Multi-tier hierarchies: an incentive approach.

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Abstract

The main aim of this paper is to analyze the internal organization of a firm that comprises an Owner, a CEO, and two agents. The main inputs of our model are externalities among divisions' projects that may require cooperative decisions, costly effort from the CEO and the two division managers, and incomplete contracts on efforts and decisions. We focus on understanding the existence of more than two layers (i.e., three layers called hierarchical delegation) of decision authority in hierarchical organizations. Hierarchical delegation may arise as the best response to the moral hazard behavior of the CEO: as the CEO cannot commit to choose a cooperative decisions over projects, the most convenient organizational design for the firm may be to give a decision right over one project to an agent willing to choose a cooperative decision, generating an additional layer in the organization. The main contribution of this paper is to identify conditions that lead hierarchical delegation as optimal under an incentive perspective, but also to find the driving force of this result.

JEL Classification: C70, D23, L22.

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

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Introduction

Hierarchies are ubiquitous in modern corporations. As the organizational operation expanded and the problem of managerial overload became apparent, the hierarchical structure evolved further into what has become to be known as a multi-divisional or multi-departmental (M-form) organization (Williamson, 1981). The main advantage of an M-form organization is its scale and scope (Chandler, 1990) which could be achieved by creating steep organizational hierarchies (Rajan and Zingales, 2001). In M-form organizations, corporate headquarters make key strategic decisions, whereas operating decisions are delegated to profit centers. However, a general conclusion from the existing literature is that centralization dominates hierarchies unless there are distinctive elements that prevent the well-functioning of the former organizations. Therefore, it is important to know why there are hierarchies. Under what circumstances do hierarchies perform better than alternative forms of organization? This paper offers an incentive perspective for the study of hierarchies. More specifically, our focus is on multi-tier hierarchies rather than two-tier hierarchies. That is, we focus on understanding the existence of more than two layers of decision authority in hierarchical organizations in order to find the right balance between coordinating project decisions and motivating agents to exert effort.

We consider a similar framework to that of Choe and Ishiguro (2011), an organization with two divisions where each division has one project, labelled A and B. There are four relevant parties, the Owner, a CEO (who works in both projects), and two Agents (named A and B who work respectively in each project). This framework comprises incentives for effort, allocation of decision rights and also externalities between divisions. The way in which decision rights are allocated defines different organizational structures. However, neither the delegation of decision rights nor incentives jointly or separately are able to explain the existence of hierarchical delegation, hence, externalities (that represent coordination profits between divisions) are very important for the understanding of hierarchies. The trade-off faced by the firm comprises the relative returns of coordination over motivation incentives and the relation of CEO's productivity over agents' productivity.

Since we have different elements that interact with each other to drive the results it is important to have reference points in order to compare the results. Consequently, we develop two baseline cases; first, the case where an utilitarian social planner maximizes a welfare function and second, a benchmark in which the owner chooses an organizational structure with enforcing decisions (each party makes a decision convenient for the overall organization value) subject to constrained efforts. In the first case, the social planner clearly implements cooperative decisions when cooperative returns are greater than motivational returns and effort encouraging (selfish) decisions otherwise. Importantly, his decisions do not depend on the relation of CEO and agents' productivity because he is not implementing a particular organizational structure. On the other hand, in the second case (benchmark case) the owner allocates decision rights and each part makes a decision with commitment (i.e., following the owner advice). In this framework, there are situations in which cooperation brings more returns than motivation for the firm but selfish decisions, that prioritize motivation, are made. When efforts are not contractible, the CEO and the agents have incentives to reduce the level of effort to exert in every scenario. The payment schemes based on both the project where the agent is involved and the project where the agent has a decision right work as the incentive device. In terms of the organizational design, the stockholder anticipates that decision making provides an additional incentives to exert effort. Consequently a selfish decision provides more incentives to exert effort than a cooperative decision, making the moral hazard problem more severe in those organizations with cooperative decisions. As a result, selfish decision are preferred as long as the profitability of cooperative decisions are moderate. Additionally, it reveals that when the CEO is more productive than the managers, centralization is the best organizational design. When the CEO is less productive than the managers, managers are in charge of making decisions: either decentralization or cross-authority. In both cases, decision making are chosen by the stockholder as described at the beginning, no matter who is in charge of making it.

When we consider the model framework we get new results. As it was mentioned above, we consider a model in which the owner allocates decision rights but is not able to control the decision made. As a consequence, each party (CEO, agents A and B) chooses the decision more convenient for his/her own utility. When the CEO is less productive than the agents, the results of the benchmark and the model remain equal. However, when the CEO is more productive than the agents, there is a new result. If the returns of cooperative decisions are moderate, centralization may no longer be the best organizational design (recall that in benchmark centralization is always preferred). Instead, cross authority or hierarchical delegation are the second best organizational designs chosen by the stockholder. The CEO knows that cooperation is profitable but she also bears the main cost of efforts for the projects to be successful. The CEO prefers instead to implement selfish decisions where the managers are also motivated to exert effort. Consequently, the owner chooses another organizational design delegating at least partially on the managers. When the CEO is slightly more productive than the managers, cross authority is the best design to balance level of efforts with cooperative decisions. When the CEO is relatively more productive than the managers, hierarchical delegation is the best organizational design to balance high effort (by the CEO) with partial cooperation (and partial motivation).

This result is considerably interesting for two reasons. The first one because it captures some empirical examples, for instance the Sony restructuring in 2009[1]. At the heart of the reorganization there is the formation of two new business groups. The Networked Products & Services Group (NPSG) is based on networked media products, including computer entertainment, personal computers, music players, new mobile products, and media software and services, whereas the New Consumer Products Group (NCPG) encompasses televisions, cameras, and components. Of particular interest in this restructuring is how Sony attempts to balance coordination and incentives within the NPSG. The President of NPSG (who used to be the president of Sony Computer Entertainment which is currently within NPSG) has been announced as the Vice President of Sony Corporation. That is, he will be the Vice President of Sony while being the president of NPSG. We may interpret this as an example of hierarchical delegation. Indeed, Sony's news release stresses that this reform will expand the innovation across the organization. In agreement with our results, hierarchical delegation will be optimal in coordinating activities within the NPSG while providing incentives to its computer entertainment division without undermining incentives at headquarters[2].

The other reason is that the result sheds light on the study of hierarchies through economic incentives. Traditionally, the incentives literature considers primarily two-tier hierarchies and not much is mentioned about multi-tier hierarchies. As a consequence, the problem solver perspective or the communication analysis of hierarchies are the consolidated explanation of hierarchies in

[1] Borrowed from Choe and Ishiguro (2011).

[2] "Consumers want products that are networked, multi-functional and service-enhanced utilizing open technologies, and user experiences that are rich, shared and, increasingly, green" ... "This reorganization is designed to transform Sony into a more innovative, integrated and agile global company with its next generation of leadership firmly in place. The changes we're announcing today will accelerate the transformation of the Company that began four years ago. They will now make it possible for all of Sony's parts to work together to assume a position of worldwide leadership and, together, achieve great things" Sony Corporation Announces Major Reorganization and New Management Team Led by Howard Stringer, February 27, 2009.

firms. In that sense, this analysis contributes with an explanation of multi-tier hierarchies as a moral hazard problem that also differs considerably from Choe and Ishiguro (2011) who show that hierarchical delegation is an optimum *in situ*.

In this paper we consider a fixed payment scheme. As a consequence, we make a comparative statics analysis in which we consider different values for participation share and decision making share of the profits in order to understand how the environments of sub-optimal organizations (hierarchical delegation and cross-authority) change with a change in these parameters values. Thus, we show that when the share for participation increases and the share of decision making decreases, it is more likely that hierarchical delegation and cross-authority arise as optimal organizations. In other words, there are more cases where the moral hazard problem in decision is more intense and the cooperative returns needed to align agents' decisions with stockholder decisions are bigger (movement towards the right). The opposite happens when the share of decision making increases and the share of participation decreases. That means that high powered incentives on decision making help to decrease the moral hazard in decisions without being able to overcome the moral hazard in efforts.

The paper is organized as follows: Section II presents related literature. Section III states the model, the first best and benchmark problem. Section IV identifies different organizational structures. Section V analyses the optimal organizational structures under benchmark and model framework. Section VI shows a comparative static analysis for the payment scheme parameters. Finally, Section VII presents the conclusions.

Related literature

There are different ways of analyzing the firm from an economic perspective. Alfred Chandler (1962 and 1977, [1993, 1990]) and Oliver Williamson (1967, 1981) developed novel contributions which over the following years became the literature of economic organizational design and firm boundaries. Particularly, we will be revising the economic literature which takes into account the economic organizational design and vertical integration in order to discover the different reasons which have been used to consider multi-tier hierarchies.

To begin with, firm boundaries and vertical integration analysis started to grow after Ronald Coase seminal paper in 1937 and the follow-up contribution by Williamson (1975). Both considered that the firm comprises a different way of allocating resources other than the market prices mechanism. The allocation of the resources in a firm is the result of the decision of an agent who is in a specific position in the organization. This agent takes decisions not only concerning his own tasks, but also other tasks managed by different individuals[3]. Due to the fact that market transactions have costs and the internal organization of the firms (as a consequence of hierarchies) can minimize those costs, called "transaction costs", this intra-firm mechanism replaces the market prices mechanism. Hence, firm boundaries show up when organizational costs are marginally higher than transaction costs in the markets. This coordination effects are considered in our analysis through externalities over projects within the organization.

In the following years, Grossman and Hart (1986) formalize Coase and Williamson's contributions into a model that analyzes the main drivers of vertical and horizontal integration. Their theory of costly contracts emphasizes that contractual rights can be specific or residual rights. When it is costly to list all specific rights over assets in the contract, it may be optimal to let one

[3]"If a workman moves from department Y to department X, he does not go because of a change in relative prices, but because he is ordered to do so" (Coase, 1937; p. 387).

party purchase all residual rights. Ownership is the purchase of these residual rights. Their main results have seeds in two key concepts, specificity assets ownership and incomplete contracts. A firm purchases or takes the control over another firm when firm l's control increases its productivity exceeding the amount of decrease of firm 2's management productivity due to the loss of control.

Traditionally, the literature considers two different kinds of hierarchies: simple or "two-tier" hierarchies and "multi-tier hierarchies". Simple hierarchies are those in which decision rights are allocated either at the top of the organization or at the bottom, whereas multi-tier hierarchies are those in which different dimensions of decision taking may exist, so the decision rights are allocated through different layers of the organization. Hierarchies in firms have different origins. Firstly, a cost/benefit analysis about the implementation of the organizational design with an incentive perspective. Secondly, an analysis of communication problems in firms. Finally, cognitive boundaries and heterogeneous abilities to solve problems faced by individuals. Thus, decentralization implies different problems faced by heterogeneous agents, hence, the optimum organizational design shows up when there is a perfect match between tasks and agents. The main contributions to these kind of theories are surveyed in Garicano and Van Zandt (2012).

The notion of multi-tier or multi-layer hierarchies with problem-solver perspective is closely related to complexity and bounded rationality. Knight (1921) was one of the first authors to highlight the entrepreneur role in these circumstances. The manager could appear as an economic agent capable of minimizing the uncertainty in the decision-taking process while coordinating different tasks among the individuals taking into account the difficulties of these tasks and the abilities of the personnel. After that, other authors have studied this notion of hierarchies known as knowledge-based hierarchies. Rajan and Zingales (2001) show the way in which a hierarchical structure implies individual interactions within the firm. 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. Garicano and Van Zandt (2012) summarize diverse papers which focus in the specialization benefits within the organization and the optimum allocation of knowledge in the organization for each task. Particularly, through this analysis hierarchies are essential to profit from the comparative advantages due to the division of labour, which actually implies specific knowledge for each task.

Dessein (2002) considers the problem of communication in hierarchies and shows under which conditions delegation to an intermediate party can be optimal. Alonso et al. (2008) and Rantakari (2008) also consider communication in organizations and focus on the fundamental trade-off between adaptation and coordination. On the one hand, divisions have to be adapted to local conditions in order to be effective. On the other hand, high firm performance requires close coordination of the divisions' activities, which can lead away from best adaptation. Alonso et al. (2008) and Rantakari (2008) analyze the conditions for decentralization or centralization as a better solution to the given trade-off. Under decentralization, division heads directly communicate with each other and then decide for their divisions, whereas under centralization the division heads communicate with the CEO who decides for the two divisions thereafter.

Throughout this paper we are going to consider hierarchies with an incentive perspective considering the Principal-Agent problem as the main framework. As a consequence, we are going to revise this kind of literature deeply though a detailed revision of this topics could be found in Gibbons and Roberts (2013) and in Mookherjee (2006). There are different variations of Principal-Agent models, and some of them have important features for the analysis of hierarchies, delegation being one them. Delegation is primarily based on Aghion and Tirole (1997), who state that the organizational design and, particularly, the allocation of the decision rights (the authority) is an informative problem. Formal authority implies the right to decide whereas real authority entails the control to decide. In their vision, the one who is going to take the decision is the agent with the greatest amount of information, independently of the formal authority. As a consequence, when the agents with more information are at the bottom of the hierarchy, due to specialization, decision rights should be allocated there and decentralization shows up. For their part, Baker et al. (1999) explain that delegation is rather difficult to implement because there is some lack of commitment in those agents at the top of the hierarchy which have the formal authority.

Other important aspect in incentive literature associated with hierarchies is the management of teams. In a firm there are essential activities in which a group of people need to interact in order to achieve a goal, especially when the tasks remain indivisible. This analysis focuses primarily in the foundational paper of Holmström and Milgrom (1991) and Alchian y Demsetz (1972) and Holmström (1982).

Since hierarchies are ubiquitous in firms, it is interesting to analyze the main drivers that make them show up and why they might be more efficient than other two-tier hierarchies, actually more developed. Hence, Choe and Ishiguro (2011) state a model through Principal-Agent analysis with incomplete contracts and externalities between departments. In this model they study the internal organization of the firm in an organization composed of four relevant parties, an Owner, a CEO and two divisional manager. The owner only decides the governance structure whereas the CEO and managers are in charge of two projects. The CEO makes a general effort and each agent makes a specific effort for one project. Thus, the expected profits of each project are composed of an intrinsic concern of a project and the externalities of the other project. The two key ingredients of their model are externalities among divisions' projects that may require coordination and effort incentives for the CEO and the two division managers. Depending on how decision authority over each project is allocated, they compare various organizational structures including centralization, different forms of partial and full delegation, and hierarchical delegation. They identify conditions under which different organizational structures can be compared.

Kräkel (2017) considers the same corporation as Choe and Ishiguro (2011). This paper is closely related to Choe and Ishiguro (2011) and takes into account the existence of externalities between the divisions. However, Kräkel (2017) puts aside the incomplete contract assumption and assumes that the owner is able to create monetary effort incentives and to allocate decision authority over the divisions. He characterizes how externalities and benefits of control determine the corporation's optimal organization. The introduction of endogenous incentives changes the major findings of Choe and Ishiguro (2011) discarding hierarchical delegation as optimal.

In this paper we focus on understanding the existence of more than two layers of decision authority in hierarchical organizations, in order to find the right balance between coordinating project decisions and motivating agents to exert effort. Depending on how decision authority over each project is allocated, alternative organizational structures can show up. Contrary to Kräkel (2017) we keep the assumption of incomplete contracts and propose a different timing which allows us to identify different conditions from Choe and Ishiguro (2011) under which hierarchical delegation structure shows up as a result of the lack of commitment of the CEO and as a "Second Best" answer to the strategic behavior of the CEO. To put it simply, we identify incentive mechanisms which make hierarchical delegation an optimum organizational structure.

The model

In this section we state the model. We consider a similar framework to Choe and Ishiguro's (2011). In the setup we describe: the basics of the technology, describing the individuals and the productive activities developed at the organization that generate rents. The utilities and the organization, explaining the distribution of these rents among agents, and how these utilities are related to the decision making process that leads to different organizational structures. The timing, and the maximization problem of the model. After that, we explain the two reference points: the first best case and the benchmark case.

Basics

We consider an organization with two divisions where each division has one project, labelled A and B. There are four relevant parties, the Owner, a CEO, and two Agents (named A and B)[4]. The owner can be considered a representative shareholder who is interested in maximizing profits of the overall organization. By contrast, the other members of the organization perceive monetary concerns about the projects through their own utility.

Each project may or may not be successful, and the probability of success of each of them depends on the effort of the agent involved in it and the CEO. Given the effort choice $e := (e_A, e_B, e_M)$ each project 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 $c_i > 0$. 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 agents. Note that the CEO's effort 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 project are perfectly complementary.

A successful project has an impact on both projects though the intensity depends on the decision taken. For example, a project can prioritize its own benefits or the 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 or a "Cooperative" one (C) which generates more spillovers. The decisions are denoted by d_j where $d_j \in \{S, C\} \cup \emptyset,\ j = A, B$ for each project A and B. Let's denote an intrinsic concern for a project or its own profit as h and the spillover or cooperative return as q. As it was mentioned, a certain revenue of a successful project has two parts which depend on decision taken, its own profit denoted by $h(d_j)$ with $j = A, B$ and an external or cooperative profit $q(d_{j'})$ with $j' = A, B$. Hence, a certain (or ex-post) revenue of two successful projects are the following for projects A and B:

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

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

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

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

The expected profits of each project depend on the efforts and types of decisions made. The

[4] In this paper we are going to consider manager and CEO as synonyms, as a consequence, as follows the reader will find the M letter as an indicator of the CEO.

expected profits are built up of two aspects, the revenue above mentioned and the probability of success. Given a pair of decisions $d := (d_A, d_B)$ and the effort choice $e := (e_A, e_B, e_M)$, the expected profits of project A and B are:

$$E(\pi_A|d,e) = P_A h(d_A) + P_B q(d_B) \quad , \quad E(\pi_B|d,e) = P_B h(d_B) + P_A q(d_A). \tag{3}$$

Utilities and Organization

The payment scheme is assumed to be exogenous, each individual that exerts an effort receives a share $\alpha > 0$ of the realized profit. The individual in charge of making a decision receives a share $\lambda > 0$ of the realized profit. So far, a share of $2\alpha + \lambda$ is allocated to the agents and to the CEO. The remaining goes to the owner, but we are going to simplify that $2\alpha + \lambda = 1$. [5]

The only contractible variable is the decision right over a project, defining the structure 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 index 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 in project A; if $(X_{MA}, X_{AA}, X_{BA}) = (0,1,0)$ agent A is in charge of making decisions in project A; finally, if $(X_{MA}, X_{AA}, X_{BA}) = (0,0,1)$ agent B is in charge of making decisions in project A. Similarly for B, where the second index is changed by B. Let $\mathcal{Y}$ be the set which defines the organizational structure comprised of the allocation of decision rights over both projects. Since there are two decision rights, one for each project, to be allocated to three parties, there are nine possible organizational structures depending on the allocation of decision authority, hence, $\#\mathcal{Y} = Y_A \times Y_B = 9$. $\mathcal{Y}$ is the only variable that the owner decides to maximize the overall organization's profit.

Next, we are going to explain manager and agents' utility functions. First, the manager utility function is:

$$U_M^Y(d,e) = \alpha\Big(E(\pi_A|d,e) + E(\pi_B|d,e)\Big) + \lambda\Big(X_{MA}E(\pi_A|d,e) + X_{MB}E(\pi_B|d,e)\Big) - g(e_M). \tag{4}$$

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's j utility function is:

$$U_j^Y(d,e) = \alpha E(\pi_j|d,e) + \lambda \sum_{j'=A,B} X_{jj'} E(\pi_{j'}|d,e) - c(e_j). \tag{5}$$

Again, the first term indicates the profits due to the effort exerted. However, 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 taken and works exactly in the same way as for the manager. To conclude, the last term is the effort cost function for the agents.

[5] There are three parties involved in each project and each one has a share of the project profits, two parties considered by the effort provision for the project to succeed and a third party for the authority pay. Then, the bargaining solution needs that $2\alpha + \lambda \leq 1$. We could analyze the case in which $2\alpha + \lambda + \gamma = 1$ where γ represents the dividends for the owner. However, we consider the case where $2\alpha + \lambda = 1$ since the solutions of the former and the latter problems are the same, but assuming $\gamma = 0$ simplifies the analysis.

Timing

The timing for the model is as follows. At date 0, the owner chooses a specific organizational design or governance structure. At date 1, the individual with the decision right makes the decision for the project defining $d = (d_A, d_B)$. At date 2, 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[6].

t_0:Owner	t_1:Involved party	t_2:Manager and agents	t_3:
Organizational design	Decisions d_i	Effort	Profits realized

Organizational design problem

The model described above considers the owner's problem of choosing an organizational design Y which maximizes the overall organization value (his own payoff) but considering that the only contractible variable is the decision right over a project but without being able to enforce a cooperative or selfish decision. To put it bluntly, the owner's problem will be to maximize the organization's value V subject to agents' and CEO's incentive compatible efforts and decisions. So, the owner's maximization problem is:

$$\max_{y \in \mathcal{Y}} \; V(d,e) = E(\pi_A|d,e) \; + \; E(\pi_B|d,e);$$

$$s.t : IC_d : \quad U_i^y(d_j|d_{j'},e) \geq U_i^y(d'_j|d_{j'},e), \; \forall i = A,B,M \text{ and } \forall j,j' = A,B, \tag{6}$$

$$IC_e : \quad e_i^* = arg \; \max_e \; U_i^y(d,e), \; \forall i = A,B,M.$$

Assumptions

Throughout this article, we assume:

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

(b) $P(e_M, e_j) = e_M + e_j$ for $j = A,B$ and $q < Z := \frac{1}{2k\alpha + max\{2k\lambda,(k+c)\lambda\}}$.

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

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 if a cooperative decision is made $q(C) = q$ and in any other case, $h(C) = q(S)$ is 0. The second assumption helps to simplify the analysis, which enables the model to have a closed form solution for equilibrium in each organizational structure. The second part is a sufficient condition under which equilibrium effort satisfies $e_M + e_j = P_j < 1, \; j = A,B$. The incomplete contracts assumption states that it is impossible to build a contingent state for each possible combination of states of nature in the organization.

[6] The timing of the model is different from Choe and Ishiguro (2011), we are considering that efforts' choices - in a sequential game (instead of considering a bayesian game)- are taken after decision making over the projects due to economic reasons. We strongly believe that important decisions in an organization are chosen before each worker decides the amount of effort because of the time needed to complete processes in production and also as a consequence of the importance of those decisions in the organization which are considerably greater than the effort choice.

Now in order to have two reference points we develop both the first best and a specific benchmark analysis as follows.

First Best

In the First Best scenario, the representative stockholder plays the role of a social planner who is able to control over all the decision making processes. The representative stockholder is able to force the CEO and the agents to make the decisions and the efforts she believes are more convenient, as long as the participation constraints are satisfied. I.e., the social planner solves the problem of maximizing total surplus (i.e., expected profits minus effort costs). We implicitly assume that the social planner can incur in fixed payments conditioning on observable efforts.[7]

The First Best analysis considers a Welfare function in which a social planner could make the decisions over the projects and control individual effort as if it were observable. As a consequence the central planner problem for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$ is:

$$\max_{d,e}\; W(d,e) = E(\pi_A|d,e) + \; E(\pi_B|d,e) - g(e_M) - c(e_A) - c(e_B) \tag{7}$$

Proposition 1: When $h > q$ the social planner chooses both decisions $d_A = d_B = S$ and each agent's effort level is $e_A = e_B = ch$ and CEO's effort is $e_M = 2kh$. Otherwise, a social planner chooses both decisions $d_A = d_B = C$ and each agent's effort level is $e_A = e_B = cq$ and the CEO's effort is $e_M = 2kq$. Hence:

$$W(d_A, d_B|e^*) = \begin{cases} 2(2k+c)\; q^2 \text{ if } q \geq h, \\ 2(2k+c)\; h^2 \text{ if } q < h. \end{cases} \tag{8}$$

In equilibrium, the social planner implements cooperative decisions when these decisions turn to be more profitable than self-motivated decisions; and self-motivated decisions otherwise. Given decisions, the social planner implements optimal efforts for CEO and managers.[8]

To compare the first best in different cases, we can solve for different parameters about effort cost and profitability of coordination versus motivation decisions. The cheapest the effort, the more the level of effort implemented. Decisions, however, are modelled as binary choices. Consequently, there is a threshold in the relevance of cooperative versus self-motivated decisions below which the social planner prefers to implement self-motivated decisions.

In picture 1a we show the optimal decision for our model using specific values of α and λ. Notice that the relative cost of effort plays no role in implemented optimal decisions. However, the profitability of coordination versus intrinsic motivation generates that cooperative decisions are implemented when its profitability is high enough (in the model, when q/h is greater than one).

Benchmark

In the *Benchmark case* we assume the representative stockholder cannot contract on or observe the effort choice of the CEO and the agents, generating a moral hazard problem. However, the

[7] Compared with the model, in the first best the stockholder can enforce decisions, contract on efforts, and can propose fixed payments conditional on observed effort. Alternatively, we could assume that the payment is an exogenous share of total profits, once the effort is above a threshold. In this alternative case, efforts are efficient only if the fixed proportion coincides with the optimal fixed payment of the problem proposed. Although the effort may be inefficient, the main concern on decisions are not altered and the main result for the comparison remain.

[8] Alternatively, the owner maximizes total profits subject to participation constraints. I.e., in order to participate, each agent (managers and CEO) receives a fixed payment that equals the effort cost.

representative stockholder can enforce the decision making process and the organization design, that also provides incentives to deal with the moral hazard problem. That is, the representative stockholder chooses the decision making process and the organizational design to maximize expected profits of the firm, subject to an incentive compatibility constraint on effort choices. For instance, he may propose a centralized organizational structure with selfish decisions, anticipating that this organization generates a with high-powered incentives payment scheme.

Formally, in the benchmark analysis the owner chooses the organizational design (Y, d) which maximizes the overall organization value (his own payoff) subject to both participation and incentive compatibility constraints of the CEO and managers. Since the problem is defined in a way that guarantee the participation constraint of the CEO and managers, the stockholder can ignored 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.[9]. So, the owner's maximization problem is:

$$\begin{aligned} &\max_{Y,d}\ V_B(d,e) = E(\pi_A|d,e)\ +\ E(\pi_B|d,e), \\ &s.t:\ IC_e:\quad e_i^* = arg\ \max_{e}\ U_i^Y(d,e),\ \forall i = A, B, M. \end{aligned} \tag{9}$$

We postpone the solution of this maximization problem until we explain the optimal organization structure. 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.

Organizational structure

As it was above mentioned, there are nine possible organizational structures depending on the allocation of decision authority, which are reduced to six due to symmetry in three of them (the last three we list as follows). We classify them in centralization, decentralization, cross authority, partial delegation, hierarchical delegation and concentrated delegation. Hence, $\mathcal{Y} := \{CE, DE, CA, PD, HD, CD\}$ where CE means *Centralization*, DE *Decentralization*, CA *Cross-Authority*, PD *Partial Delegation*, HD *Hierarchical Delegation* and CD *Concentrated Delegation*. This last organizational structure, called Concentrated Delegation, which consists of delegating the decision rights over both projects to one agent, A or B, is discarded because it is always dominated by other organizational structures (for the proof see the *appendix A*).

Centralization

In centralization, the manager has the decision authority over both projects: $X_{MA} = X_{MB} = 1$ and $X_{jj'} = 0$ for $j, j' = A, B$. Thus, the manager's expected payoff and agent j expected payoff become:

$$\begin{aligned} &U_M^{CE}(d,e) = (\alpha + \lambda) \sum_{j=A,B} E(\pi_j|d,e) - g(e_M), \\ &U_j^{CE}(d,e) = \alpha\ E(\pi_j|d,e) - c(e_j). \end{aligned} \tag{10}$$

[9]Note that value V_B has a subscript B which indicates that this value is computed under benchmark framework.

Centralization provides the largest effort incentives to the manager. Moreover, since the manager makes both decisions, coordination can be achieved in centralization under certain circumstances. The downside of centralization is that the agents' effort incentives are weaker in relation to some alternative organizational structures that we describe below.

Decentralization

Each agent has decision authority over his own project: $X_{MA} = X_{MB} = 0$ and $X_{jj} = 1$ for $j = A, B$. Decentralization shifts control benefits from the manager to each agent. Thus, the manager's expected payoff and agent j expected payoff become:

$$\begin{aligned} U_M^{DE}(d, e) &= \alpha \sum_{j=A,B} E(\pi_j|d, e) - g(e_M), \\ U_j^{DE}(d, e) &= (\alpha + \lambda)\ E(\pi_j|d, e) - c(e_j). \end{aligned} \tag{11}$$

In decentralization, each agent has larger effort incentives relative to centralization, although the manager's effort incentives are smaller.

Cross-Authority

Each agent has decision authority over the other project: $X_{MA} = X_{MB} = 0$ and $X_{jj'} = 1$ for $j \neq j'$ where $j, j' = A, B$. As decentralization, cross-authority shifts control benefits from the manager to each agent. In cross-authority delegation, the CEO's expected payoff is the same as that in decentralization and agent j's expected payoff is given by:

$$\begin{aligned} U_M^{CA}(d, e) &= \alpha \sum_{j=A,B} E(\pi_j|d, e) - g(e_M), \\ U_j^{CA}(d, e) &= \alpha\ E(\pi_j|d, e) + \lambda\ E(\pi_{j'}|d, e) - c(e_j). \end{aligned} \tag{12}$$

In cross-authority, each agent has larger effort incentives relative to centralization and manager's effort incentives are smaller, such as decentralization, though the cross allocation of the decisions should help with coordination issues.

Partial Delegation

In partial delegation the manager has the decision authority over one project, say project A, whereas agent B 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, agent B 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:

$$\begin{aligned} U_M^{PD}(d, e) &= (\alpha + \lambda)\ E(\pi_A|d, e) + \alpha\ E(\pi_B|d, e) - g(e_M), \\ U_A^{PD}(d, e) &= \alpha\ E(\pi_A|d, e) - c(e_A), \\ U_B^{PD}(d, e) &= (\alpha + \lambda)\ E(\pi_B|d, e) - c(e_B). \end{aligned} \tag{13}$$

Hierarchical Delegation

The last type of organizational structure is called hierarchical delegation, in which authority over one project, say project A, is allocated to the manager, whereas authority over the other project is allocated to agent A: $X_{MA} = X_{AB} = 1$ and $X_{Bj} = 0$ and for $j = A, B$. We call this the M - A - B hierarchy. In this case, a three-tier hierarchy is characterized by successive allocation of decision authority where agent A 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; the link between the delegated agent and the other project is absent in partial delegation. The manager's and agents' expected payoff in partial delegation is given by:

$$\begin{aligned} U_M^{HD}(d,e) &= (\alpha+\lambda)\ E(\pi_A|d,e) + \alpha\ E(\pi_B|d,e) - g(e_M), \\ U_A^{HD}(d,e) &= \alpha\ E(\pi_A|d,e) + \lambda\ E(\pi_B|d,e) - c(e_A), \\ U_B^{HD}(d,e) &= \alpha\ E(\pi_B|d,e) - c(e_B). \end{aligned} \tag{14}$$

Optimal Organizational Structure

In this section, we compare various organizational structures to analyze their performance under the benchmark and the model framework. For each of the five organizational structures that we take into account, we present the total expected profit of the organization and the optimum effort for each agent. After that, we compute the optimal organization structure depending on the parameters values and we compare the optimality map in each case in order to understand the reasons that have determined different organizational structures. The Benchmark case is analyzed in propositions 2 to 7 and the main model in propositions 8 to 13. To make a clear presentation of the results, we prove proposition 2 for centralization in the Benchmark case and the remaining proofs are in *Appendix B* for propositions 3 to 7 and in *Appendix C* for propositions 8 to 13.

Two factors are of main importance in identifying an optimal organizational structure both in the benchmark case (proposition 7) and the model framework (proposition 13). First, relative importance of cooperative versus motivation decisions, measured by q/h. Second, the relation of CEO's productivity over agents' productivity; 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[10]. 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 manager contributes more to the organization than both agents combined given the same level of effort, and the other way around if $k < c/2$.

[10]Note that when $1/k = 2/c$ the marginal cost of effort per unit for the manager equals the marginal cost of effort per unit for both agents

Benchmark case

In the benchmark case, the representative stockholder choose (Y, d) to maximize V_B subject to incentive compatibility constraint in the effort choice, as stated in Equation (9). In other words, the stockholder designs the organization and chooses the decisions in order to deal with the moral hazard problem. In terms of the first best problem, the stockholder faces incomplete contracting in the exogenous share payment scheme and the agents effort choice. Hence, the relation between CEO's and the agents' productivity is important in order to increase primarily the effort of the most productive person.

Since it is a sequential game, this problem is solved by backward induction. We proceed by analyzing each organizational design, choosing the best decision making d subject to the incentive constraint in the effort choice. Finally, proposition 7 summarizes the solution to Equation (9).

Centralization

In centralization, as above-mentioned, the manager has the decision authority over both projects: $X_{MA} = X_{MB} = 1$ and $X_{jj'} = 0$ for $j, j' = A, B$. And the utility functions are those stated in Equation 10.

Proposition 2: When $q/h \geq \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}$ the CEO chooses both decisions $d_A = d_B = C$ and each agent's effort is $e_A = e_B = 0$ while CEO's effort is $e_M = 2k(\alpha + \lambda)q$. Otherwise, the CEO chooses both decisions $d_A = d_B = S$ and each agent chooses $e_A = e_B = c\alpha h$ whereas the CEO's choice is $e_M = 2k(\alpha + \lambda)h$. Hence the overall value of the firm is:

$$V_B^{CE}(d_A, d_B|e^*) = \begin{cases} 4k(\alpha+\lambda)\ q^2 & \text{if } q/h \geq \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}, \\ \big(4k(\alpha+\lambda) + 2c\alpha\big)\ h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{15}$$

Proof

Solving by backward induction, at time 2 the CEO and each agent maximize their utility function given decisions d_A and d_B. If both decisions are cooperative $d_A = d_B = C$, then $e_A = e_B = 0$ and $e_M = 2k(\alpha + \lambda)q$. If both decisions are selfish $d_A = d_B = S$, then $e_A = e_B = c\alpha h$ and $e_M = 2k(\alpha + \lambda)h$. If $d_A = C$ and $d_B = S$, $e_A = 0$, $e_B = c\alpha(h + q)$ and $e_M = k(\alpha + \lambda)(q + h)$. The last case is the same as the previous but with Agents A and B's efforts symmetrically changed.

After that, at time 1 the CEO chooses a cooperative or selfish decision for each project, considering which is the most convenient for the owner. In order to decide which is the most convenient organizational structure, the CEO needs to compare the profits value for the overall organization under each possible decision set, that is, to compare $V_B^{CE}(d|e^*)$ for each $d \in \{(S, S), (S, C), (C, S), (C, C)\}$.

Since $d = (S, C)$ and $d = (C, S)$ has the same V_B value for the owner, we compare 3 cases: $d = (S, S), d = (S, C)$ and $d = (C, C)$. The key element to choose which type of decision will be more profitable within an organizational structure, in this case centralization, is the ratio of cooperative profits over motivation incentives (q/h).

$V_B^{CE}(C, C|e^*) = 4k(\alpha + \lambda)\ q^2.$

$V_B^{CE}(S, S|e^*) = (4k(\alpha + \lambda) + 2c\alpha)\ \ h^2.$

$V_B^{CE}(C, S|e^*) = k(\alpha + \lambda)\ (q + h)^2 + c\alpha h^2.$

First Case: $V_B^{CE}(C, C|e^*) \geq V_B^{CE}(S, S|e^*) \iff q/h \geq \epsilon_1 = \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}.$

Second Case: $V_B^{CE}(C,C|e^*) \geq V_B^{CE}(C,S|e^*) \Leftrightarrow q/h \geq \epsilon_2 = \frac{1+\sqrt{4+3\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}}{3}$, *considering only the positive root.*

Last Case: $V_B^{CE}(C,S|e^*) \geq V_B^{CE}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_3 = -1+\sqrt{4+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$, *considering only the positive root.*

In the three cases solved above ϵ_1, ϵ_2 and ϵ_3 represent the minimum surplus of cooperation needed to fulfill the conditions. ϵ_1 represents the condition under which $V_B^{CE}(C,C|e^*) \geq V_B^{CE}(S,S|e^*)$, and likewise the others. It can be proved that $\epsilon_2 \leq \epsilon_1 \leq \epsilon_3$,[11] and consequently prove that $d = (C,C)$ are preferred over $d = (C,S)$ under very small cooperative surplus. Additionally, $d = (C,S)$ over $d = (S,S)$ requires a cooperative surplus ϵ_3 higher than the surplus needed to make $d = (C,C)$ preferred over $d = (S,S)$. Finally, $d = (C,S)$ will be dominated and the only two set of decisions taken are $d = (C,C)$ and $d = (S,S)$.

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 11.

Proposition 3: When $q/h \geq \sqrt{\frac{1}{2}(1+\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha})}$ each agent decides both decisions $d_A = d_B = C$ and each agent's effort is $e_A = e_B = 0$ while CEO's effort is $e_M = 2k\alpha q$. Otherwise, the agents choose both decisions $d_A = d_B = S$ and each agent chooses $e_A = e_B = c(\alpha+\lambda)h$ whereas the CEO's choice is $e_M = 2k\alpha h$. Hence the overall value of the firm is:

$$V_B^{DE}(d_A, d_B|e^*) = \begin{cases} 4k\alpha q^2 & \text{if } q/h \geq \sqrt{\frac{1}{2}(2+\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha})}, \\ 2\big(c(\alpha+\lambda)+2k\alpha\big)h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{16}$$

Proof

See appendix B.

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 12.

Proposition 4: When $q/h \geq \sqrt{\frac{2k\alpha+c\alpha}{2k\alpha+c\lambda}}$ each agent decides both decisions $d_A = d_B = C$ and each agent's effort is $e_A = e_B = c\lambda q$ while CEO's effort is $e_M = 2k\alpha q$. Otherwise, the agents choose both decisions $d_A = d_B = S$ and each agent chooses $e_A = e_B = c\alpha h$ whereas the CEO's choice is $e_M = 2k\alpha h$. Hence the overall value of the firm is:

$$V_B^{CA}(d_A, d_B|e^*) = \begin{cases} 2(2k\alpha+c\lambda)\ q^2 & \text{if } q/h \geq \sqrt{\frac{2k\alpha+c\alpha}{2k\alpha+c\lambda}}, \\ 2(2k\alpha+c\alpha)\ h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{17}$$

Proof

See appendix B.

[11] Under request, it is not difficult to prove though the proof is long and impractical to keep the audition attention. Also, it is rather easy to check it with numerical examples.

Partial Delegation

In partial delegation, the CEO has the decision over project A and Agent B over his own project (it could be the other way around symmetrically): $X_{MA} = 1$, $X_{MB} = 0$, $X_{AA} = 0$ and $X_{BB} = 1$. And the utility functions are those stated in Equation 13.

Proposition 5: When $q/h \geq \sqrt{1 + \frac{c}{2k}}$ the CEO and agent B decide a cooperative decision $d_A = d_B = C$, each agent's effort $e_A = e_B = 0$ and CEO's effort is $k(2\alpha + \lambda)q$. Otherwise, the CEO and agent B choose both decisions $d_A = d_B = S$ and each agent chooses $e_A = c\alpha h$, $e_B = c(\lambda + \alpha)h$ whereas the CEO's choice is $e_M = k(2\alpha + \lambda)h$. Hence the overall value of the firm is:

$$V_B^{PD}(d_A, d_B|e^*) = \begin{cases} 2k(2\alpha + \lambda)q^2 & \text{if } q/h \geq \sqrt{1 + \frac{c}{2k}}, \\ (2k(2\alpha + \lambda) + c(2\alpha + \lambda))\, h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{18}$$

Proof

See appendix B.

Hierarchical Delegation

In hierarchical delegation, the CEO has the decision over project A and Agent A 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 13.

Proposition 6:

When $q/h \geq \bar{\epsilon} = \frac{1}{k(1+\alpha)+c\lambda}\left((k(\alpha + \lambda) + \sqrt{k^2(\alpha + \lambda)^2 + [k(\alpha + \lambda) + c\alpha][k(1 + \alpha) + c\lambda]}\right)$ the CEO and agent A decide a cooperative decision, $d_A = d_B = C$ and each agent's effort is $e_A = c\lambda q$, $e_B = 0$ and CEO's effort is $e_M = k(2\alpha + \lambda)q$. If $-1 + \sqrt{2 + \frac{2\alpha}{\alpha+\lambda} + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}} = \underline{\epsilon} \leq q/h < \bar{\epsilon}$, CEO chooses a selfish decision while agent A a cooperative one, $d_A = S$ and $d_B = C$, $e_A = c\alpha h$, $e_B = 0$ and $e_M = k(\alpha + \lambda)(h + q)$. Otherwise, the CEO and agent A choose both decisions $d_A = d_B = S$ and each agent choose $e_A = e_B = c\alpha h$ and the CEO's choice is $e_M = k(2\alpha + \lambda)h$. Hence the overall value of the firm is:

$$V_B^{HD}(d_A, d_B|e^*) = \begin{cases} (2k(2\alpha + \lambda) + c\lambda)\, q^2 \text{ if } \epsilon > \bar{\epsilon}, \\ k(\alpha + \lambda)(h + q)^2 + c\alpha h^2 \text{ if } \underline{\epsilon} < \epsilon \leq \bar{\epsilon}, \\ (2k(2\alpha + \lambda) + 2c\alpha)\, h^2 \text{ otherwise}. \end{cases} \tag{19}$$

Proof

See appendix B.

The Best Organization to the Benchmark Case

We now compare the results in propositions 2 to 6, obtaining the best organizational design for an stockholder that is in control of the decision making process but not on the effort exerted by the CEO or the managers.

Proposition 7: When $k/c \geq 1/2$, that is the CEO is more productive than both agents, there is only one organizational structure: centralization (in which the CEO can choose $d = (C, C)$ when $q/h > \epsilon_{B1}$ or $d = (S, S)$ otherwise). When $k/c < 1/2$, decentralization with $d = (S, S)$ will be chosen when $q/h < \epsilon_{B2}$ or cross-authority with $d = (C, C)$ otherwise. Thresholds ϵ_{B1} and ϵ_{B2} are values of q/h which depend on k, c, α and λ, the expression of these thresholds are in the proof.

Proof

See appendix B.

Compared with the first best scenario, every organization design (Y) with every decision (d) suffers the moral hazard problem. Moreover, the incentives to exert effort with cooperative decisions are lower than with selfish decisions. This means that the moral hazard problem is potentially more severe with cooperative decisions. This weakness of cooperative decisions motivates the stockholder to choose selfish decision in cases where she would have chosen cooperative decisions under the first best scenario. This is represented in those cases where $q/h < \epsilon_{B1}$ (or $q/h < \epsilon_{B2}$). However, when the effects of cooperation are really important ($q/h > \epsilon_{B1}$ or $q/h > \epsilon_{B2}$), the owner prefer to face moral hazard problem, facing the cost of smaller efforts.

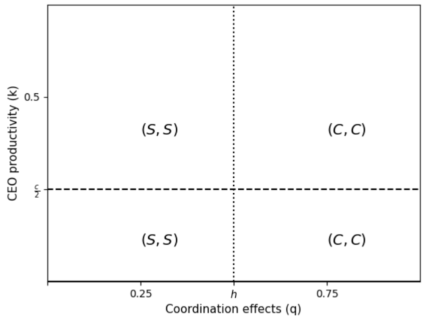
In terms of the organizational design, the stockholder anticipates that decision making provides an additional incentives to exert effort. As the weakness of cooperative is present in all organizational designs, she allocates the decisions rights to the part that is more productive in exerting effort. When the CEO is more productive than the managers, centralization is the best organizational design; with centralization, the decision is selfish or cooperative depending on the relative return of each decision and the incentives that decisions generate on exerting efforts. When the CEO is less productive than the managers, managers are in charge of making decisions: choosing decentralization with selfish decisions if cooperation is not so profitable, or choosing cross-authority with cooperative decisions if cooperation is profitable enough.

We illustrate these intuitions with a numerical example plotted in figures 1a and 1b. In the First Best scenario (in figure 1a), the main issue is whether decisions are selfish or cooperative. As efforts can be contractible, there is no moral hazard problem; then decisions are selfish when the coordinated effects are smaller or equal than a threshold represented by $q/h = 0.5$ in the example, and cooperative otherwise. Notice that independently of the case, below $k/c = 1/2$ the stockholder promotes organizational structures where the decision rights are allocated to the agents; above that threshold, she offers a centralised organizational structure.

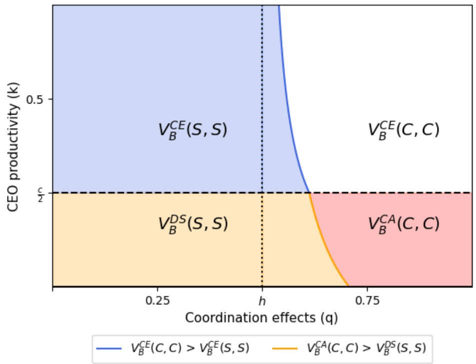
When efforts are not contractible, the CEO and the agents have incentives to reduce the level of effort to exert in each scenario. The payment schemes based on both the project where the agent is involved and the project where the agent has a decision rights work as the incentive device. Consequently a selfish decision provides more incentives to exert effort than a cooperative decision, making the moral hazard problem more severe in those organizations with cooperative decisions. As a result, selfish decision are preferred as long as the profitability of cooperative decisions are moderate. In figure 1b the preference over selfish decisions is represented by the blue area (with centralization) and the yellow area (with decentralization).

In short, the moral hazard problem generates a cost to the representative stockholder, reducing the profitability of the firm in every scenario. This cost reduces the profitability of all decisions in all organizational designs. However, the moral hazard problem is handled relatively better with selfish decisions than with cooperative decisions, favoring the organizations that are complemented better with selfish decisions. But if cooperation is too important for the profits of the organization, the owner prefers to suffer the effects of the moral hazard problem.

(a) First Best



(b) Benchmark



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

The model case

In the main model, the representative stockholder choose (Y) to maximize V subject to incentive compatibility constraint in the effort choice and in the decision making, as stated in Equation (6). In other words, the stockholder designs the organization in order to deal with the moral hazard problem in the effort and decision choices. In terms of the first best problem, the stockholder faces incomplete contracting several restrictions: first, the payment scheme is quite restrictive, second there is no commitment in the decision made and the effort chosen by the agents. Hence, the relation between CEO's and the agents' productivity is important in order to increase the effort of the most productive person and to motivate the best decisions.

Due to the fact that it is a sequential game, this problem will be solved by backward induction, for each organizational structure. For each type of organizational structure Y there is an incentive to make a decision d in each project (by the person in charge in each project) and, then, an effort chosen by each agent $e = (e_M, e_A, e_B)$. the firm's profit V is computed. The owner chooses the organizational design Y that maximizes V.

The only difference between the profit computed before is the step at time 1 in which the decision is implemented by whoever is in charge of decision making without commitment. The propositions stated below have the same strategy of proof as propositions 2 - 7. However, at time 1 the part involved in decision making maximizes his own utility anticipating the incentives on efforts. We only state here the propositions since the proofs are available at *Appendix C*. After propositioins 8-12, we state the main result of the paper in proposition 13.

Centralization

Proposition 8: When $q/h \geq \sqrt{1 + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$ the CEO chooses both decisions $d_A = d_B = C$ and each agent's effort is $e_A = e_B = 0$ while CEO's effort is $e_M = 2k(\alpha + \lambda)q$. Otherwise, the CEO chooses both decisions $d_A = d_B = S$ and each agent chooses $e_A = e_B = c\alpha h$ whereas the CEO's choice is $e_M = 2k(\alpha + \lambda)h$. Hence the overall value of the firm is:

$$V^{CE}(d_A, d_B|e^*) = \begin{cases} 4k(\alpha+\lambda)\ q^2 & \text{if } q/h \geq \sqrt{1 + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}, \\ \big(4k(\alpha+\lambda) + 2c\alpha\big)\ h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{20}$$

Decentralization

Proposition 9: When $q/h \geq \sqrt{1+\frac{1}{4}\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha}}$ each agent decides both decisions $d_A = d_B = C$ and each agent's effort is $e_A = e_B = 0$ while CEO's effort is $e_M = 2k\alpha q$. Otherwise, the agents choose both decisions $d_A = d_B = S$ and each agent chooses $e_A = e_B = c(\alpha+\lambda)h$ whereas the CEO's choice is $e_M = 2k\alpha h$. Hence the overall value of the firm is:

$$V^{DE}(d_A, d_B|e^*) = \begin{cases} 4k\alpha q^2 & \text{if } q/h \geq \sqrt{1+\frac{1}{4}\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha}}, \\ 2\big(c(\alpha+\lambda)+2k\alpha\big)h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{21}$$

Cross-authority

Proposition 10: When $q/h \geq \sqrt{\frac{(\alpha+\lambda)(2\alpha k+c\alpha)-\frac{c\alpha^2}{2}}{(\alpha+\lambda)(2\alpha k+c\lambda)-\frac{c\lambda^2}{2}}}$ each agent decides both decisions $d_A = d_B = C$ and each agent's effort is $e_A = e_B = c\lambda q$ while CEO's effort is $e_M = 2k\alpha q$. Otherwise, the agents choose both decisions $d_A = d_B = S$ and each agent chooses $e_A = e_B = c\alpha h$ whereas the CEO's choice is $e_M = 2k\alpha h$. Hence the overall value of the firm is:

$$V^{CA}(d_A, d_B|e^*) = \begin{cases} 2(2k\alpha + c\lambda)\ q^2 & \text{if } q/h \geq \sqrt{\frac{(\alpha+\lambda)(2\alpha k+c\alpha)-\frac{c\alpha^2}{2}}{(\alpha+\lambda)(2\alpha k+c\lambda)-\frac{c\lambda^2}{2}}}, \\ 2(2k\alpha + c\alpha)\ h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{22}$$

Partial Delegation

Proposition 11: When $q/h \geq -1+\sqrt{4+\frac{2c}{\alpha k}+\frac{4\alpha\lambda+\alpha^2}{\alpha^2}}$ the CEO and agent B decides both decisions $d_A = d_B = C$ and each agent's effort is $e_A = e_B = 0$ while CEO's effort is $e_M = 2k\alpha q$. Otherwise, the CEO and agent B choose both decisions $d_A = d_B = S$ and each agent chooses $e_A = c\alpha h$, $e_B = c(\lambda+\alpha)h$ and whereas the CEO's choice is $e_M = k(2\alpha+\lambda)h$. Hence the overall value of the firm is:

$$V^{PD}(d_A, d_B|e^*) = \begin{cases} 2k(2\alpha+\lambda)q^2 & \text{if } q/h - 1+\sqrt{4+\frac{2c}{\alpha k}+\frac{4\alpha\lambda+\alpha^2}{\alpha^2}}, \\ \big(2k(2\alpha+\lambda)+c(\alpha+\lambda)\big)h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{23}$$

Hierarchical Delegation

Proposition 12:
When $q/h \geq \bar{\epsilon} = \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \sqrt{\big(\frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]}\big)^2 + \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \frac{2c(\alpha+\lambda)}{k(3\alpha+2\lambda)+2c\lambda}}$ the CEO and agent A decide a cooperative decision, $d_A = d_B = C$ and each agent's effort is $e_A = c\lambda q$, $e_B = 0$ and CEO's effort is $e_M = k(2\alpha+\lambda)q$. If $-1+\sqrt{2+\frac{\lambda}{\alpha}+\frac{c}{k}\frac{\alpha\lambda}{\alpha(\alpha+\lambda)}} = \underline{\epsilon} \leq \epsilon < \bar{\epsilon}$, CEO chooses a selfish decision while agent A a cooperative one, $d_A = S$ and $d_B = C$, $e_A = c\alpha h$, $e_B = 0$ and $e_M = k(\alpha+\lambda)(h+q)$. Otherwise, the agents choose both decisions $d_A = d_B = S$ and each agent chooses $e_A = c\alpha h$,$e_B = c\alpha h$ and the CEO's choice is $e_M = k(2\alpha+\lambda)h$. Hence the overall value of the firm is:

$$V^{HD}(d_A, d_B|e^*) = \begin{cases} (2k(2\alpha+\lambda)+c\lambda)\, q^2 \text{ if } \epsilon \geq \bar{\epsilon}, \\ k(\alpha+\lambda)(h+q)^2 + c\alpha h^2 \text{ if } \underline{\epsilon} \leq \epsilon < \bar{\epsilon}, \\ (2k(2\alpha+\lambda)+c\alpha)\, h^2. \text{ if } \textit{otherwise}. \end{cases} \tag{24}$$

Proposition 13: When $k/c \geq 1/2$, the owner chooses centralization with $d = (S, S)$ when $q/h < \epsilon_{M1}$. When $\epsilon_{M1} < q/h < \epsilon_{M2}$, he chooses either hierarchical delegation with $d = (S, C)$ if $\epsilon < \epsilon_{M1'}$ or cross-authority with $d = (C, C)$ otherwise. Finally, when $q/h \geq \epsilon_{M2}$ he chooses centralization with $d = (C, C)$. When $k/c < 1/2$, the results of benchmark remain without modifications. Thresholds ϵ_{M1} and ϵ_{M2} are values of q/h which depend on k, c, α and λ, the expression of these thresholds are in the proof.

Proposition 13 highlights some differences from the result in proposition 7 and states our main result. Recall that in figure 1b there are three optimum organizational structures: centralization, decentralization and cross authority. When $k/c < 1/2$ results in proposition 7 and 13 remain equal (decentralization and cross authority are optimum depending on q/h), we concentrate in the difference when $k/c \geq 1/2$. Note that when $k/c \geq 1/2$ we get a new result: hierarchical delegation or cross-authority may appear as the best organizational design of the firm. While in the benchmark case centralization was the main organizational design when the CEO is more productive than the agents, the incomplete contracting situation in enforcing decisions generates a new cost for the firm that motivates a change in the organizational design of the firm.

To understand the main result we must recall that the moral hazard problem on effort is important, but it affects more to cooperative decisions. This implies that selfish decisions are preferred by the organization (and by every agent that faces an effort cost) if cooperative decisions are not so profitable for the firm. The main problem arises when the cooperative decisions are relatively more profitable than selfish decisions.

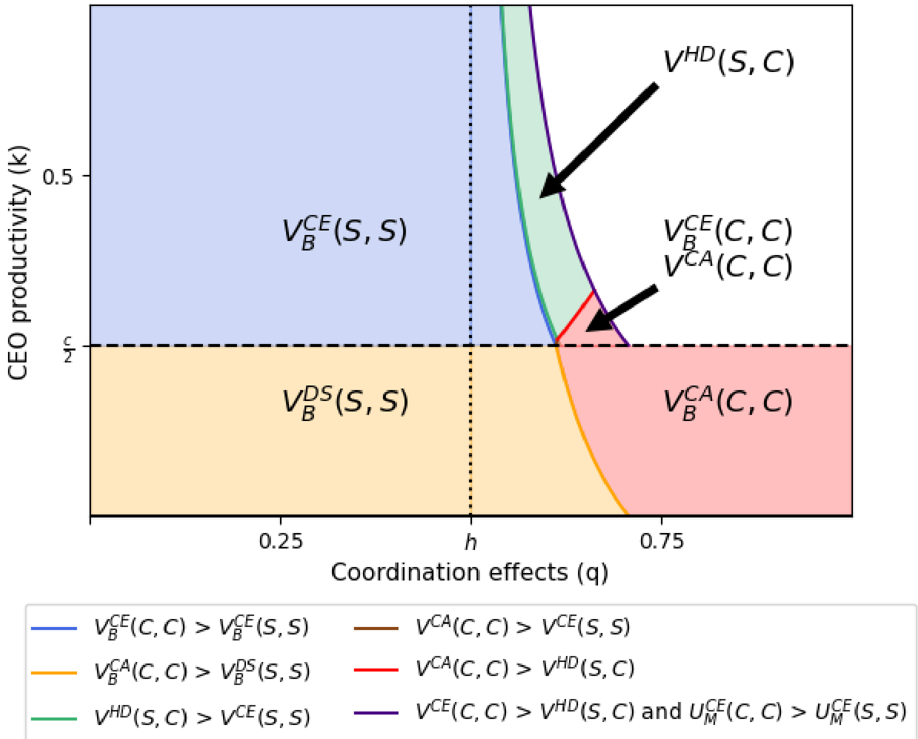
When cooperative decisions are relatively more important than selfish decisions there are three possible scenarios: first, when cooperative decisions are really important, any agent understand that the moral hazard problem in the effort choice is an inevitable cost for the firm; in this case centralization is the best organizational design, the CEO chooses cooperative decisions and efforts are reduced.

When cooperative decisions are relatively important, the CEO prefers selfish decisions to motivate managers effort but the firm's profits decrease. The main problem arises because the firm's profits depend on the effort of the CEO without taking into account the CEO's cost of the effort. But under centralization it is the CEO the one in charge of decisions, and he strictly prefers selfish decisions. The way to deal with this situations is twofold, depending on how productive is the CEO relative to the managers. If the CEO is slightly more productive than the managers, the stockholder chooses a cross authority design: each manager benefits more from a cooperative decision over the other project, then cooperative decisions are guarantee. If the CEO is substantially more productive than the agents, the stockholder moves to a hierarchical delegation design: the CEO has one decision right on one project (e.g., say A), and give the manager of that project the decision right over the other project (e.g., manager A chooses the decision over project B).

The main trade-off for the stockholder arises because not only the decision made but also the right allocated to the decision making process provide incentives to make effort. Consequently, when the CEO is more productive in exerting effort than the managers and the cooperative decisions are relatively important for the profits, the stockholder prefers a hierarchical delegation design.

Another way to put the intuition behind this result is the following: even when the cooperation over motivation returns ratio increases, the stockholder prefers some coordination but the CEO chooses selfish decisions under centralization (in which the effort incentives are prioritized). However, at the same time the CEO is more productive than both managers, so it is necessary to keep her motivated to exert effort. As a consequence, the owner decides to delegate one decision right over the manager of the second project to generate some coordination, and the first decision right stays with the CEO who takes a selfish decision and keeps a high value of effort. To sum up, hierarchical delegation with $d = (S, C)$ shows up as a result of the moral hazard behavior of the CEO. Anticipating that the CEO is not going to make the decision which is the most profitable for the organization, the owner prefers to choose a "Second Best" organizational structure with hierarchical delegation.

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 13. The thresholds defines some areas: The blue area is the one where $V_B^{CE}(S, S)$ is highest. This area expands until the green line (that is close to the blue line). In this area both the CEO and the owner prefers selfish decisions. The white area (when q is quite high) is the area where both the CEO and the owner prefers cooperative decisions and the organization profits are maximized with $V_B^{CE}(C, C)$, even under the moral hazard problem in efforts. 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 is 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 productive, then a hierarchical delegation is the best organizational design.

Comparative Static Analaysis

In this section we show how the optimal organization space changes with changes in the payment scheme structure. Since figures 1b and 2 illustrate the results for particular values of project participation returns and decision rights returns, $\alpha = \lambda = 1/3$,[12] we consider other two cases. The first case considers takes into account a higher share of the profits related to the participation on it and a lower decision-making payment, $\alpha = 2/5$ and $\lambda = 1/5$: In the second case, we analyze the opposite scenario where the fixed component related to participation is lower and the decision-making share is more important, $\alpha = 1/4$ and $\lambda = 1/2$. Figures D1 and D2 (available in *Appendix D*) depict these two cases.

The first case shows that the are of optimality of hierarchical delegation and cross-authority increases with an increase in the share of profits by participating but it also requires a greater cooperative return to be implemented. In other words, incentives with less powered incentives on decision making increase the area of sub-optimal organizational structures and face a higher space of double moral hazard problem (on efforts and decisions). On the other hand, in the second case when the share for decision making increases, the area of optimality of hierarchical delegation and cross-authority decreases (without disappearing) and requires less cooperative returns to implement hierarchical delegation. In other words, high powered incentives focused on decision making tend to reduce the area of implementation of sub-optimal organizational structures (without making them disappear), and tend to align better the decision-making by the CEO or managers with the optimal decision making that the owner would prefer.

Conclusion

One of the central issues in organization design is to find the optimum way to coordinate organizational activities while motivating different parties within the organization. Conventional wisdom and many studies have shown that centralization is best in coordinating activities although it can undermine incentives at the divisional level. Recently, some studies with technological arguments have shown that such a trade-off between coordination and incentives is not necessarily an issue since decentralization with horizontal communication can achieve coordination without reducing incentives at the divisional level. However, decentralization can provide powerful incentives at the divisional level but decreasing the incentives at the top of the organization, that means to organizational headquarters. Hence, when we introduce incentives at both levels of organizational hierarchy, this trade-off between coordination and motivation becomes more complex to solve than when incentives matter at only one level.

This article has addressed the trade-off between coordination and motivation by studying internal organization of a firm that comprises an owner, a CEO and two agents through an incentive perspective. The three key ingredients of our model are externalities among divisions' projects that may require coordination, effort incentives and allocation over decision rights for the CEO and the two agents under incomplete contracts. Depending on how decision authority over each project is allocated, we have studied the exhaustive list of all possible organizational structures.

We find that when decisions are controlled by the owner the only organizational structures that are going to be implemented are centralization, decentralization and cross-authority. Centralization when the productivity of the CEO is greater than the productivity of the agents; decentralization when both the coordination effects and the CEO's productivity over agents' productivity are low and, cross-authority when cooperative effects are higher than motivational effects but the productivity of the agents is still higher than the CEO's productivity. Under incomplete contracts we get new results when the CEO is more productive than the agents. In this case, the owner is not able to enforce the the right decision of the CEO under centralization, as the CEO makes a sub-optimal

[12] Note that the proof results are general for different values of α and λ.

decision (less cooperative than needed) for the overall organization. The owner can anticipate this strategic behavior and decides to choose a hierarchical delegation organization in which the owner gives a decision right to an agent who is willing to cooperate (following his own incentives). In fact, hierarchical delegation appears, due to a moral hazard problem in decision making of the CEO, as an optimum implementable organizational structure under a framework with incomplete contracts with non-contractible efforts and decisions.

This paper contributes to the literature by finding some incentives conditions under which hierarchical delegation and cross authority are optimal and as a consequence, better than other organizational structures. But specifically it sheds light on the understanding of the incentives mechanisms that make hierarchical delegation showed up.

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Appendix

A. Auxiliary proofs

Propositions 1: First Best

In First Best analysis the Social Planner maximizes the Welfare function W under each set of decisions in order to obtain the optimum efforts in each case. If both decisions are cooperative $d_A = d_B = C$, then $e_A = e_B = cq$ and $e_M = 2kq$. If both decisions are selfish $d_A = d_B = S$, then $e_A = e_B = ch$ and $e_M = 2kh$. If $d_A = C$ and $d_B = S$, $e_A = cq$, $e_B = ch$ and $e_M = k(q + h)$. The last case is the same as the previous but with Agents A and B's efforts symmetrically changed.

Note that:

$W(C, C) = (2k + c)q^2$.

$W(S, S) = (2k + c)h^2$.

$W(C, S) = \frac{k(h+q)^2+c(h^2+q^2)}{2}$.

First Case: $W(C, C) \geq W(S, S) \;\Leftrightarrow\; q/h \geq 1$.

Second Case: $W(C, C) \geq W(C, S) \;\Leftrightarrow\; q/h \geq 1$.

Last Case: $W(C, S) \geq W(S, S) \;\Leftrightarrow\; q/h \geq 1$.

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

Concentrated Delegation

The intuition behind this proof is clear. When $k/c \geq 1/2$ concentrated delegation as other forms of complete delegation (decentralization and cross authority) are less preferred than other structures which offer better incentives to the CEO. On the other hand, when $k/c < 1/2$ it is not a good strategy to give all the incentives to one agent instead of both because the cost function of effort is 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.

Computing the V_B value of the Concentrated Delegation structure in the same way as the other organizational structures.

$$V_B^{CD}(d_A, d_B|e^*) = \begin{cases} \big(4k\alpha + c\lambda\big)q^2 \text{ if } q/h \geq \sqrt{1 + \frac{2c\alpha}{4k\alpha + c\lambda}}, \\ \big(4k\alpha + c(2\alpha + \lambda)\big)h^2 \text{ otherwise.} \end{cases} \tag{25}$$

Note that concentrated delegation is never preferred to other forms of dominated organization structures, so it is not a valuable alternative. Comparing with decentralization when q/h is small for all k/c:

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

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 hierarchical delegation when $q/h \geq \sqrt{1 + \frac{2c\alpha}{4k\alpha + c\lambda}}$ for all $k, c > 0$:

$V_B^{HD}(C,C) \geq V_B^{CD}(C,C) \;\Leftrightarrow\; 2k\lambda q^2 \geq 0.$

Since concentrated delegation is always dominated by alternative organizational structures which are not optimum, it will not be consider in this analysis.

Lemma

From proposition 8, the equilibrium success probability in centralization is $P_j = 2k(\alpha + \lambda)q$ for $j = A, B$ if $q \geq \sqrt{1 + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}h$ 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 and k small enough. Also the former probability is less than one if:

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

From proposition 9, the equilibrium success probability in decentralization is $P_j = [2k\alpha + c(\alpha + \lambda)]h$ for $j = A, B$. Again this can be made less than one by choosing small enough c and k.

In partial delegation, Proposition 11 shows that the equilibrium success probabilities are such that $\max\{P_A; P_B\} = 2k(\alpha + \lambda)q$ if $q \geq \left(-1 + \sqrt{1 + \frac{(2\alpha+\lambda)^2}{\alpha(\alpha+2\lambda)}}\right)h$, and $\max\{P_A; P_B\} = [k(2\alpha + \lambda) +$

$c(\alpha+\lambda)]h$ otherwise. The latter does not depend on q and the same argument applies as in the previous cases. The former is less than one if $q < 1/(2k\lambda + 2k\alpha)$, which is satisfied if L1 is.

In cross-authority delegation, Proposition 10 shows that the equilibrium success probability is $P_j = (c\lambda + 2k\alpha)q$ for $j = A, B$ when $q \geq \sqrt{\frac{(\alpha+\lambda)(2\alpha k + c\alpha) - \frac{c\alpha^2}{2}}{(\alpha+\lambda)(2\alpha k + c\lambda) - \frac{c\lambda^2}{2}}}h$, 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 12, the equilibrium success probabilities in hierarchical delegation are such that $\max\{P_A; P_B\} = [k(2\alpha+\lambda) + c\lambda]q$ if $q \geq \bar{\epsilon}h$, $\max\{P_A; P_B\} = k(\alpha+\lambda)(h+q) + c\alpha h$ if $\underline{\epsilon}h \leq q < \bar{\epsilon}h = \bar{q}$, and $\max\{P_A; P_B\} = [k(2\alpha+\lambda) + c\alpha]h$ otherwise[13]. The last probability can be made less than one for small values of c and k. The second probability can be made less than one for small values of c, k and h replacing q by $\bar{q}$ in $q < \frac{1}{k(\alpha+\lambda)(h+\bar{q})+c\alpha h}$ since $q < \bar{q}$. 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 11.

Solving by backward induction, at time 2 the CEO and each agent maximize their utility function given decisions d_A and d_B. If both decisions are cooperative $d_A = d_B = C$, then $e_A = e_B = 0$ and $e_M = 2k\alpha q$. If both decisions are selfish $d_A = d_B = S$, then $e_A = e_B = c(\alpha+\lambda)h$ and $e_M = 2k\alpha h$. If $d_A = C$ and $d_B = S$, $e_A = 0$, $e_B = c(\alpha+\lambda)h$ and $e_M = k\alpha(q+h)$. The last case is the same as the previous but with Agents A and B's efforts symmetrically changed.

After that, at time 1 the agents choose a cooperative or selfish decision for each project, considering which is the most convenient for the owner. In order to decide which is the most convenient organizational structure, agents need to compare the profits value for the overall organization under each possible decision set, that is, to compare $V_B^{DE}(d|e^*)$ for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$.

Since $d = (S,C)$ and $d = (C,S)$ has the same V_B value for the owner, we compare 3 cases: $d = (S,S), d = (C,S)$ and $d = (C,C)$. The key element to choose which type of decision will be more profitable within an organizational structure, in this case decentralization, is the ratio of cooperative profits over motivation incentives (q/h).

$V_B^{DE}(C,C|e^*) = 4k\alpha q^2$.

$V_B^{DE}(S,S|e^*) = 2\big(c(\alpha+\lambda) + 2k\alpha\big)h^2$.

$V_B^{DE}(C,S|e^*) = k\alpha\ (q+h)^2 + c(\alpha+\lambda)h^2$.

[13] $\underline{\epsilon}$ and $\bar{\epsilon}$ are those from Proposition 12.

First Case: $V_B^{DE}(C,C|e^*) \geq V_B^{DE}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_1 = \sqrt{\frac{1}{2}(2+\frac{c}{k}\frac{(\alpha+\lambda)}{\alpha})}$.

Second Case: $V_B^{DE}(C,C|e^*) \geq V_B^{DE}(C,S|e^*) \Leftrightarrow q/h \geq \epsilon_2 = \frac{1}{3} + \sqrt{\frac{1}{3}(\frac{1}{3}+\frac{c}{k}\frac{\alpha+\lambda}{\alpha})}$, *considering only the positive root.*

Last Case: $V_B^{DE}(C,S|e^*) \geq V_B^{DE}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_3 = -1 + \sqrt{4+\frac{c}{k}\frac{\alpha+\lambda}{\alpha}}$, *considering only the positive root.*

In the three cases solved above ϵ_1, ϵ_2 and ϵ_3 represent the minimum surplus of cooperation needed to fulfill the conditions. ϵ_1 represents the condition under which $V_B^{DE}(C,C|e^*) \geq V_B^{DE}(S,S|e^*)$, and likewise the others. It is straightforward that $\epsilon_2 \leq \epsilon_1 \leq \epsilon_3$, and consequently prove that $d = (C,C)$ are preferred over $d = (C,S)$ under very small cooperative surplus. Additionally, $d = (C,S)$ over $d = (S,S)$ requires a cooperative surplus ϵ_3 higher than the surplus needed to make $d = (C,C)$ preferred over $d = (S,S)$. Finally, $d = (C,S)$ will be dominated and the only two sets of decisions taken are $d = (C,C)$ and $d = (S,S)$.

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 12.

Solving by backward induction, at time 2 the CEO and each agent maximize their utility function given the decisions d_A and d_B. If both decisions are cooperative $d_A = d_B = C$, then $e_A = e_B = c\lambda q$ and $e_M = 2k\alpha q$. If both decisions are selfish $d_A = d_B = S$, then $e_A = e_B = c\alpha h$ and $e_M = 2k\alpha h$. If $d_A = C$ and $d_B = S$, $e_B = c\alpha h$, $e_A = c\lambda q$ and $e_M = k\alpha(q+h)$. The last case is the same as the previous but with Agents A and B's efforts symmetrically changed.

After that, at time 1 agents choose the decision cooperative or selfish for each project, considering which is the most convenient for the owner. In order to decide which is the most convenient organizational structure, agents need to compare the profits value for the overall organization under each possible decision set, that is, to compare $V_B^{CA}(d|e^*)$ for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$.

Since $d = (S,C)$ and $d = (C,S)$ has the same V_B value for the owner, we compare 3 cases: $d = (S,S), d = (C,S)$ and $d = (C,C)$. The key element to choose which type of decision will be more profitable within an organizational structure, in this case cross authority, is the ratio of cooperative profits over motivation incentives (q/h).

$V_B^{CA}(C,C|e^*) = 2(2k\alpha + c\lambda)\ q^2$.

$V_B^{CA}(S,S|e^*) = 2(2k\alpha + c\alpha)\ h^2$.

$V_B^{CA}(C,S|e^*) = k\alpha\ (h+q)^2 + c(\alpha h^2 + \lambda q^2)$.

First Case: $V_B^{CA}(C,C|e^*) \geq V_B^{CA}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_1 = \sqrt{\frac{2k\alpha+c\alpha}{2k\alpha+c\lambda}}$.

Second Case: $V_B^{CA}(C,C|e^*) \geq V_B^{CA}(C,S|e^*) \Leftrightarrow q/h \geq \epsilon_2 = \frac{1}{3k\alpha+c\lambda}\left(k\alpha+\sqrt{7k^2\alpha^2+c^2\alpha\lambda+k\alpha c\lambda}\right)$, *considering only the positive root.*

Last Case: $V_B^{CA}(C,S|e^*) \geq V_B^{CA}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_3 = -1 + \sqrt{\frac{1}{(k\alpha+c\lambda)^2}+\frac{3k\alpha+c\lambda}{k\alpha+c\lambda}}$, *considering only the positive root.*

In the three cases solved above ϵ_1, ϵ_2 and ϵ_3 represent the minimum surplus of cooperation needed to fulfill the conditions. ϵ_1 represents the condition under which $V_B^{CA}(C,C|e^*) \geq V_B^{CA}(S,S|e^*)$, and likewise the others. It can be proved that $\epsilon_2 \leq \epsilon_1 \leq \epsilon_3$,[14] and consequently

[14] Under request, it is not difficult to prove though the proof is long and impractical to keep the audition attention. Also, it is rather easy to check it with numerical examples.

prove that $d = (C,C)$ are preferred over $d = (C,S)$ under very small cooperative surplus. Additionally, $d = (C,S)$ over $d = (S,S)$ requires a cooperative surplus ϵ_3 higher than the surplus needed to make $d = (C,C)$ preferred over $d = (S,S)$. Finally, $d = (C,S)$ will be dominated and the only two sets of decisions taken are $d = (C,C)$ and $d = (S,S)$.

Proposition 5: Partial Delegation

In partial delegation, the CEO has the decision over project A and Agent B over his own project (it could be the other way around symmetrically): $X_{MA} = 1$, $X_{MB} = 0$, $X_{AA} = 0$ and $X_{BB} = 1$. And the utility functions are those stated in Equation 13.

Solving by backward induction, at time 2 the CEO and each agent maximize their utility function given the decisions d_A and d_B. If both decisions are cooperative $d_A = d_B = C$, then $e_A = e_B = 0$ and $e_M = k(2\alpha + \lambda)q$. If both decisions are selfish $d_A = d_B = S$, then $e_A = c\alpha h$,$e_B = c(\lambda + \alpha)h$ and $e_M = k(2\alpha + \lambda)h$. If $d_A = C$ and $d_B = S$, $e_A = 0$, $e_B = c(\lambda + \alpha)h$ and $e_M = k\alpha(h+q)$. In the last case, $d_A = S$ and $d_B = C$, $e_A = c\alpha h$, $e_B = 0$ and $e_M = k(\alpha+\lambda)(h+q)$.

After that, at time 1 the CEO and agent B choose the cooperative or selfish decision for each project, considering which is the most convenient for the owner. In order to decide which is the most convenient organizational structure, the CEO and agent B need to compare the profits value for the overall organization under each possible decision set, that is, to compare $V_B^{PD}(d|e^*)$ for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$.

$V_B^{PD}(C,C|e^*) = 2k(2\alpha + \lambda)q^2$.

$V_B^{PD}(C,S|e^*) = k\alpha(h + q)^2 + c(\alpha + \lambda)h^2$.

$V_B^{PD}(S,C|e^*) = k(\alpha + \lambda)(h + q)^2 + c\alpha h^2$.

$V_B^{PD}(S,S|e^*) = \big(2k(2\alpha + \lambda) + c(2\alpha + \lambda)\big)h^2$.

First Case: $V_B^{PD}(C,C|e^*) \geq V_B^{PD}(S,S|e^*) \;\Leftrightarrow\; q/h \geq \epsilon_1 = \sqrt{1 + \frac{c}{2k}}$.

Second Case: $V_B^{PD}(C,S|e^*) \geq V_B^{PD}(S,S|e^*) \;\Leftrightarrow\; q/h \geq \epsilon_2 = -1 + \sqrt{4 + \frac{2\lambda}{\alpha} + \frac{c}{k}}$, *considering only the positive root.*

Third Case: $V_B^{PD}(S,C|e^*) \geq V_B^{PD}(S,S|e^*) \;\Leftrightarrow\; q/h \geq \epsilon_3 = -1 + \sqrt{2 + \frac{2\alpha}{\alpha+\lambda} + \frac{c}{k}}$, *considering only the positive root.*

Last Case: $V_B^{PD}(C,C|e^*) \geq V_B^{PD}(S,C|e^*) \;\Leftrightarrow\; q/h \geq \epsilon_4 = -\frac{\alpha+\lambda}{3\alpha+\lambda} + \sqrt{\left(\frac{\alpha+\lambda}{3\alpha+\lambda}\right)^2 + \frac{\alpha+\lambda}{3\alpha+\lambda} + \frac{c}{k}\frac{\alpha}{3\alpha+\lambda}}$, *considering only the positive root.*

In the four cases solved above ϵ_1, ϵ_2, ϵ_3 and ϵ_4 represent the minimum surplus of cooperation returns needed to fulfill the conditions. It can be proved that $\epsilon_3 \leq \epsilon_1 \leq \epsilon_2$,[15] and consequently prove that $d = (C,S)$ are preferred over $d = (S,S)$ under very small cooperative surplus. Additionally, $d = (C,S)$ over $d = (S,S)$ requires a cooperative surplus ϵ_2 higher than the surplus needed to make $d = (C,C)$ preferred over $d = (S,S)$, thus, $d = (C,S)$ will be dominated. Since, $\epsilon_4 \leq \epsilon_3$, the owner will prefer to encourage taking both cooperative decisions under smaller cooperation returns to those necessary to encourage $d = (S,C)$. Therefore, $d = (S,C)$ will be dominated and the only two sets of decisions taken are $d = (C,C)$ and $d = (S,S)$.

[15] Under request, it is not difficult to prove though the proof is long and impractical to keep the audition attention. Also, it is rather easy to check it with numerical examples.

Proposition 6: Hierarchical Delegation

In hierarchical delegation, the CEO has the decision over project A and Agent A 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 13.

Solving by backward induction, at time 2 the CEO and each agent maximize their utility function given the decisions d_A and d_B. If both decisions are cooperative $d_A = d_B = C$, then $e_A = c\lambda q$, $e_B = 0$ and $e_M = k(2\alpha + \lambda)q$. If both decisions are selfish $d_A = d_B = S$, then $e_A = e_B = c\alpha h$ and $e_M = k(2\alpha + \lambda)h$. If $d_A = C$ and $d_B = S$, $e_A = 0$, $e_B = c\alpha h$ and $e_M = k\alpha(h+q)$. In the last case, $d_A = S$ and $d_B = C$, $e_A = c\alpha h$, $e_B = 0$ and $e_M = k(\alpha+\lambda)(h+q)$.

After that, at time 1 the CEO and agent A choose the cooperative or selfish decision for each project, considering which is the most convenient for the owner. In order to decide which is the most convenient organizational structure, the CEO and agent A need to compare the profits value for the overall organization under each possible decision set, that is, to compare $V_B^{HD}(d|e^*)$ for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$.

$V_B^{HD}(C,C|e^*) = \big(2k(2\alpha+\lambda) + c\lambda\big)q^2.$

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

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

$V_B^{HD}(S,S|e^*) = \big(2k(2\alpha+\lambda) + 2c\alpha\big)h^2.$

First Case: $V_B^{HD}(C,C|e^*) \geq V_B^{HD}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_1 = \sqrt{\frac{2k(2\alpha+\lambda)+2c\alpha}{2k(2\alpha+\lambda)+c\lambda}}$.

Second Case: $V_B^{HD}(C,S|e^*) \geq V_B^{HD}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_2 = -\frac{-\alpha k}{k\alpha+c\lambda} + \sqrt{\big(\frac{\alpha k}{k\alpha+c\lambda}\big)^2 + \frac{k(3\alpha+\lambda+c\alpha)}{k\alpha+c\lambda}}$, *considering only the positive root.*

Third Case: $V_B^{HD}(S,C|e^*) \geq V_B^{HD}(S,S|e^*) \Leftrightarrow q/h \geq \epsilon_3 = -1 + \sqrt{2 + \frac{2\alpha}{\alpha+\lambda} + \frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$, *considering only the positive root.*

Last Case: $V_B^{HD}(C,C|e^*) \geq V_B^{HD}(S,C|e^*) \Leftrightarrow q/h \geq \epsilon_4 =$

$= \frac{1}{k(1+\alpha)+c\lambda}\big((k(\alpha+\lambda) + \sqrt{k^2(\alpha+\lambda)^2 + [k(\alpha+\lambda)+c\alpha][k(1+\alpha)+c\lambda]}\big)$, *considering only the positive root.*

In the four cases solved above ϵ_1, ϵ_2, ϵ_3 and ϵ_4 represent the minimum surplus of cooperation returns needed to fulfill the conditions. It can be proved that $\epsilon_3 \leq \epsilon_1 \leq \epsilon_4 \leq \epsilon_2$,[16] and consequently prove that $d = (S,C)$ are preferred over $d = (S,S)$ under very small cooperative surplus. Additionally, $d = (C,S)$ over $d = (S,S)$ requires a cooperative surplus ϵ_3 higher than the surplus needed to make $d = (C,C)$ preferred over $d = (S,S)$, thus, $d = (C,S)$ will be dominated. As a consequence, the decision sets that will be implemented are $d = (S,S)$, $d = (S,C)$ and $d = (C,C)$.

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) $q/h \in (1, \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}})$ where the upper limit is the threshold under which $V_B^{CE}(C,C) > V_B^{CE}(S,S)$, and (iii) $q \in [\sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}, Z/h)$.

[16] Under request, it is not difficult to prove though the proof is long and impractical to keep the audition attention. Also, it is rather easy to check it with numerical examples.

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 structures 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 $\epsilon_{B2} = q/h < \sqrt{1+\frac{c\alpha}{c\lambda+2k\alpha}}$ 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 $\epsilon_{B1} = \sqrt{1+\frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}$. The other organizational structures 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 structure: centralization (in which the CEO can choose $d = (C,C)$ when $q/h > \epsilon_{B1}$ or $d = (S,S)$ otherwise). When $k/c < 1/2$, decentralization with $d = (S,S)$ will be chosen when $q/h < \epsilon_{B2}$ 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.

Proposition 8: Centralization

The effort levels are the same as those calculated in *Appendix B: Centralization.* Nevertheless, the person in charge of decision making takes into account his/her own utility to take the decision within this framework at time t_1. At time 1 the CEO chooses a cooperative or selfish decision for each project. In order to decide which is the most convenient organizational structure for herself, the CEO needs to compare her own utility under each possible decision set, that is, to compare $U_M^{CE}(d|e^*)$ for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$. Since $d=(S,C)$ and $d=(C,S)$ has the same U_M^{CE} value for the CEO, we compare 3 cases: $d=(S,S), d=(C,S)$ and $d=(C,C)$. The utility function for the manager in each case is:

$U_M^{CE}(C,C|e^*) = 2k(\alpha+\lambda)^2\ q^2.$

$U_M^{CE}(S,S|e^*) = 2k(\alpha+\lambda)^2\ h^2 + 2c\alpha(\alpha+\lambda)h^2.$

$U_M^{CE}(C,S|e^*) = \frac{k(\alpha+\lambda)^2\ (h+q)^2}{2} + c\alpha(\alpha+\lambda)h^2.$

First Case: $U_M^{CE}(C,C|e^*) \geq U_M^{CE}(S,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_1 = \sqrt{1+\frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$.

Second Case: $U_M^{CE}(C,C|e^*) \geq U_M^{CE}(C,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_2 = \frac{1}{3} + \sqrt{\frac{1}{9}+\frac{2}{3}\frac{c}{k}\frac{\alpha}{\alpha+\lambda}}$, *considering only the positive root.*

Last Case: $U_M^{CE}(C,S|e^*) \geq U_M^{CE}(S,S|e^*) \ \Leftrightarrow\ (q/h) \geq \epsilon_3 = -1 + \sqrt{4+\frac{2c}{k}\frac{\alpha}{\alpha+\lambda}}$, *considering only the positive root.*

In the three cases solved above ϵ_1, ϵ_2 and ϵ_3 represent the minimum surplus of cooperation needed to fulfill the conditions. ϵ_1 represents the condition under which $U_M^{CE}(C,C|e^*) \geq U_M^{CE}(S,S|e^*)$, and likewise the others. It is straightforward that $\epsilon_2 \leq \epsilon_1 \leq \epsilon_3$, and consequently prove that $d = (C,C)$ are preferred over $d = (C,S)$ under very small cooperative surplus. Additionally, $d = (C,S)$ over $d = (S,S)$ requires a cooperative surplus ϵ_3 higher than the surplus needed to make $d = (C,C)$ preferred over $d = (S,S)$. Finally, $d = (C,S)$ will be dominated and the only two set of decisions taken are $d = (C,C)$ and $d = (S,S)$.

Proposition 9: Decentralization

The effort levels are the same as those calculated in *Appendix B: Decentralization.* Nevertheless, each agent takes into account their own utility to take the decision within this framework at time t_1. Hence, note that each agent takes the decision S or C in the same moment since they have the same utility function. As a consequence there only two decision sets implementable $d = (S,S)$ or $d = (C,C)$. The utility function for each agent j in each case is:

$U_j^{DE}(C,C|e^*) = (\alpha+\lambda)\ 2k\alpha q^2.$

$U_j^{DE}(S,S|e^*) = (\alpha+\lambda)\ 2k\alpha h^2 + \frac{c(\alpha+\lambda)^2 h^2}{2}.$

As a consequence:

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

Proposition 10: Cross-authority

The effort levels are the same as those calculated in *Appendix B: Cross-Authority.* Nevertheless, each agent takes into account their own utility to take the decision within this framework at time t_1. Hence, note that each agent takes the decision S or C in the same moment since they have the same utility function. As a consequence there are only two implementable decision sets $d = (S,S)$ or $d = (C,C)$. The utility function for each agent j in each case is:

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

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

As a consequence:

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

Proposition 11: Partial Delegation

The effort levels are the same as those calculated in *Appendix B: Partial Delegation.* Nevertheless, the person in charge of decision making takes into account his/her own utility to take the decision within this framework at time t_1. At time 1 the CEO and agent B choose a cooperative or selfish decision for each project. In order to decide which is the most convenient organizational structure for themselves, the CEO and agent B need to compare their own utility under each possible decision set, that is, to compare $U_M^{PD}(d|e^*)$ and $U_B^{PD}(d|e^*)$ for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$. The utility function for the manager in each case is:

$U_M^{PD}(C,C|e^*) = \frac{k(2\alpha+\lambda)^2\ q^2}{2}$.

$U_M^{PD}(S,S|e^*) = \frac{k(2\alpha+\lambda)^2\ h^2}{2} + c(2\alpha+\lambda)^2h^2$.

$U_M^{PD}(C,S|e^*) = \frac{k\alpha^2(h+q)^2}{2} + c\alpha(\alpha+\lambda)h^2$.

The utility function for the agent B in each case is:

$U_B^{PD}(C,C|e^*) = k(\alpha+\lambda)(2\alpha+\lambda)\ q^2$.

$U_B^{PD}(S,S|e^*) = k(\alpha+\lambda)(2\alpha+\lambda)\ h^2 + \frac{c(\alpha+\lambda)^2h^2}{2}$.

$U_B^{PD}(S,C|e^*) = 0$.

$U_B^{PD}(C,S|e^*) = k\alpha(\alpha+\lambda)(h+q)^2 + \frac{c(\alpha+\lambda)^2h^2}{2}$.

Notice that $d = (S,C)$ is not going to be implemented, because agent B under whichever other decision set has positive utility while with $d = (S,C)$ has zero utility. Hence, he will never choose a cooperative decision when the CEO chooses a selfish decision. The CEO is going to implement $d = (C,S)$ when:

First Case: $U_M^{PD}(C,S|e^*) \geq U_M^{PD}(S,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_1 = -1 + \sqrt{4 + \frac{2c}{\alpha k} + \frac{4\alpha\lambda+\alpha^2}{\alpha^2}}$.

Agent B is going to choose a cooperative decision instead of a selfish one when the utility of this decision set $d = (C,C)$ is greater than the utility of $d = (C,S)$. As a consequence, agent B chooses a cooperative decision when:

Second Case: $U_B^{PD}(C,C|e^*) \geq U_B^{PD}(C,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_2 = \frac{\alpha}{\alpha+\lambda} + \sqrt{\frac{\alpha^2}{(\alpha+\lambda)^2} + \frac{c}{2k}}$.

Note that $\epsilon_1 > \epsilon_2$ but keep in mind that agent B will never choose a cooperative decision when the manager chooses a selfish one. As a consequence, agent B will take a cooperative decision when he knows that the CEO is choosing cooperative also. Finally, the decision set $d = (C,C)$ will be implemented when $q/h \geq \epsilon_1$ and $d = (C,S)$ will be dominated.

Proposition 12: Hierarchical Delegation

The effort levels are the same as those calculated in *Appendix B: Hierarchical Delegation.* Nevertheless, each agent takes into account their own utility to take the decision within this framework at time t_1. At time 1 the CEO and agent A choose a cooperative or selfish decision for each project. In order to decide which is the most convenient organizational structure for themselves, the CEO and agent A need to compare their own utility under each possible decision set, that is, to compare $U_M^{HD}(d|e^*)$ and $U_A^{HD}(d|e^*)$ for each $d \in \{(S,S),(S,C),(C,S),(C,C)\}$. The utility function for the manager in each case is:

$U_M^{HD}(C,C|e^*) = \frac{k(2\alpha+\lambda)^2\ q^2}{2} + c\alpha\lambda q^2$.

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

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

$U_M^{HD}(S,S|e^*) = \frac{k(2\alpha+\lambda)^2\ h^2}{2} + c\alpha(2\alpha+\lambda)h^2$.

The utility function for the agent A in each case is:

$U_A^{HD}(C,C|e^*) = k(\alpha+\lambda)(2\alpha+\lambda)\ q^2 + \frac{c\lambda^2q^2}{2}$.

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

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

$U_A^{HD}(S,S|e^*) = k(\alpha+\lambda)(2\alpha+\lambda)\ h^2 + c\alpha\lambda h^2 + \frac{c\alpha^2h^2}{2}$.

The manager and agent A have to decide whether to change from a selfish to a cooperative decision or not. As a consequence, the CEO needs to choose between two decision sets $d = (S,S)$ or $d = (C,S)$. At the same time, agent A needs to choose between $d = (S,C)$ or $d = (S,S)$. The CEO is going to implement $d = (C,S)$ when:

First Case: $U_M^{HD}(C,S|e^*) \geq U_M^{HD}(S,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_1 = -1 + \sqrt{4 + \frac{4\alpha\lambda+\lambda^2}{\alpha^2} + \frac{2c}{k}\frac{\alpha+\lambda}{\alpha}}$.

Agent A is going to choose a cooperative decision instead of a selfish, hence, he is going to implement $d = (S,C)$ when:

Second Case: $U_A^{HD}(S,C|e^*) \geq U_A^{HD}(S,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_2 = -1 + \sqrt{2 + \frac{\lambda}{\alpha} + \frac{c}{k}\frac{\alpha\lambda}{\alpha(\alpha+\lambda)}}$.

Note that $\epsilon_1 > \epsilon_2$ so agent A is taking a cooperative decision under cooperative returns over motivational ones lower than the manager. Then, $d = (C,S)$ is not implemented and the CEO takes a cooperative decision $d = (C,C)$ when is more convenient for herself than $d = (S,C)$:

Third Case: $U_M^{HD}(C,C|e^*) \geq U_M^{HD}(S,C|e^*) \ \Leftrightarrow$

$$\Leftrightarrow\ q/h \geq \epsilon_3 = \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \sqrt{\left(\frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]}\right)^2 + \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \frac{2c(\alpha+\lambda)}{k(3\alpha+2\lambda)+2c\lambda}}.$$

As a consequence, agent A chooses a cooperative decision over a selfish when $q/h \geq \epsilon_2$ and the CEO chooses a cooperative decision over a selfish one when $q/h \geq \epsilon_3$, and there are three implementable decision sets, $d = (S,S)$, $d = (S,C)$ and $d = (C,C)$.

Proposition 13

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 structures 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[17]. 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 $\epsilon_{B2} = q/h < \sqrt{1+\frac{c\alpha}{c\lambda+2k\alpha}}$ 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 $-1+\sqrt{4+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}} \leq q/h < \sqrt{1+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$. Additionally, $V^{CA}(C,C) > V^{HD}(S,C)$ if and only if $q/h \geq \frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda} + \sqrt{\left(\frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda}\right)^2+\frac{k(\alpha+\lambda)+c\alpha}{k(3\alpha-\lambda)+2c\lambda}} = \epsilon_{M1'}$. 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 structure when $\epsilon_{M1} = -1+\sqrt{4+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}} \leq q/h < \epsilon_{M1'}$ and cross-authority becomes optimal for $\epsilon_{M1'} \leq q/h \leq \sqrt{1+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$.

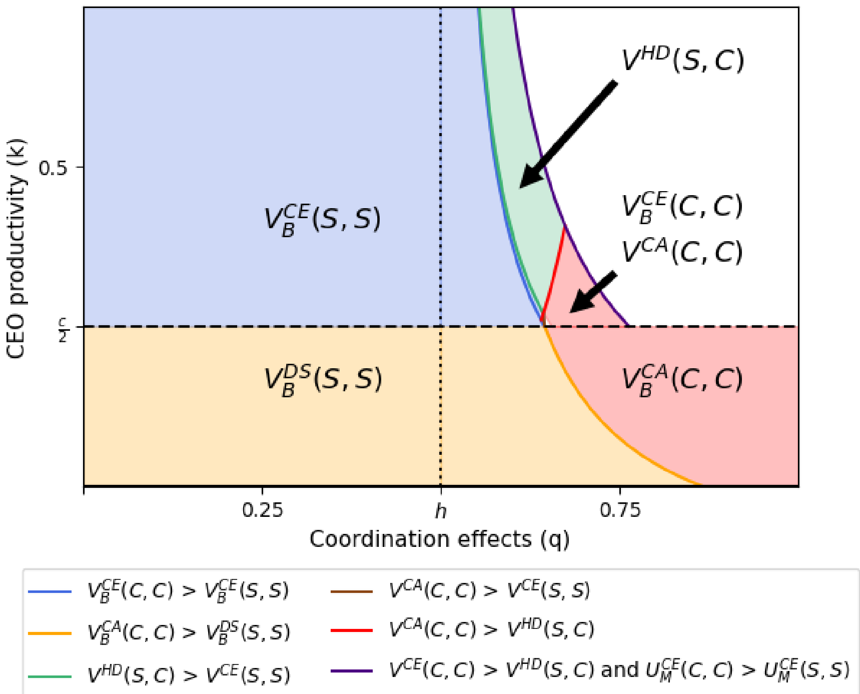
Finally, consider case (iii). The lower limit is the threshold under which the CEO chooses $d = (C,C)$ over $d = (S,S)$, we call this ratio $\epsilon_{M2} = \sqrt{1+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$. The results in this region remain equal to that of benchmark proof. Then, centralization with 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 $k/c \geq 1/2$, the owner chooses centralization with $d = (S,S)$ when $q/h < \epsilon_{M1}$, then he chooses hierarchical delegation with $d = (C,S)$ when $\epsilon_{M1} < q/h < \epsilon_{M2}$ and centralization with $d = (C,C)$ when $q/h \geq \epsilon_{M2}$. When $k/c < 1/2$, the results of benchmark remain without modifications, decentralization with $d = (S,S)$ will be chosen when $q/h < \epsilon_{B2}$ or cross-authority with $d = (C,C)$ otherwise.

[17] 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 $V^{DE}(C,C)$, $V^{CA}(C,C) > V^{DE}(C,C), \forall q/h \geq 1$

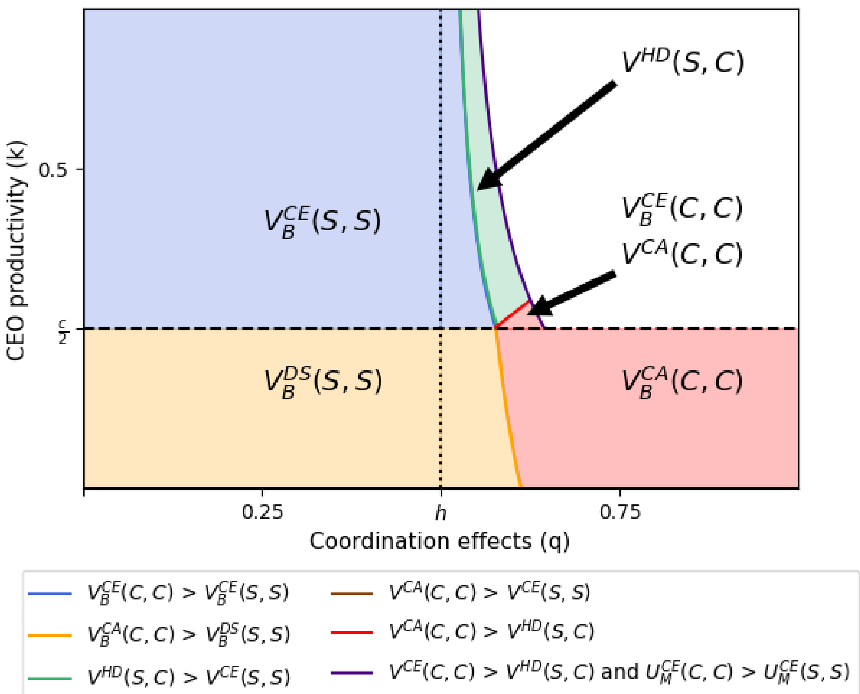
D. Simulations

Figure D1: Simulation 1



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

Figure D2: Simulation 2



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