{CE}(C,C|e^*) \geq U_M^{CE}(C,S|e^*) \ \Leftrightarrow\ q/h \geq \hat{q}_2 = \frac{1}{3} + \sqrt{\frac{1}{9} + \frac{2}{3}\frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$, *considering only the positive root.*
- Last Case: $U_M^{CE}(C,S|e^*) \geq U_M^{CE}(S,S|e^*) \ \Leftrightarrow\ (q/h) \geq \hat{q}_3 = -1 + \sqrt{4 + \frac{2c}{k}\frac{\alpha}{\alpha+\lambda}}$, *considering only the positive root.*

By exactly the same argument as in propositions 2-4, we can note that the only relevant threshold is $\hat{q}_1$. Therefore, we denote $\hat{q}^{CE} = \hat{q}_1$ the relevant cutoff for equation (17). Note that the actual value for the model for a given d and e^* is the same as in the *benchmark* (since efforts are the same), the only relevant changes is the cutoff.

□

Proposition 8: Decentralization

Anticipating those efforts $e^*(d)$, each agent chooses the decision in his own project. Consider agent j, he chooses d_j given the decision of agent $-j$ regarding d_{-j} in order to maximize $U_j^{DE}(d, e^*(d))$:

$$\begin{aligned} U_A^{DE}((C,C), e^*(C,C)) = &\ (\alpha+\lambda)\ 2k\alpha q^2. \\ U_A^{DE}((S,S), e^*(S,S)) = &\ (\alpha+\lambda)\ 2k\alpha h^2 + \tfrac{c(\alpha+\lambda)^2 h^2}{2}. \\ U_A^{DE}((S,C), e^*(S,C)) = &\ (\alpha+\lambda)\ k\alpha(h+q)^2 + \tfrac{c(\alpha+\lambda)^2 h^2}{2}. \\ U_A^{DE}((C,S), e^*(C,S)) = &\ 0. \end{aligned}$$

We can compute the same for Bob. Note that agent A never makes $d_A = C$ when Bob makes $d_B = S$ because it brings utility of zero. Equivalently, since agents are symmetric, Bob never makes $d_B = C$ when Bob makes $d_A = S$. They make cooperative decisions, when they are sure that it will enforce joint cooperative decisions. Therefore, the only relevant comparison is:

$$U_j^{DE}((C,C), e^*(C,C)) \geq U_j^{DE}((S,S), e^*(S,S)) \ \Leftrightarrow\ q/h \geq \hat{q}^{DE} := \sqrt{1 + \frac{1}{4}\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha}}.$$

Therefore, $\hat{q}^{DE}$ is the relevant cutoff for equation (18).

□

Proposition 9: Cross-authority

Anticipating those efforts $e^*(d)$, each agent chooses the decision in the other project. Consider agent j, he chooses d_j given the decision of agent $-j$ regarding d_{-j} in order to maximize $U_j^{CA}(d, e^*(d))$.

By exactly the same argument as in the previous proposition, there are only two important utilities to consider:

$$U_j^{CA}((C,C),e^*(C,C)) = \quad [(\alpha+\lambda)(2\alpha k + c\lambda) - \tfrac{c\lambda^2}{2}]\ q^2.$$
$$U_j^{CA}((S,S),e^*(S,S)) = \quad [(\alpha+\lambda)(2\alpha k + c\alpha) - \tfrac{c\alpha^2}{2}]\ h^2.$$

As a consequence:

$$U_j^{CA}((C,C),e^*(C,C)) \geq U_j^{CA}((S,S),e^*(S,S)) \ \Leftrightarrow\ q/h \geq \hat{q}^{CA} := \sqrt{\frac{(\alpha+\lambda)(2\alpha k + c\alpha) - \frac{c\alpha^2}{2}}{(\alpha+\lambda)(2\alpha k + c\lambda) - \frac{c\lambda^2}{2}}}.$$

Therefore, $\hat{q}^{CA}$ is the relevant cutoff for equation (19).

□

Proposition 10: Hierarchical Delegation

Anticipating those efforts $e^*(d)$, the CEO makes the decision in project A and the Ari in project B. The utility function for the CEO in each case is:

$$U_M^{HD}((C,C),e^*(C,C)) = \quad \tfrac{k(2\alpha+\lambda)^2\ q^2}{2} + c\alpha\lambda q^2.$$
$$U_M^{HD}((C,S),e^*(C,S)) = \quad \tfrac{k\alpha^2(h+q)^2}{2} + c\alpha^2 h^2.$$
$$U_M^{HD}((S,C),e^*(S,C)) = \quad \tfrac{k(\alpha+\lambda)^2(h+q)^2}{2} + c\alpha(\alpha+\lambda)h^2.$$
$$U_M^{HD}((S,S),e^*(S,S)) = \quad \tfrac{k(2\alpha+\lambda)^2\ h^2}{2} + c\alpha(2\alpha+\lambda)h^2.$$

The utility function for Ari in each case is:

$$U_A^{HD}((C,C),e^*(C,C)) = \quad k(\alpha+\lambda)(2\alpha+\lambda)\ q^2 + \tfrac{c\lambda^2 q^2}{2}.$$
$$U_A^{HD}((C,S),e^*(C,S)) = \quad k\alpha\lambda(h+q)^2 + \tfrac{c\lambda^2 q^2}{2} + c\lambda\alpha h^2.$$
$$U_A^{HD}((S,C),e^*(S,C)) = \quad k\alpha(\alpha+\lambda)(h+q)^2 + \tfrac{c\alpha^2 h^2}{2}.$$
$$U_A^{HD}((S,S),e^*(S,S)) = \quad k(\alpha+\lambda)(2\alpha+\lambda)\ h^2 + c\alpha\lambda h^2 + \tfrac{c\alpha^2 h^2}{2}.$$

Since the CEO controls only d_A, she has two comparisons to make:

- First Case: $U_M^{HD}((C,S),e^*(C,S)) \geq U_M^{HD}((S,S),e^*(S,S)) \ \Leftrightarrow\ q/h \geq \hat{q}_1 := -1+\sqrt{4+\frac{4\alpha\lambda+\lambda^2}{\alpha^2}+\frac{2c}{k}\frac{\alpha+\lambda}{\alpha}}$.
- Second Case: $U_M^{HD}((C,C),e^*(C,C)) \geq U_M^{HD}((S,C),e^*(S,C)) \ \Leftrightarrow\ q/h \geq \hat{q}_2 := \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \sqrt{\left(\frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]}\right)^2 + \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \frac{2c(\alpha+\lambda)}{k(3\alpha+2\lambda)+2c\lambda}}$, *considering only the positive root.*

Ari controls d_B, he has two comparisons to make. However, note that it is simple to see that $d_B = S$ is dominated when $d_A = C$[37]. Therefore, the only relevant comparison is

- Third Case: $U_A^{HD}((S,C),e^*(S,C)) \geq U_A^{HD}((S,S),e^*(S,S)) \ \Leftrightarrow\ q/h \geq \hat{q}_3 = -1+\sqrt{2+\frac{\lambda}{\alpha}+\frac{c}{k}\frac{\alpha\lambda}{\alpha(\alpha+\lambda)}}$, *considering only the positive root.*

Note that $\hat{q}_1 > \hat{q}_3$ so Ari requires less relative cooperative returns to implement $d_B = C$ than the CEO. As a consequence, Ari makes $d_A = C$ when $q/h \geq \hat{q}_3$ and the CEO makes $d_A = C$ when $q/h \geq \hat{q}_2$, and there are three implementable decision sets, $d = (S,S)$, $d = (S,C)$ and $d = (C,C)$.

[37]Assume that $q = h$, which makes $d = (C,C)$ less profitable than $d = (S,C)$ and in any case the utilities for Ari are higher under $d = (C,C)$.

Therefore, the relevant cutoffs for equation (20) are $\hat{q}_0^{HD} = \hat{q}_3$ and $\hat{q}_1^{HD} = \hat{q}_2$.

□

Proposition 11

In this proof we are going to use the same strategy as in proposition 7. We partition the range of $q/h \in (0, Z/h)$ further into three regions: (i) $q/h \in [0,1]$ where the cooperative returns are lower or equal to motivational returns, (ii) $q/h \in (1, \sqrt{1 + \frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}})$ where upper limits is the threshold under which centralization with $d = (C, C)$ is implemented over centralization with $d = (S, S)$, and (iii) $q/h \in [\sqrt{1 + \frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}, Z/h)$.

Note that the first case (i), still being the same since the V^y values of the firms have not change in spite of the fact that their decision thresholds have changed. It follows that centralization is optimal if $k > c/2$ and decentralization is optimal otherwise.

Consider next case (ii). As in Benchmark the only organizational designs which change their decisions are hierarchical delegation and cross-authority, so they are the only ones that need to be compared with decentralization and centralization. Note that when $k/c < 1/2$, $V^{CA}(C, C) > V^{DE}(S, S)$ if and only if $q/h \geq \sqrt{1 + \frac{c\alpha}{c\lambda+2k\alpha}}$ and $V^{HD}(S, C) > V^{DE}(S, S)$ if and only if $q/h \geq -1 + \sqrt{1 + \frac{c}{k}\frac{(\alpha+2\lambda)}{(\alpha+\lambda)} + \frac{(3\alpha-\lambda)}{(\alpha+\lambda)}}$. Notice that cross-authority needs less cooperative returns over motivational returns than hierarchical delegation[38]. Finally, $V^{CA}(C, C) > V^{HD}(S, C)$ if and only if $q/h \geq \frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda} + \sqrt{\left(\frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda}\right)^2 + \frac{k(\alpha+\lambda)+c\alpha}{k(3\alpha-\lambda)+2c\lambda}}$, that is lower than the threshold q/h for $V^{HD}(S, C) > V^{DE}(S, S)$. As a consequence, decentralization is optimum if $\hat{q}_{B2} = q/h < \sqrt{1 + \frac{c\alpha}{c\lambda+2k\alpha}}$ and cross-authority otherwise, as in the benchmark case.

Suppose $k/c \geq 1/2$, $V^{HD}(S, C) > V^{CE}(S, S)$ if and only if $-1 + \sqrt{4 + \frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}} =: \hat{q}_{M1} \leq q/h < \sqrt{1 + \frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$. Additionally, $V^{CA}(C, C) > V^{HD}(S, C)$ if and only if $q/h \geq \hat{q}_{M1'} := \frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda} + \sqrt{\left(\frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda}\right)^2 + \frac{k(\alpha+\lambda)+c\alpha}{k(3\alpha-\lambda)+2c\lambda}}$. As a consequence, $V_B^{CE}(S, S)$ still being optimum until $q/h < -1 + \sqrt{4 + \frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$ if $k/c \geq 1/2$, but hierarchical delegation shows up as an optimum organizational design when $\hat{q}_{M1} \leq q/h < \hat{q}_{M1'}$ and cross-authority becomes optimal for $\hat{q}_{M1'} \leq q/h \leq \sqrt{1 + \frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$.

Finally, consider case (iii). The lower limit is the threshold under which the CEO chooses $d = (C, C)$ over $d = (S, S)$, we call this ratio $\hat{q}_{M2} = \sqrt{1 + \frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$. The results in this region remain equal to that of benchmark proof. Then, centralization with both decisions cooperative is optimum if $k/c \geq 1/2$ while cross authority with both decisions cooperative is optimum otherwise.

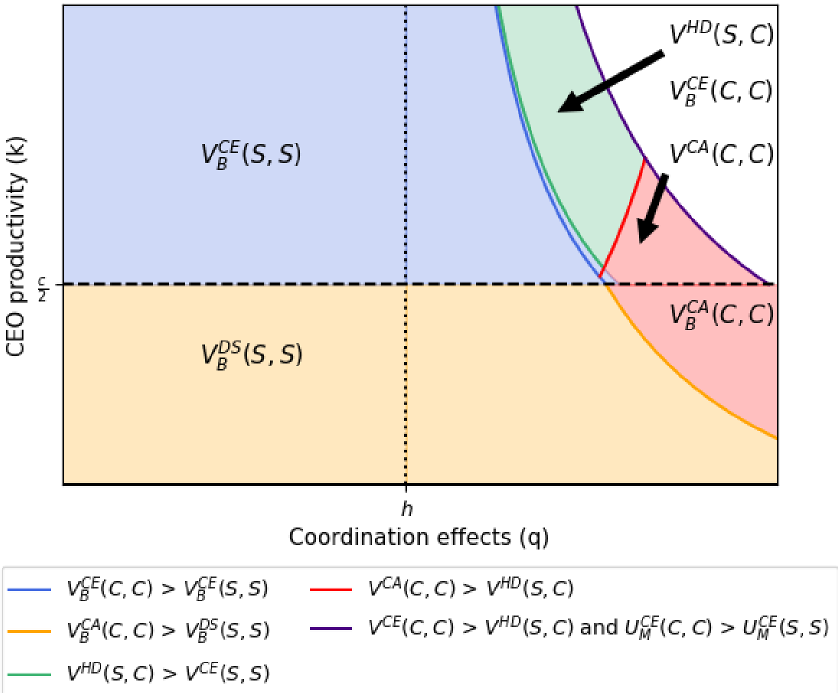
It follows that when $k/c < 1/2$, the results of benchmark remain without modifications. When $k/c \geq 1/2$, the owner chooses centralization with $d = (S, S)$ when $q/h < \hat{q}_{M1}$. When $\hat{q}_{M1} < q/h < \hat{q}_{M2}$, he chooses either hierarchical delegation with $d = (S, C)$ if $q/h < \hat{q}_{M1'}$ or cross-authority with $d = (C, C)$ otherwise. Finally, when $q/h \geq \hat{q}_{M2}$ he chooses centralization with $d = (C, C)$.

□

[38] We are considering that the ratio q/h needed in decentralization to change the decision set from $d = (S, S)$ to $d = (C, C)$ is greater than the upper limit of this region. So, implicitly, we are considering that $3\alpha^2 - 2\alpha\lambda - \lambda^2 > 0$. However, note that if we consider the comparison between $V^{CA}(C, C)$ and $V^{DE}(C, C)$, $V^{CA}(C, C) > V^{DE}(C, C), \forall q/h \geq 1$

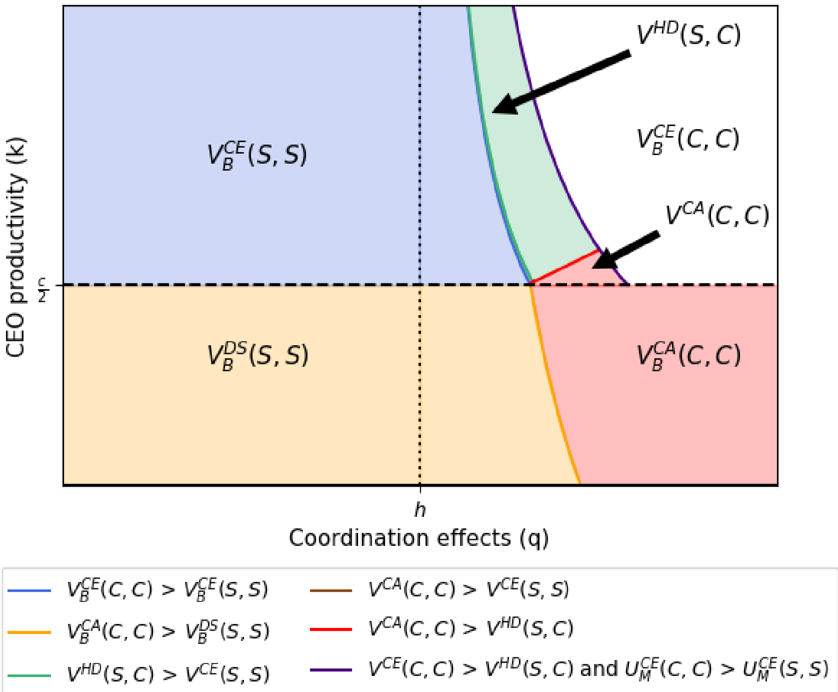
D. Comparative statics

Figure D1: Example 2



Note: This figure considers parameters $\alpha = 2/5$ and $\lambda = 1/5$ and $h = c = 1/2$ as an example.

Figure D2: Example 3



Note: This figure considers parameters $\alpha = 1/4$ and $\lambda = 1/2$ and $h = c = 1/2$ as an example.

E. Case of study

Table 1: Statistics of use

App	2010	2014	2018
Facebook	608m	1.4b (130%)	2.3b (64%)
Whatsapp	10m	600m (590%)	1.5b (159%)
Instagram	Founded	200m	1b (400%)

Note: Each terms represent number of users, 'b' is referred to billion and 'm' to million of users. The increasing percentages and the numbers are rounded .The statistics are available at `statista.com`, `datareportal.com` *and* `demandsage.com`.