Maestría en Economía
Facultad de Ciencias Económicas
Universidad Nacional de La Plata

TESIS DE MAESTRIA

ALUMNO
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TITULO
Jerarquías Múltiples. Una Aproximación desde los Incentivos Económicos

DIRECTOR
Joaquín Coleff y Walter Cont (codirector)

FECHA DE DEFENSA
8/7/2018

Maestría en Economía
Facultad de Ciencias Económicas
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Tesis de Maestría

Maestría en Economía

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Fecha de defensa: 07/08/2018

Códigos JEL: C70, D23, L22

Multi-tier hierarchies: an incentive approach.*

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July 2018

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 two main inputs of my model are externalities among divisions' projects that may require coordination and costly effort from the CEO and the two division managers. 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 herself to choose a cooperative decision, the most convenient decision for the firm may be to give a decision right 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 externalities returns are greater than motivational effects and effort encouraging decisions otherwise; also, 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 taken. Due to the unobservability in efforts, there is a moral hazard problem in efforts that requires more cooperative over motivational returns than in the first best analysis to change from cooperative to selfish decisions. Nevertheless, the results remain similar to the first best and are also consequent with the strand of literature, that is, when coordination profits (or spillover effects) are greater enough than motivational ones, cooperative decisions are made and conversely otherwise. Furthermore, the benchmark also shows that when the CEO is more productive than agents, centralization is the best organizational structure whereas when the agents are more productive than the CEO, different forms of delegation (decentralization or cross authority) are the best. Hence, in this case hierarchical delegation is not better than other forms of organizational design.

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 difference, recall that in benchmark centralization is always preferred (combined with cooperative decisions, when cooperative returns being high enough, and with selfish decisions otherwise). Since each agent and the CEO make a team within each project and the CEO is the one who decides, she can take over some benefits from agents' effort so that she is able to decide both selfish decisions even when cooperative over motivational returns are higher (and cooperative decisions are preferred for the organization). As a consequence, the owner can anticipate this strategy of the CEO and choose to give one decision right for an agent willing to cooperate. Then, hierarchical delegation structure shows up, with a selfish decision in one project and a cooperative decision in the other, as a result of the lack of commitment of the CEO and as a "Second Best" answer to the strategic behavior of the CEO.

This result is considerably interesting for two reasons. The first one because it captures some empirical examples, for instance the Sony restructuring in 2009. 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[1].

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 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 motivation and delegation incentives to show how the optimality map reacts when we change parameters values. Thus, we show that

[1]"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.

when the motivation incentives (share of profits in return to make effort) increase, the hierarchical delegation optimality space grows and when the delegation incentives (share of profits in return to decision making) increase, this space declines without disappearing.

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[2]. 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 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

[2]"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).

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. In the setup we describe: the individuals that comprises the organization and the way they interact each other within, the productive activities developed at the organization related to the decision making and how this decision making 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.

Setup

We consider a similar framework to Choe and Ishiguro's (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, and two Agents (named A and B)[3]. The owner can be considered a representative shareholder who is interested in maximizing net 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 $P_j = P(e_M, e_j) \in (0, 1)$. Note that the CEO's effort denoted by $e_M \in [0, 1]$ has an impact in both projects. This effort has an associated cost given by $g(e_M) = \frac{1}{2k}\, e_M^2$, where $k > 0$. On the other hand, each Agent A and B can be considered as a "specialist" whose effort affects only his own project j, where $j = A, B$. The effort level chosen by agent j denoted by $e_j \in [0, 1]$ has a quadratic cost function denoted by $c(e_j) = \frac{1}{2c}\, e_j^2$, where $c > 0$.

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 which has a stronger impact on its own profits or a "Cooperative" one 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 revenue function of a successful project A (and similarly for B) is:

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

The expected profits of each project depend on the efforts and types of decisions made. The expected profits are built up of two aspects, the 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:

$$E(\pi_A | d, e) = P_A h(d_A) + P_B q(d_B) \quad , \quad E(\pi_B | d, e) = P_B h(d_B) + P_A q(d_A). \tag{2}$$

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 $2\alpha + \lambda = 1$. [4]

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 j by $Y_j := \{X_{Mj}, X_{Aj}, X_{Bj}\} \subset \{0, 1\}^3$ where $j = A, B$. 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

[3]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.

[4]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.

$(X_{MA}, X_{AA}, X_{BA}) = (0, 0, 1)$ agent B is in charge of making decisions in project A. 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:

$$U_M(d, e) = \alpha\Big(E(\pi_A|d, e) + E(\pi_B|d, e)\Big) + \lambda\Big(X_{MA}E(\pi_A|d, e) + X_{MB}E(\pi_B|d, e)\Big) - g(e_M). \quad (3)$$

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:

$$U_j(d, e) = \alpha E(\pi_j|d, e) + \lambda \sum_{j'=A,B} X_{jj'}E(\pi_{j'}|d, e) - c(e_j). \quad (4)$$

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.

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.

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[5].

[5] 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

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

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:

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

$$s.t: IC_d: \quad U_i^y(d_j|d_{j'},e) \geq U_i^y(d_j'|d_{j'},e), \ \forall i = A,B,M \text{ and } \forall j,j' = A,B, \tag{5}$$

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

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

First Best

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:

$$\max_{d,e} \ W(d,e) = E(\pi_A|d,e) + \ E(\pi_B|d,e) - g(e_M) - c(e_A) - c(e_B) \tag{6}$$

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:

$$W(d_A, d_B|e^*) = \begin{cases} (2k+c) \ q^2 \text{ if } q \geq h, \\ (2k+c) \ h^2 \text{ if } q < h. \end{cases} \tag{7}$$

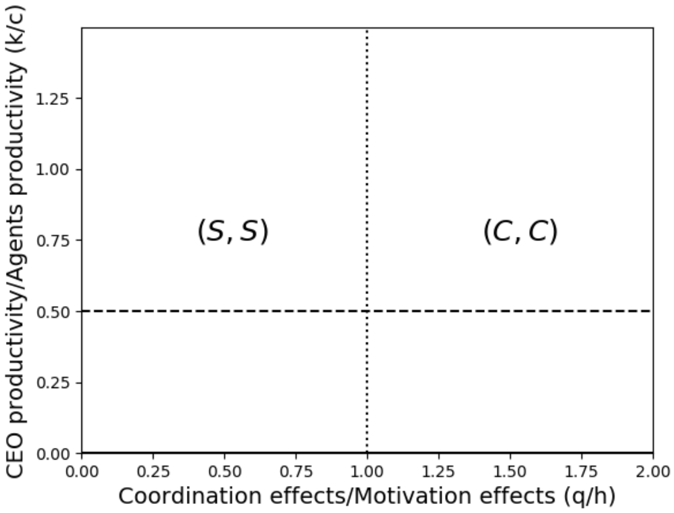
The social planner takes identical decisions over both projects, because it will always be convenient to choose a cooperative decision for the projects if the coordination is more profitable than the agents' motivation, and selfish otherwise. The social planner could never have chosen an asymmetric decision because in such case one of the agents would have made zero effort and, as a consequence, the welfare would have decreased. For the proof see *Appendix A*.

This social planner is able to control the individual effort of the agents and also, to implement decisions over projects A and B which are more profitable for all the members in the organization. The implementation of the optimum decision is independent of who is taking the decision over

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.

each project. As a consequence the main force which determines the decision is the ratio q/h or intuitively the coordination benefits relative to the intrinsic concerns or motivation benefits. Figure 1 is an example for specific values of $\alpha = \lambda = 1/3$ and $h = c = 1$, x-axis reflects the coordination *versus* motivation force whereas y-axis presents the CEO productivity over both agents productivity force, which is not important for the First Best analysis.

Figure 1: First Best



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

Benchmark

We consider a benchmark analysis where the owner chooses the organizational design $y \in \mathcal{Y}$ which maximizes the overall organization value (his own payoff). To put it simply, the owner's problem will be to maximize the organization's value V_B subject to agents' and CEO's incentive compatible effort choice, where he is in control of the decision making[6]. So, the owner's maximization problem is:

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

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, $\mathcal{Y} :=$

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

$\{CE, DE, CA, PD, HD, CD\}$ 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:

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

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:

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

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:

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

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:

$$\begin{aligned}
U_M^{PD}(d,e) &= (\alpha+\lambda)\ E(\pi_A|d,e) + \alpha\ E(\pi_B|d,e) - g(e_M), \\
U_A^{PD}(d,e) &= \alpha\ E(\pi_A|d,e) - c(e_A), \\
U_B^{PD}(d,e) &= (\alpha+\lambda)\ E(\pi_B|d,e) - c(e_B).
\end{aligned} \tag{12}$$

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:

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

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 for each organizational structure in propositions 2 to 6 for the benchmark case and 8 to 12 for the model case, the former ones are shown in *Appendix B* while the latter are in *Appendix C.* Propositions 7 and 13 state the comparison between those organizations in equilibrium under each framework (benchmark or model), so proposition 7 is proved in *Appendix B* and proposition 13 in *Appendix C.*

Two factors are of main importance in identifying an optimal organizational structure in the benchmark and the model framework. First, the cooperation benefits relative to motivation incentives 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[7]. 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 $k < c/2$.

In this section we compute the optimum effort for each organizational structure under the benchmark case and the model case. After that we compare the optimality map in each case in order to understand the reasons that have determined different organizational structures. To make a clear presentation of the results, we prove proposition 2 for centralization and the remaining proofs are in *Appendix B* for propositions 3 to 7 and in *Appendix C* for propositions 8 to 13.

Benchmark case

In the benchmark case, the person in charge of the decision chooses the one which maximizes the overall organization profit V_B as if the owner were able to force the implementation of a decision convenient for himself in each project. That means, that the owner controls everything except the effort choices. Hence, the relation between CEO's and the agents' productivity is important in order to increase primarily the effort of the most productive person. The computation of this optimal decision is the solution of the maximization program in Equation 8 for each organizational structure $y \in \mathcal{Y}$. This maximization problem takes into account only the moral hazard problem in the effort. Since it is a sequential game, this problem is solved by backward induction.

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 9.

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 $e_A = e_B = c\alpha h$ while CEO's effort is $e_M = 2k(\alpha + \lambda)h$. 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:

$$V_B^{CE}(d_A, d_B|e^*) = \begin{cases} 4k(\alpha + \lambda)\, q^2 & \text{if } q/h \geq \sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}, \\ \big(4k(\alpha + \lambda) + 2c\alpha\big)\, h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{14}$$

Proof

Solving by backward induction, at time 2 the CEO and each manager 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

[7] 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

$e_M = 2k(\alpha+\lambda)h$. 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).

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

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

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

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

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

Last Case: $V_B^C(C,S|e^*) \geq V_B^C(S,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_3 = -1+\sqrt{4+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$, *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 $V_B^C(C,C|e^*) \geq V_B^C(S,S|e^*)$, and likewise the others. It can be proved that $\epsilon_2 \leq \epsilon_1 \leq \epsilon_3$[8], 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 10.

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:

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

Proof

See appendix B.

[8] 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.

Cross-authority

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

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:

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

Proof

See appendix B.

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): $X_{MA} = 1$ y $X_{MB} = 0$ and $X_{AA} = 0$ and $X_{BB} = 1$. And the utility functions are those stated in Equation 12.

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:

$$V_B^{PD}(d_A, d_B|e^*) = \begin{cases} 2k(2\alpha + \lambda)q^2 & \text{if } q/h \geq \sqrt{1 + \frac{c}{2k}}, \\ (2k(2\alpha + \lambda) + c(2\alpha + \lambda))\, h^2 & \text{if } otherwise. \end{cases} \tag{17}$$

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): $X_{MA} = 1$ y $X_{MB} = 0$ and $X_{AB} = 0$. And the utility functions are those stated in Equation 12.

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 agents chooses both decisions $d_A = d_B = S$ and each agent choose $e_A = c\alpha h$,$e_B = c\alpha h$ and the CEO's choice is $e_M = k(2\alpha + \lambda)h$. Hence the overall value of the firm is:

$$V_B^{HD}(d_A, d_B|e^*) = \begin{cases} (2k(2\alpha+\lambda)+c\lambda)\, q^2 \text{ if } \epsilon > \overline{\epsilon}, \\ k(\alpha+\lambda)(h+q)^2 + c\alpha h^2 \text{ if } \underline{\epsilon} < \epsilon \leq \overline{\epsilon}, \\ (2k(2\alpha+\lambda)+2c\alpha)\, h^2 \text{ otherwise.} \end{cases} \tag{18}$$

Proof

See appendix B.

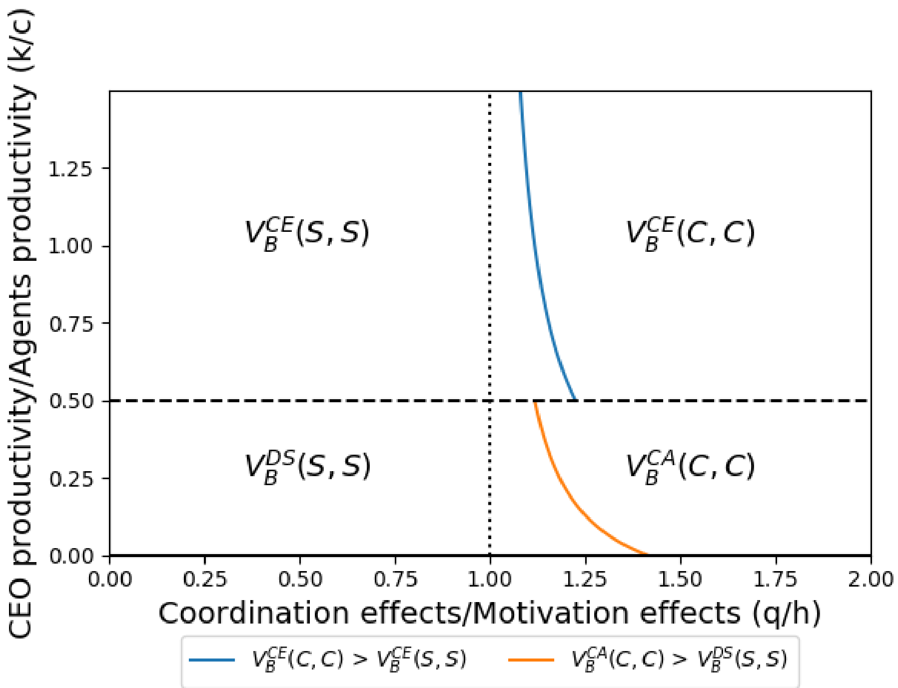
Proposition 7: When $k/c \geq 1/2$, that is the CEO is more productive than both agents, there is only one organizational structure: Centralization (in which the CEO can choose $d = (C, C)$ when $q/h > \epsilon_{B1}$ or $d = (S, S)$ otherwise). When $k/c < 1/2$, Decentralization with $d = (S, S)$ will 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.

Under benchmark case, only three organizational structures are going to be implemented. Firstly, decentralization with a selfish decision over each project when coordination effects are lower than motivational effects and the CEO's productivity in relation to the agents' productivity also. Secondly, cross-authority with cooperative decisions over the two projects when cooperative effects are higher than motivational effects but the agents' productivity is higher than the CEO's productivity. Finally, when the CEO's productivity is greater than agents' productivity, centralization will be convenient for the owner, with both cooperative decisions when coordination effects are higher enough than motivational effects and with both selfish decisions otherwise.

Figure 2: Benchmark



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

Figure 2 is an example for specific values of $\alpha = \lambda = 1/3$ and $h = c = 1$ and the same variables are represented in x-axis and y-axis as in figure 1. The dotted line represents the threshold under which $q = h$, that is, coordination returns equal motivation incentives, while the dash line states the value in which $k = 2c$, the CEO's productivity is the same as the two agents. Additionally, the blue line pictures the frontier value under which the CEO changes from choosing selfish decisions for both projects to cooperative decisions. Likewise, the yellow line refers to the precise place in which decentralization with two selfish decisions starts to be lower than cross authority organization with both cooperative decisions.

The benchmark case shows some inefficiencies in comparison to the first best analysis. Clearly there are two areas in which different decisions from the optimum are made. The area within the dash line, dotted line and blue line shows a particular space of the optimality map in which $V_B^C(S,S)$ is greater than $V_B^C(C,C)$ even when in the first best analysis we have shown that the optimum decision set is $d = (C,C)$ in this region. Similarly, below the dash line there is a region within the dotted line and the yellow line with the same issue. The main reason that explains this difference is a moral hazard problem in efforts due to incomplete contracts and the fixed payment scheme. To put it simply, in the first best analysis the social planner takes into account all agents' efforts whereas in benchmark analysis the owner is only maximizing the value of the overall organization putting aside the effort needed to achieve the goal. That is, the owner has not internalized the cost of effort of the agents. Furthermore, the social planner can pay the exact amount of effort made by each agent whereas in the benchmark analysis the returns to effort are given by the fixed pay scheme described before.

As it can be seen the yellow and blue lines have a smooth behaviour and also moving to the right while q increases. Consider $k/c > 1/2$, as blue line defines whether centralization will be implemented with $d = (S,S)$ or $d = (C,C)$ when the CEO is considerably more efficient than both agents then the coordination returns need not be so high because the CEO's effort is enough to achieve the goals (keep in mind that centralization with both decisions cooperative leads to agents' effort equal to zero). However, when the CEO is not much more efficient than the agents,the agents' efforts are more important than before. Hence, additional values of cooperation returns are needed to make both decisions cooperative. Something similar happens when $k/c < 1/2$, on the one hand decentralization prioritizes agents' incentives while cross authority not only takes into account agents' efforts. In fact, even when each agent makes less effort than in decentralization (specifically $c\alpha h$ for each agent), it may be compensated with the premium of cooperative efforts in agents and the CEO. As a consequence, it is straightforward that when k decreases, a premium q over h greater is needed to compensate the loss in agents' efforts.

The model case

For each type of organizational structure there will be an optimum decision which maximizes the owner's profit V. The computation of this optimal decision is the solution of the maximization program in Equation 5 for each organizational structure in $\mathcal{Y}$. This maximization problem takes into account the moral hazard problem in the effort and also in the decision taking. Due to the fact that it is a sequential game, this problem will be solved by backward induction, for each organizational structure. The only difference between the profit computed before is the step at time 1 in which the decision is implemented by the agents without being forced to choose the best for the owner. The propositions stated below have the same strategy of proof as propositions 2 - 7. However, at time 1 the part involved in decision taking instead of making a decision convenient for the owner decides to take the decision convenient for himself, comparing his own utility under a different set of decisions. The efforts and Y_j are the same as in benchmark so we only state here the propositions since the proofs are available at *Appendix C*. After that, we compare all the implementable organizational structures for their performance in order to develop the optimality map for the model framework.

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 $e_A = e_B = c\alpha h$ while CEO's effort is $e_M = 2k(\alpha+\lambda)h$. 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:

$$V^{CE}(d_A, d_B|e^*) = \begin{cases} 4k(\alpha+\lambda)\ q^2 & \text{if } q/h \geq \sqrt{1+\frac{c}{k}\frac{\alpha}{\alpha+\lambda}}, \\ \big(4k(\alpha+\lambda)+2c\alpha\big)\ h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{19}$$

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:

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

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:

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

Partial Delegation

Proposition 11: When $q/h - 1 + \sqrt{4+\frac{2c}{\alpha k}+\frac{4\alpha\lambda+\alpha^2}{\alpha^2}}$ 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:

$$V^{PD}(d_A, d_B|e^*) = \begin{cases} k\alpha(h+q)^2 + c(\alpha+\lambda)h^2 & \text{if } q/h \geq -1+\sqrt{4+\frac{2c}{\alpha k}+\frac{4\alpha\lambda+\alpha^2}{\alpha^2}}, \\ \big(2k(2\alpha+\lambda)+c(\alpha+\lambda)\big)h^2 & \text{if } \textit{otherwise}. \end{cases} \tag{22}$$

Hierarchical Delegation

Proposition 12:
When $q/h \geq \bar{\epsilon} = \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \sqrt{\left(\frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]}\right)^2 + \frac{k(\alpha+\lambda)^2}{\alpha[k(3\alpha+2\lambda)+2c\lambda]} + \frac{2c(\alpha+\lambda)}{k(3\alpha+2\lambda)+2c\lambda}}$ 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, $d_A = C$ and $d_B = S$, $e_A = c\lambda q$, $e_B = 0$ 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:

$$V^{HD}(d_A, d_B|e^*) = \begin{cases} \left(2k(2\alpha+\lambda) + c\lambda\right) q^2 \text{ if } \epsilon \geq \bar{\epsilon}, \\ k(\alpha+\lambda)(h+q)^2 + c\alpha h^2 \text{ if } \underline{\epsilon} \leq \epsilon < \bar{\epsilon}, \\ \left(2k(2\alpha+\lambda) + c\alpha\right) h^2. \text{ if } \textit{otherwise}. \end{cases} \tag{23}$$

Proposition 13: 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 $d = (S,C)$ 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. 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 the benchmark mapping there are three optimum organizational structures: centralization, decentralization and cross authority. When $k/c < 1/2$ the 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, while in the benchmark centralization is always the optimal organizational design, in the model hierarchical delegation appears as a better alternative to centralization.

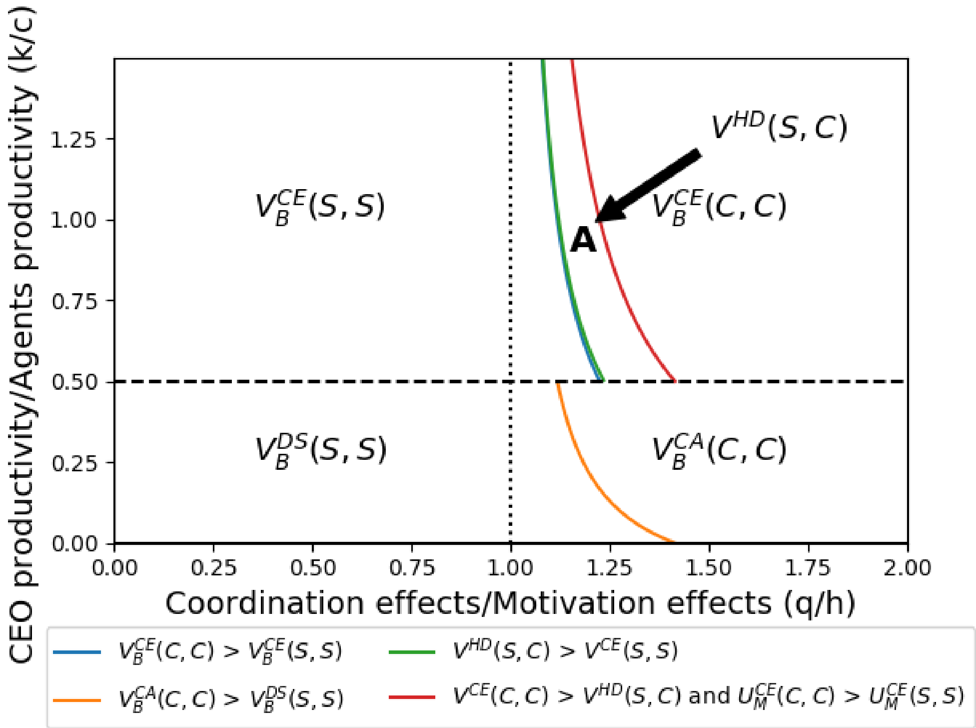
Keep in mind that in the model framework in equation 5 the CEO takes the decision considering his own utility. That means, she will choose cooperative instead of selfish decisions when $U_M^C(C,C) > U_M^C(S,S)$ and not when $V_B^C(C,C) > V_B^C(S,S)$. Since her own utility depends on the agents' effort, she is able to profit from these efforts. The manager prefers to profit from this takeover of agents' effort under selfish decisions (remember that under cooperative decisions agents choose a zero effort) while this rent-seeking over agents is greater than the benefits of increasing her own effort under centralization with two cooperative decisions. As a consequence, the manager needs a greater cooperative over motivational returns than in benchmark to make her change the selfish decision to a cooperative decision putting aside this rent-seeking over agents. Hence, there is a circumstance in benchmark in which centralization with $d = (C,C)$ is preferred but it is not implementable in the model framework. Thus, when $q > h$, but not considerably greater, hierarchical delegation with $d = (S,C)$ is implementable and therefore generates more value for the overall organization than centralization with $d = (S,S)$[9].

The intuition behind this result is that even when the cooperation over motivation returns ratio increases, the owner prefers some coordination but the CEO chooses both selfish decisions under centralization (in which the effort incentives are prioritized). However, at the same time the CEO is more productive than both agents, so it is necessary to keep her motivated to exert effort. As a

[9]Note that this result is important in the model case but not in benchmark, because in this space in benchmark centralization with $d = (C,C)$ is greater than hierarchical delegation with $d = (S,C)$ and implementable also.

consequence, the owner decides to delegate one decision right over the agent of the other project to coordinate, and the other 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. As the owner can anticipate that the CEO is not going to make the decision which is the most profitable for the organization, the former prefers to choose a constrained optimal organization (in benchmark) or a sort of "Second Best" organizational structure.

Figure 3: Model results



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

Figure 3 is an example for specific values of $\alpha = \lambda = 1/3$ and $h = c = 1$ and replicates the optimality map drawn in figure 2 but adds other thresholds computed in proposition 13. As a consequence, the blue line and yellow line represent exactly the same, the threshold in which $V_B^C(S,S)$ is greater than $V_B^C(C,C)$ (in benchmark) and the place where decentralization with two selfish decisions starts to be smaller than cross authority organization with both cooperative decisions, respectively. However, note that there are two additional lines, the red line states two things: the threshold under which centralization with $d = (C, C)$ is implementable (incentive compatible over centralization with $d = (S, S)$) for the CEO who is in charge of decision making in centralization and the value in which centralization with $d = (C, C)$ is greater than hierarchical delegation with $d = (S, C)$. The green line shows the frontier value under which hierarchical delegation with one decision selfish and the other cooperative is higher than centralization with both decisions selfish. The area within the red line, the green line and the dotted line shows the result of proposition 13 that we explain below.

Note that figure 3 of model results shows an interesting difference from figure 2 of the benchmark case. This difference appears above the dashed-line where the CEO is more productive than both agents. Comparing equations 5 and 7 clearly we see that the model framework takes into account the moral hazard problem in decisions. As benchmark shows, it would always be convenient to choose a centralization organization when the CEO is more productive than the agents. However, when the owner is not able to enforce the part which takes the decision (in this case the CEO), centralization with two cooperative decisions tends to be implementable far from where it is optimum (this distance is the difference between the blue and the red line) due to the fact that in centralization with two selfish decisions the CEO can take over profits from the efforts made by the agents. As a consequence, the owner can anticipate this strategical behavior and decides to choose a hierarchical organization with a decision cooperative and the other decision selfish, this is the "A" area marked in the figure among the red, the blue and the dash line. In fact, that results in a second best solution for the owner to the strategic behavior of the CEO.

Comparative Static Analysis

In this section we analyze how the optimum space of hierarchical delegation reacts under changes in the payment scheme structure. Since figures 2 and 3 illustrate the results for particular values of motivation returns and decision rights returns, $\alpha = \lambda = 1/3$,[10] we simulate other two cases to understand the changes above-mentioned. The first simulation considers a motivational effect higher than the delegation returns, $\alpha = 2/5$ and $\lambda = 1/5$, while the second simulation analyzes the other way around, $\alpha = 1/4$ and $\lambda = 1/2$. Figures D1 and D2 (available in *Appendix D*) depict these two cases.

In the first case, it shows that when the motivational effects increase the hierarchical delegation optimality space grows but it also requires a greater cooperative return. On the other hand, in the second case when the returns to decision making increase, the "A" area decreases (without disappearing) but requires less cooperative returns to implement hierarchical delegation.

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 division managers 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.

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

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, centralization will be convenient for the owner; 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, since the owner is not able to enforce the party which takes the decision, in centralization the CEO, she may take a decision which increases her own profits. As a result, she makes a sub-optimal 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 he 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 and unobserved effort and decisions.

This paper contributes to the literature by finding some incentives conditions under which hierarchical delegation is optimum 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. We are considering two possible extensions: i) to implement an endogenous fixed payment scheme, and ii) to analyze the career concerns problem and whether hiring a CEO from the market instead of taking her from the organization impacts on the optimality mapping of the organization.

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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 $k/c \leq 1/2$ 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.

$$V_B^{CD}(d_A, d_B|e^*) = \begin{cases} \big(4k\alpha + c\lambda\big)q^2 \text{ if } q/h \geq \sqrt{1+\frac{2c\alpha}{4k\alpha+c\lambda}}, \\ \big(4k\alpha + c(2\alpha+\lambda)\big)h^2. \text{ otherwise} \end{cases} \tag{24}$$

Note that concentrated delegation is never preferred to other forms of dominated organization structures when $k/c \geq 1/2$, so it is not a valuable alternative. Comparing with decentralization (which is dominated by centralization) 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 $P_i = 2k(\alpha+\lambda)q$ for $j = A, B$ if $q \geq \sqrt{1+\frac{c}{k}\frac{\alpha}{\alpha+\lambda}}h$ and $P_i = [c\alpha + 2k(\alpha+\lambda)]h$ 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 $P_i = [2k\alpha + c(\alpha+\lambda)]h$ 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 $q \geq -1 + \sqrt{1+\frac{(2\alpha+\lambda)^2}{\alpha(\alpha+2\lambda)}}h$, 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 $P_i = (c\lambda + 2k\alpha)q$ 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 $P_i = (c\alpha + 2k\alpha)h$ 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 $q \geq= \overline{\epsilon}$, $\max\{P_A; P_B\} = k(\alpha+\lambda)(h+q) + c\alpha h$ if $\underline{\epsilon} \leq q < \overline{\epsilon} = \overline{q}$, and $\max\{P_A; P_B\} = [k(2\alpha+\lambda) + c\alpha]h$ otherwise[11]. 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 $\overline{q}$ in $q < \frac{1}{k(\alpha+\lambda)(h+\overline{q})+c\alpha h}$ since $\overline{q} < q$. 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 10.

Solving by backward induction, at time 2 the CEO and each manager 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

[11] $\underline{\epsilon}$ and $\overline{\epsilon}$ are those from Proposition 12.

$e_M = 2k\alpha h$. 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 $V_B^{DS}(d|e^*)$ 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).

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

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

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

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 $V_B^C(C,C|e^*) \geq V_B^C(S,S|e^*)$, 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 11.

Solving by backward induction, at time 2 the CEO and each manager 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 chooses 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 $d \in \{(S,S),(S,C),(C,S),(C,C)\}$.

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

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

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

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

Last Case: $V_B^{CA}(C,S|e^*) \geq V_B^{CA}(S,S|e^*) \ \Leftrightarrow\ q/h \geq \epsilon_3 = -1+\sqrt{\frac{1}{(k\alpha+c\lambda)^2}+\frac{3k\alpha+c\lambda}{k\alpha+c\lambda}}$, *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 $V_B^C(C,C|e^*) \geq V_B^C(S,S|e^*)$, and likewise the others. It can be proved that $\epsilon_2 \leq \epsilon_1 \leq \epsilon_3$[12], 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 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): $X_{MA}=1$ y $X_{MB}=0$ and $X_{AA}=0$ and $X_{BB}=1$. 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 $e_A=e_B=0$ 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, agents 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.*

[12] 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.

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 $\epsilon_3 \leq \epsilon_1 \leq \epsilon_2$[13], 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_3 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 $d = (S, S)$.

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): $X_{MA} = 1$ y $X_{MB} = 0$ and $X_{AB} = 0$. And the utility functions are those stated in Equation 12.

Solving by backward induction, at time 2 the CEO and each manager 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 chooses the decision cooperative or selfish for each project, considering which is the most convenient for the owner.

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, agents 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 $\epsilon_2 \leq \epsilon_1 \leq \epsilon_3$[14], and consequently prove

[13] 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.

[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.

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 than 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 $V_B^{DE}(S, S) > V_B^{CA}(C, C)$, and (iii) $q \in [\sqrt{1 + \frac{c}{2k}\frac{\alpha}{(\alpha+\lambda)}}, Z/h)$.

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 upper 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 his 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: $d=(S,S), d=(S,C)$ and $d=(C,C)$. The utility function for the manager in each case is:

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

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

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

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:

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

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

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:

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

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

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

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

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

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

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

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

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 selfish 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 $U_M^{PD}(d|e^*)$ 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:

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

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

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

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

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

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

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

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

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

The manager and agent B 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 $d = (S,S)$. Hence, he will never choose a selfish decision when the CEO chooses a selfish decision. 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 before the manager. Then, $d = (C,S)$ is not implemented and the CEO takes a cooperative decision when $d = (C,C)$ is more convenient for himself 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 proof 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 than 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) $q \in [\sqrt{1+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}, Z/h)$.

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, cross-authority and delegation, 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[15]. 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 $k/c \geq 1/2$, $V^{HD}(S,S) > V^{CE}(S,S)$ 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 $q/h \geq \frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda} + \sqrt{\left(\frac{k(\alpha+\lambda)}{k(3\alpha-\lambda)+2c\lambda}\right)^2 + \frac{k(\alpha+\lambda)+c\alpha}{k(3\alpha-\lambda)+2c\lambda}}$, which for this values of k/c is greater than the upper limit of this region. 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 $\epsilon_{M1} = -1+\sqrt{4+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}} \leq q/h < \sqrt{1+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$.

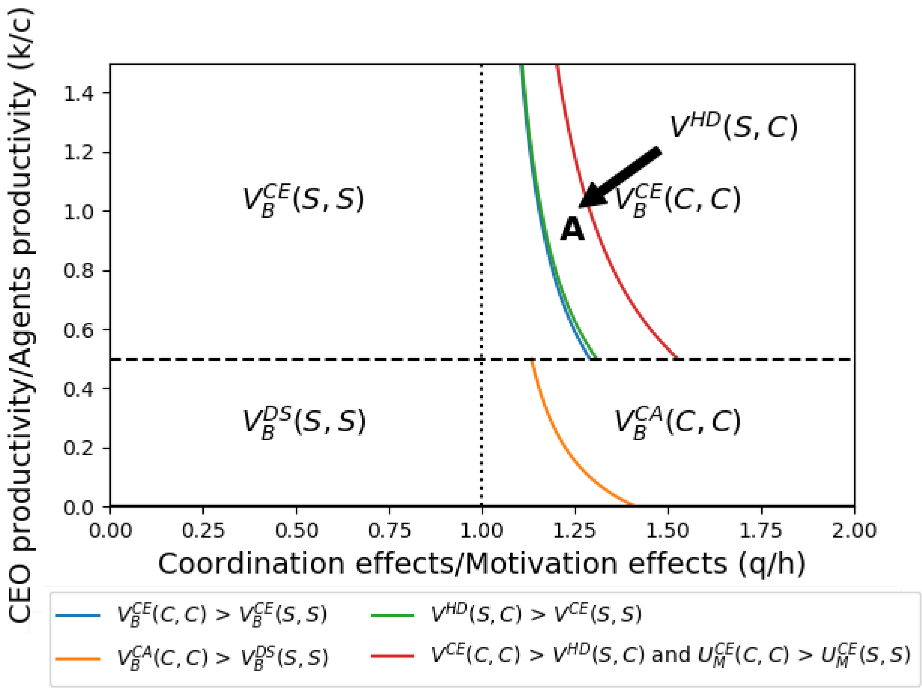
Finally, consider case (iii). The upper limit is the threshold under which the CEO chooses $d=(C,C)$ over $d=(S,S)$, we call this ratio $\epsilon_{M2} = q/h = \sqrt{1+\frac{c}{k}\frac{\alpha}{(\alpha+\lambda)}}$. The results in this region remain equal to that of benchmark proof. Then, centralization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

[15] We are considering that the ratio q/h needed to change the decision set from $d=(S,S)$ to $d=(S,S)$ 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 $V^{DE}(C,C)$, $V^{CA}(C,C) > V^{DE}(C,C), \forall q/h \geq 1$

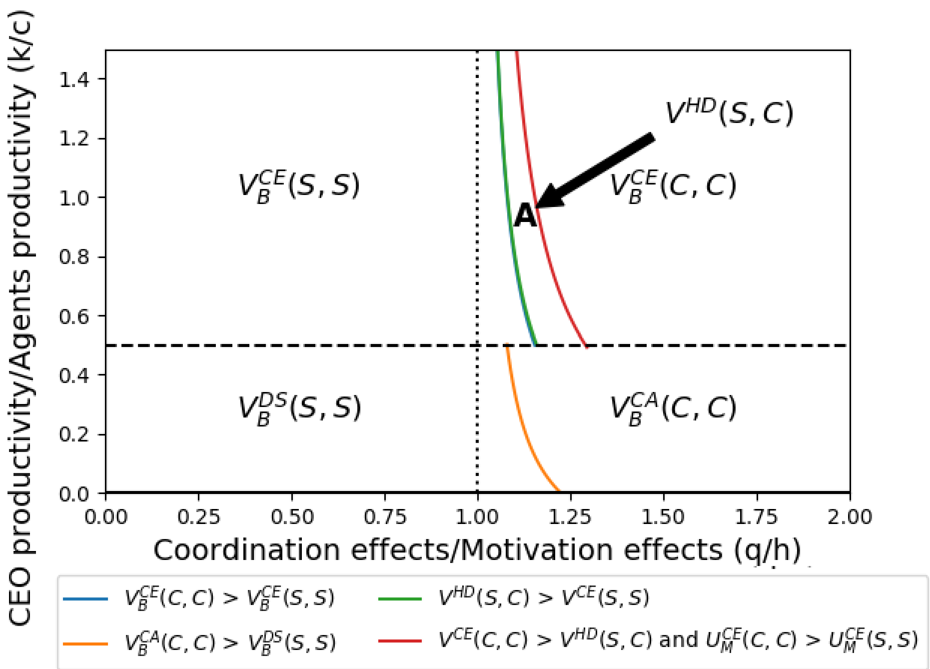
D. Simulations

Figure D1: Simulation 1



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

Figure D2: Simulation 2



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