Centralising or decentralising information: motivation and decision efficiency

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Abstract

Knowledge is power and power corrupts. If a principal's decision reveals private information about a project's payoff to the agent, the principal has an incentive to make inefficient decisions to induce effort. Therefore, it is better to commit to first-best decision making or allocate information to the agent if his incentives are sufficiently aligned with the principal's. This idea is tested in a model where coordination between two agents (divisions) is required. The result holds if the project's maximum payoff is not very low and not too high compared to the agents' outside option. It is then better not to patronise agents, but rather let them select their next task on their own. This contradicts a literature on coordination that assumes that it is always optimal to allocate information to the principal if possible. However, if unfavourable states of the world are less likely, the opposite can also hold. It is then optimal to keep the agents in the dark about the state of the world, and the ability to deviate from the first-best decision rule benefits the principal.

Keywords: effort, information, centralisation, delegation, coordination

JEL: D23, D82, D83, L23, M11, M54

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Contents

"Knowledge is power."

Francis Bacon in his *Meditationes Sacrae* (1597)

"Power tends to corrupt."

Lord Acton in a letter to Mandell Creighton (1887)

"There is no presence of American infidels in the city of Baghdad."

Muhammad Saeed al-Sahhaf, then serving as Iraq's minister of Information, trying to keep up morale with American forces a few hundred meters away from his press conference (2003)

1 Introduction

Former chess world champion Michael Tal once happily admitted that he had willingly played a bold but objectively bad move in an important match, because it made it look as if he had seen a devestating refutation for his opponent's best countermove. "There must be something to it, otherwise he would not have played that!", his opponent thought - and he responded with an inferior defending move. Tal won the game, because his opponent had believed that his decision making was first-best and fell for his bluff. The game of poker is basically built on this idea - calculating complex probabilities is not what gives it its cool image or appeal. And the story goes that when general Cao Cao faced the loathsome task to defend a town with a force of a hundred against a thousand times as many, he ordered the streets emptied, opened the gates, and calmly stood on the walls, playing an instrument. The opposing general suspected a trap and did not attack. All are examples of the so-called Empty Fort Strategy: using reverse psychology to trick your opponent into believing something is going on. The red line running through all of these examples is that strictly rational decisions convey information about the underlying state of the world to those who observe that decision, and the decision maker can use that to fool them. Therefore, seemingly irrational decisions are sometimes very attractive - and effective. In this thesis, I explore how this incentive affects the optimal allocation of information and decision rights between a principal and one or two agents.

There are modern-day examples too, and the topic of this thesis is not hypothetical. Before it went into a spectucular bankruptcy, Enron kept paying dividends, even though it was actually in no state to do so. Its fraudulent management did not have much of a choice, since not paying dividend would have been a clear signal that something was wrong. Another one is how (then Federal Reserve chairman) Ben Bernanke infamously insisted that the subprime mortgage crisis would not spill over to the real economy, to avoid a panick. These well known-examples illustrate that the idea that a decision contains information about some privately known state of the world is still relevant. In fact, in this age of information where more and more things are monitored, reported and shared with the public, it is more relevant than ever.

I deal with this topic using a principal-agent framework of delgation in a (multi-division) firm, where the principal chooses whether he or the agent becomes informed. While this framework allows me to deal with the topic in a more general fashion, the question that I ultimately try to answer is: *can it be optimal to decentralise information in a multi-division firm that requires coordination, and if so, when?* As it turns out, the answer is yes, particularly if the agent's (or agents') incentive to exert effort is relatively weak.

This thesis builds on a literature about the allocation of decision rights within an organisation. The question whether to keep decision making rights at the top of the pyramid (*centralisation*) or delegate it to lower-level employees (*decentralisation*, or delegation) has received plenty of attention. Its relevance is clear, as all large and many medium-sized firms must decide how to organise themselves. The consequences of this decision can obviously be enormous (see, for example, Garicano and Rayo [2016] for a discussion of organisational failures). Top-down decision making can be more efficient because a central management is able to take better decisions, or coordinate better between several divisions. However, bottom-up decision making may induce more effort by local managers. Despite - or maybe thanks to - all the attention that this topic has received, the best answer the economic literature seems to offer is: *it depends*. It depends on the objectives of the principal and agent, it depends on the quality of information, it depends on how information is gathered, and so on. Because it all depends on the circumstances, it is important to know which factors can influence the decision to (de)centralise. This thesis contributes to that by exploring an incentive that thus far has not received specific attention in this literature.

To be entirely accurate, this thesis does not deal so much with allocation of decision rights, but rather with the allocation of *information*. This decision can be equally important for the performance of an organisation (Grant [1996], Garicano and Rossi-Hansberg [2015]), and is a crucial determinant for who should have the authority to make a decision (Aghion and Tirole [1997]). It is not always possible to centralise information (e.g. Fama and Jensen [1983]), but some coordination literature, like Alonso, Dessein and Matouschek (2008 - I will also refer to them as 'ADM'), assumes that it would be optimal if it were. I explore the ability of a principal with private information about the state of the world to convince an agent to participate in a project by altering his own decision, and show that this ability may be a 'curse', because it leads to less efficient decision making. In particular, I apply this idea to a principal-agent problem where the principal has an incentive to deviate from his first-best decision to motivate the agent to exert effort for a project if his first-best decision would reveal a too unfavourable state. I do this in a number of settings. First, I apply the idea to a simple principal-agent problem with one agent and a uniform distribution of the possible states of the world. Then, I analyse a two-agent problem, where coordination is necessary. Finally, I explore what happens if unfavourable states of the world are *ex ante* less likely to occur.

The key results are as follows. In the single-agent setting, I show that asymmetric information enables the principal to motivate the agent more often than under perfect information, but that it would be better for the principal to let the agent be informed. The driver behind this result is that the principal has to deviate from his first-best decision more often than he would like to, because his incentive to deviate lowers the agent's expected utility for decisions that would have looked good enough under first-best decision making. This result holds if information is always asymmetric and the agent's decisions are sufficiently close to the principal's first-best decision path. That is: if the principal's only way to let the agent be informed is to give him a monopoly on information (and thereby *de facto* the authority to make decisions), it may still be optimal to do it. This contradicts the notion that it is always optimal to let the principal be informed and take decisions (ADM, Bester and Krähmer [2008]).

The two-agent coordination model is based on ADM. I show that even if the agents only learn a local state of the world under decentralisation, they are (weakly) more informed than under centralisation. Decentralisation can therefore be better if the agents' quasi-rent of the project is such that they would exert effort if and only if they knew that the state of the world is (reasonably) favourable. If the agents' willingness to participate is very high, but not so high that they would participate even under the most unfavourable conditions, it is better to keep them uninformed. The principal can then motivate them more often by keeping them in the dark. If the states of the world are uniformly distributed, this intuition always holds if the agents' decisions are first-best, so it would be optimal for the principal to commit himself to first-best decision making. It can also hold if the agents' decisions are not first-best either (i.e. they coordinate insufficiently). If unfavourable states are less likely, the ability to deviate dominates first-best decision making if the project's payoff is high. If the project's payoff is lower, decentralisation is optimal.

My results apply first and foremost to the internal distribution of information in an organisation with either a manager and multiple agents or a headquarters with multiple divisions, plants or stores. I discuss some other applications in the literature section and throughout my analysis. One interesting question that I mention here (and do not revisit) is how they relate to the public sector. Since elected officials have an incentive to pretend their policies are working well, it may be better to delegate some parts of information gathering and decision making that reveal information to (quasi-)independent institutions like government agencies (Gilardi [2002]). One example would be a central bank (not an agency), which in many developed countries is independent not *despite*, but *because* of the great economic importance of its decisions - although the earlier mentioned FED example shows that it may still have incentives to give its own interpretation of the facts, of course.

The scope of my results is limited by two assumptions I make. Firstly, the agent's choice of effort is binary. The results of this thesis do not apply to situations where the agent's choice of effort (or participation) is continuous.[1] The model reflects any situation where the agent can either participate or not. Take, for example, an investment decision, or a worker who cannot (costlessly) divide his effort between an infinite number of tasks (as suggested by Holmstrom and Milgrom [1991]).[2] The second key assumption is that performance pay is not possible. The state of the world is not verifiable *ex post*, and neither is the agent's effort. This allows me to focus on the principal's incentive to misrepresent information without any unnecessary complications. It also allows me to compare my results with ADM.

The structure of this thesis is as follows. I start with a review of the related literature on delegation and coordination, and some related topics. Then, to answer my main question, I first explore the tradeoff of delegating information to an agent in a single-agent setting in chapter 3. This analysis shows that under some general conditions it is optimal to allocate information to the agent when no coordination is required. Continuing, I analyse the same tradeoff in a coordination model based on ADM in chapters 4 and 5. I start with an integer version of the model in chapter 4 for expositional simplicity. This already allows me to answer my main question. Chapter 5 is an expansion to a continuous model. Although I have to make some limiting assumptions, I show that the same intuition holds. Chapter 6 concludes.

2 Related literature

This thesis is mostly related to literatures that deal with the allocation of authority. The first is on delegation and examines the impact of the allocation of decision rights on an agent's willingness

[1] With binary effort, deviating from the first-best decision path is often effective in the sense that the principal can convince the agent to exert effort more often. With a continuous effort function and costs of effort that are more convex than the project's payoff, the agent would exert strictly less effort than under first-best decision making.

[2] If an agent has a choice between two (or more) options, it is not unreasonable to assume that his binary choice between those options matters more than his continuous choice of effort for the option he chooses. That is, on a continuous scale he may exert more or less effort on a project based on its merits, but that difference is likely to be smaller than the difference between any effort and no effort at all.

to exert effort. The second deals with centralisation versus decentralisation and examines the efficiency of decision making when multiple agents (or divisions) with private information have to cooperate. Both are part of a larger literature on the allocation of decision rights within an organisation, which I will not discuss here (see e.g. Klein, Crawford and Alchian [1978]). I first discuss a number of papers on delegation and their relation to this thesis. For the coordination part, I focus on ADM, whose model I use. In the last section of this chapter, I discuss the few papers that combine motivation and coordination, some literatures that my paper bears resemblence to, and finally some emperical evidence.

2.1 Delegation: control versus effort

It is a common notion that principals face a tradeoff between having control over a decision and the (unverifiable) effort of the agent who must execute it (Gibbons et al. [2013]). Aghion and Tirole (1997, I will also refer to this article as 'AT') show that it can be optimal for the principal to remain uninformed, in order to increase the agent's incentive to gather information and his participation. The main driver of this result is that if the principal keeps the authority to overrule the agent's decision if it conflicts with his own interest, the agent is less motivated to put effort into finding a good project because he knows that his effort may be in vain. It can therefore be optimal for the principal to be ill-informed, so that he can credibly rely on the agent's judgment. The agent then has *real* authority, even though the principal may still have *formal* authority. Aghion and Tirole show that the principal just rubber-stamps the agent's choices. Obviously, delegation comes at a cost: the private interests of the agent (based on which he selects a project) may conflict with the principal's objectives.

Similarly, it can be better for the principal to not act on the information he receives. Zábojník (2002) considers a model where a principal and an agent both have (different) private information about a project's payoff. If the principal believes the agent has made a wrong decision and interferes, it can be very costly to motivate the agent *ex post* if he beliefs that the project he wanted to work on was better than the one assigned to him. This cost can be so high that the principal prefers to keep his information to himself (even if its quality is superior to the agent's) and delegate the decision to the agent. This result particularly holds if the agent is liquidity constrained. His model is one that includes incentive pay. In the same category falls Bester (2009), who examines the reward scheme for a risk-averse agent and shows that it can be cheaper to let the agent choose projects that require less effort, rather than having to compensate him for the risk that the principal will select a large and difficult project.

The idea that decision making by a principal may not be first-best because he takes the agent's incentive to exert effort into account is not novel, and was explored in Bester and Krähmer (2008). Their conclusion is quite the opposite of mine, though. In their model, an agent with a bias towards certain projects chooses his effort after the project has been selected, based on public information about its payoff. Delegation is often not optimal, because the principal can credibly commit to taking the agent's preferences into account, since the agent has the last say in the game (since he chooses his effort after the project has been chosen - as Bester and Krähmer note, it seems that the timing of the agent's decision to exert effort may be crucial to whether delegation is optimal or not). Introducing information asymmetry leads me to the opposite conclusion. Whereas in Bester and Krähmer's analysis it is optimal to decentralise because the principal credibly takes the agent's effort into account, I show that centralisation can be strictly dominated by decentralisation because of that very reason, as the principal deviates from the choice that would be optimal for both him and the agent. This goes to show that specific circumstances can indeed be critical for whether (de)centralisation is optimal.

I conclude this part with a few remarks on the origin of the principal-agent problem that is analysed in the 'control-versus-effort' literature.[3] Quite often, the principal-agent problem arises because the agent is biased towards certain decisions (AT, Bester and Krähmer [2008], other examples are Dessein [2002] and Harris and Raviv [2005]). In other papers, like Zábojník (2002) and Van den Steen (2010) the problem is that the principal's and the agent's information may be different, leading them to different beliefs about the best project. In any case, the agent has an effort function or constraint of some sort. A different approach can be found in Sappington (1991), who proposes that an agent's decision making may be clouded if his optimal decisions reveal private information about his productivity, which would allow the principal to extract his full surplus. Revealing his private information causes a ratchet effect. In this thesis, I examine the same idea but reversed: the *principal* does not want to reveal his private information to the agent, whose willingness to exert effort disappears at some point. Ultimately, I analyse a tradeoff between this 'agent-principal problem' and the principal-agent problem that is caused by coordination. The principal-agent part of my model is trivial compared to most control-versus-effort literature: the agent simply has an outside option.

2.2 Coordination

The coordination part of this thesis is a variation on the paper by Alonso, Dessein and Matouschek (2008), in which they develop a model of a firm with a headquarters (HQ; the principal) and two division managers (agents). The setting is as follows: the managers know the local state of the world, and HQ must decide whether it keeps decision making authority to itself (centralisation) or delegates it to the managers (decentralisation). Payoffs are a combination of local adaptation (i.e. how close local decisions are to the local state) and coordination (i.e. how close the decisions are to each other). After HQ makes its decision, the managers send a cheap talk message to HQ or the other manager and decisions are made. Like in Dessein (2008), this is where the problems arise, because the managers will try to push the receiver of their message in a certain direction and are unable to tell the truth.

Their analysis shows that if information about the state of the world is located at the managers, it is often optimal to let them make decisions rather than communicate with HQ and let that decide. The managers do not coordinate as well as HQ would like, but if their objectives are aligned reasonably well and/or the need for coordination is not too high, the result of their coordination is the best attainable outcome. The reason is that the managers do not communicate the state of the world honestly to either HQ or the other manager. Under decentralisation, this leads to a coordination loss that is higher than under centralisation, because the managers do not take into account the coordination loss sufficiently from HQ's perspective. However, the managers are efficient at avoiding adaptation losses, because they know perfectly what their local state is. Under centralisation, the adaptation loss is always bigger because HQ has inaccurate information (and coordinates more, but that is a necessity). The main point of ADM's analysis is that the reduction of the adaptation loss under decentralisation compared to centralisation can be larger than the increase of the coordination loss, which makes it optimal to allocate decision making authority to the division managers.

An important notion in ADM is that it is always optimal to allocate authority to HQ if it can become sufficiently informed. Therefore, it would be optimal to let HQ be informed, so it can take first-best decisions. This is where I combine ADM with the control-versus-effort literature:

[3]An interesting sidenote is that allocating information can also solve principal-agent problems. For example, Rajan and Zingales (1998) argue that access to scarce resources of the firm, like research capacity etc., is a vital source of power. Allocating access to information can then be a more efficient way of allocating power than allocating property rights, because the employees only benefit from their access if they use the resources in a way that makes them (being the resources and primarily *themselves*, as human capital) useful for the firm.

is it still optimal to allocate information and decision rights to HQ if the agents do not always exert effort, and do not have hard information about the state of the world?

2.3 Combinations and other related literature

There is a small number of papers that treat the combination of coordination and (unverifiable) effort, of which an even smaller number is relevant to the topic of this thesis. For example, Athey and Roberts (2001) look for an incentive scheme that induces both effort and the right decision, but do not consider the allocation of information. Van den Steen (2010) explores a tradeoff between coordination and motivation. His contribution is mostly to the delegation literature, since he considers coordination between the principal and the agent (rather than between different agents). His results bear strong resemblances to those of AT and Bester and Krähmer (2008): if effort by the agent is important, it may be better to rely on his judgment because that increases his motivation. Most closely related to this thesis is the analysis of Dessein, Garicano and Gertner (2006). Like this thesis, they examine the impact of centralisation on the motivation of division managers when centralised decision making is optimal for the firm as a whole, but not for them privately. One example they give of such a situation is that standardisation may make production more efficient, but leads to products that are less fitting to the demands in specific markets. Concerning effort, their main result is that centralisation is less attractive if effort by the managers is important. One of the reasons that coordination is costly is that it is harder to provide effective incentives for the individual managers (this argument is, of course, strongly related to motivation in teams). A key difference between their paper and this thesis is that they assume information to be only available to local managers, like in ADM. Their work thus does not examine the allocation of information. Also, they include incentive pay in their model.

Centralisation may bear other downsides than those that are explored in this thesis. One example is that a central decision maker (HQ), although superiourly informed, may be less able to react swiftly to locally changing circumstances. This problem was famously explored by Masahiko Aoki (1988, 1990) in his analysis of so-called vertical or horizontal information allocation within a firm. Although the focus of his analysis is different, his insights provide useful context. In particular, his conclusion that horizontally working divisions can learn to coordinate more efficiently as time passes gives some independent viability to a simplified version of the model that I consider in chapter 5, where the managers both learn the complete state of the world under decentralisation. Another illustration of considerations that are not related to principal-agent problems is a reseach by Dewar and Dutton (1986) on the adoption of technological advances in manufacturing firms. They show that the presence expertise in the firm was the most important determinant. (De)centralisation - that is, where the expertise was present - appeared to play little to no role. It seems then that sometimes, it matters less *who* exactly possesses relevant knowledge, than that *anyone at all* possesses it.

The idea that I apply to delegation has earlier also been applied in the literature on decision making with reputational concerns. One example is decision making in committees. Visser and Swank (2007) point out that committees often make poor decisions, and note that this may be (partly) because committee members with reputational concerns may be afraid to disagree with their peers. In their model, the committee members care about being perceived as well-informed. Showing disagreement to the outside world is a sign that at least one of the committee members is ill-informed, so the committee always acts unanimously. A result can be that 'unconventional' decisions with a negative expected value are implemented, because they make the committee look confident of its own judgment. The driver behind their result is similar to the one in this thesis: agents take decisions that are inefficient, but look better to the outside world. Other examples where the same idea applies are political correctness (Morris [2001]) and investment decisions (Scharfstein and Stein [1990]).

The result of this thesis can also apply to the integration (make or buy) literature. Biased and therefore inefficient decision making towards one division is used as a motivation not to integrate two firms (Grossman and Hart [1986]). This thesis shows that such a bias is not required to let seperation be more efficient than integration (see also Dessein et al. [2006]). Suppose that an investor sees a possibility to acquire two independent firms and save costs by integrating the research departments, as a result of which the formerly independent firms must rely on information provided by a new headquarters. While it may seem like an efficient way to save costs, it may make decision making less efficient and reduce the newly found divisions' incentive to exert effort. Integration may then backfire, even if the headquarters does not have a bias.

As the literature on the matters of this thesis is mostly theoretical, emperical evidence is scarce (Colombo and Delmastro [2004]). Some can be drawn from a literature on the role of trust in organisations: implicitly, this thesis deals with the trust an employee has in his manager. If the employee trusts his manager's decisions, it is efficient to centralise information and decision making. In a study in the restaurant industry, Davis et al. (2000) find that the employees' perception of their manager's ability, benevolence and integrity significantly impacted sales and profits. This may be partially explained by the speculating that distrust is associated with managers who do not always take efficient decisions. Managers who are committed to first-best decisions are more trustworthy in the sense that they do not try to fool their employees. Other empirical research has shown positive correlation between how open managers communicate and the level of trust in them that employees have (Mishra and Morrissey [1990], Tzafrir et al. [2004]). Sharing information in particular has been associated with higher levels of trust (Randolph [1995]). Relatedly, Bowen and Lawler (1995) and Seitbert et al. (2004) submit that employees feel more 'empowered' and exert more effort if they know how their work contributes to the organisation.

Hard, specific empirical evidence on delegation and coordination is especially scarce because it is hard to measure and isolate effects. Evidence from the lab suggests that being a subordinate reduces effort on its own (Fehr, Herz and Wilkening [2013]). In an experiment based on the model from AT, it appeared that the subjects experienced a (non-monetary) disutility from being subordinate and potentially being overruled. They also systematically exerted less effort that would have been strictly rational (i.e. what would be expected in the theoretical equilibrium). In a field study, Colombo and Delmastro (2004) find that organisations with multiple manufacturing plants were more likely to decentralise decision making. Their findings can be explained in various ways. This thesis suggests one: as the number of divisions between which the headquarters has to coordinate increases, the amount of information that the divisions get from a decision decreases, and the centralised decisions are less likely to fit to the local conditions of a plant.

3 A general model of delegation

3.1 The model

This chapter examines the question whether information and decision rights should be allocated to a single agent or the principal, without considering coordination between different agents. This chapter builds a foundation for the rest of the analysis, both with regard to the model and the results. The numbered assumptions I establish here apply in all following chapters as well, *mutatis mutandis*. Consider a simple model of information allocation, where a principal engages a risk-neutral agent to work on a project $d \in D$ that first has to be selected. Which project is optimal depends on the state of the world $\theta \in \Theta$, which is unknown at first. Like in most related literature, I assume that the states of the world are distributed uniformly for simplicity.

Assumption 1 *The state of the world θ is distributed uniformly with compact support.*

In particular, let $\theta \sim U[0,1]$ in this chapter.

Learning the state of the world is costly, so the principal chooses one party (himself or the agent) who will carry out research. The results of this research are non-verifiable by third parties, so the state of the world is 'soft information' in the meaning of AT that the informed party cannot credibly share his information. The principal thus chooses to whom he allocates private information.

Assumption 2 *Only the informed party can verify the state of the world.*

The payoff of the project depends on how well the project is suited to the state of the world and on the state of the world itself. For simplicity, the principal and agent agree on what is the best project. This is captured by the following payoff functions:

$$\pi(d) = K - c(d,\theta), \qquad U(d) = \alpha K - c(d,\theta). \tag{3.1}$$

The project's maximum payoff $K \in (0,1)$ is the principal's quasi-rent of the agent's involvement, and $\alpha \in (0,1]$ measures the quasi-rent of the agent compared to the principal's. It is an indirect measurement of the size of the agency problem, as it determines the gap between the principal's and agent's incentives to complete the project. The agent may have a private rent of the project's payoff because it earns him a reputation, acquires human capital or signals ability (AT). The function $c(d,\theta)$ is the cost of the project, or a negative measurement of its profitability. It has the properties that $\partial c/\partial\theta > 0$ and that $\partial c/\partial d < 0$ and $\partial^2 c/\partial d^2 < 0$ for all $d < \theta$. That is, the cost of an inefficient project choice is increasing in how far it is away from the optimal choice, and higher d indicate lower payoffs. Let

$$c(d,\theta) = (d-\theta)^2 + \theta^2 \tag{3.2}$$

map the project's costs. The choice for a quadratic loss term as used in *inter alia* Crawford and Sobel (1982) and ADM is intuitive. The second term of the function is chosen to reduce the length of the expressions in the analysis. In general, choosing a linear rather than quadratic cost would increase the agent's willingness to participate, but the qualitative results remain unchanged. As will become clear, the incentive to deviate from the first-best decision (and thereby its costs) only depends on the first term.

After the state of the world has been drawn and revealed to the informed party, that party makes the decision for project d to maximise his expected payoff. The first-best decisions from the agent's and principal's perspectives are aligned, as $d_a^* \equiv \arg\max U(d) = d_p^* \equiv \arg\max \pi(d)$. The first-best decision $d^* \equiv d_a^* = d_p^*$ is

$$d^*(\theta) = \theta. \tag{3.3}$$

For each θ there is a unique $d^*(\theta)$ which is the optimal project given the situation, and the optimal choice of project thus reveals the state of the world to the uninformed party. For example, a decision to produce large quantities of a newly developed product can communicate to the uninformed world that it has superior qualities, and that the firm has private information that indicates that it will be a huge success. This decision then influences the willigness of others to cooperate. In this example, it may persuade investors to buy stocks or retailers to purchase larger quantities of the product. It is easy to see that the principal therefore has an incentive to 'polish' his decision to make it look like his situation is well, especially if it is in fact not. That comes at the cost of inefficiency, but if it induces engagement from other agents, it may be worth it. To study this incentive, I assume that the principal wants to motivate an agent who chooses between high or low effort. High effort leads to a guaranteed rent of K, while low effort leads to a payoff of 0. If the agent chooses low effort, he can spend his time on an outside option. In that case he does not receive any payoff from the project and his utility is normalised to 0. Hence, the agent only exerts effort under centralisation if he believes the project's net payoff to be high enough.

After the decision is made, the agent chooses whether he commits his effort to the project or to some outside option ω. Let his effort e be 1 if he chooses the project and 0 if he chooses the outside option. The project is riskless, and if $e = 1$ he will receive αK. Otherwise, he will receive ω. His utility $U(d, e)$ is mapped by

$$U(d, e) = e\left[\alpha K - (d - \theta)^2 - \theta^2\right] + (1 - e)\,\omega, \tag{3.4}$$

where his effort incentive constraint is

$$e = \underset{e \in \{0,1\}}{\arg\max} U(d, e). \tag{3.5}$$

For simplicity, let $\omega = 0$. Performance pay is not feasible because effort is not verifiable. This may well be the case if effort is not externally verifiable, or even internally, if the result of the agent's decision does not become clear for some time. The fact that there is a huge literature about the difficulties and costs of monitoring the agent in a princpal-agent relationship shows that this is rather plausible. In general, performance pay may also be unfeasible because of liquidity constraints. The preceding implies the following assumption.

Assumption 3 *The agent exerts effort if and only if* $E[U(d)] \geq 0$.

The principal is assumed to be committed to the project in any case (i.e. he always incurs the costs). For example, he allocates assets that have no residual value. He may also receive other rents than from the agent's effort.

Assumption 4 *The principal always receives* π.

His payoff conditional on the agent's effort is

$$\pi(d, e) = eK - (d - \theta)^2 - \theta^2. \tag{3.6}$$

The agent executes the project if $\alpha K \geq E[c(d, \theta)|d]$, so given d^*, his decision depends on $E[\theta|d^*]$. It becomes immediately apparent that since the principal's incentive to let the project go through is stronger than the agent's, there is a range of θ for which the principal would like to execute the project but the agent does not. Since d in fact contains a signal about θ to the uninformed party, the principal may have reason to fiddle with his decision if the first-best decision would reveal an unfavourable state to the agent.

The timeline of the model can be summarised as follows.

Timeline of the model

1. The principal decides which party becomes informed.
2. Nature draws $\theta \in \Theta$ and reveals θ to the informed party.
3. The informed party makes decision $d \in D$.

4. The agent chooses $e \in \{0, 1\}$.

5. Payoffs $\pi(d, e)$ and $U(d, e)$ are realised.

This chapter continues as follows. I start by comparing centralisation to delegation when the agent's project choice is first-best. This yields the most important result of this section, namely that the possibility to deviate is bad for the principal. I then add a degree of inefficiency to the agent's project choice to show how this affects the tradeoff. From this, I derive three factors that determine whether the principal prefers centralisation or decentralisation. These three factors will be used throughout this thesis. In the conclusion, I discuss some alternative applications of the model.

3.2 Analysis

3.2.1 Decentralisation

Under decentralisation decision making is uncomplicated and first-best, which makes it a good place to start. It is also a benchmark of what would happen if the principal would not deviate, since the agent makes the first-best decision, $d_a(\theta) = \theta$. He exerts effort if and only if

$$\theta \leq \sqrt{\alpha K} \equiv \tau. \tag{3.7}$$

The principal's expected payoff is then given by $E\left[\pi^d(d, e)\right] = \tau K - E\left[\theta^2\right]$ where τ is the ex ante probability that the agent exerts effort, so

$$E\left[\pi^d(d, e)\right] = K\sqrt{\alpha K} - \frac{1}{3}. \tag{3.8}$$

3.2.2 Centralisation

Under centralisation, the principal takes the agent's effort incentive constraint into account when making a decision. That is, he maximises (3.6) subject to (3.5). It follows that he does not always decide $d^*(\theta)$, as any decision $d > d^*(\tau)$ leads to no effort. If $d^*(\theta) - d^*(\tau)$ is sufficiently small, the principal therefore has an incentive to *deviate* from the first-best decision to a lower d for which the agent would exert effort based on his belief about θ. This is the highest d for which the agent's effort incentive constraint is satisfied, given that the principal sometimes deviates. Let this decision be

$$x \equiv \{d : E[U(x)] = 0\}. \tag{3.9}$$

Because the principal sometimes deviates, the agent's expected utility $E[U(d)]$ decreases for all values to which the principal might deviate. This means that the principal has to deviate to a value lower than $d^*(\tau)$ to convince the agent. That also implies that the principal is forced to deviate even if $\theta = \tau$. The decision to which the principal has to deviate to convince the agent to exert effort must be so low that the higher utilities associated with $\theta < \tau$ compensate the lower utilities of $\theta > \tau$.

Since deviating to the same point is more costly for higher θ, deviating is not just 'cheap talk'. The principal only deviates if the cost of deviating is sufficiently small, so θ must be sufficiently close to x. Define the θ for which the principal is indifferent about deviating as

$$y \equiv \{\theta : E[\pi(x, 1)|\theta] = E[\pi(y, 0)|\theta]\}. \tag{3.10}$$

The following lemma characterises the equilibrium.

Lemma 3.1 *In the unique Bayesian centralisation equilibrium, the principal's (pure) strategy is to take the first-best decision* $d(\theta) = d^*(\theta)$ *for all* $\theta \leq x$ *and* $\theta > y$, *and deviate to* $d(\theta) = x$ *for all* $\theta \in (x, y]$, *where* x *is defined in (3.13) and* y *in (3.11). The agent's beliefs are* $\theta = d$ *with* $E[U^c(d)] = K - \theta^2$ *for all* $d < x$ *and* $d \geq y$, *and* $\theta \in [x, y]$ *with* $E[U^c(d)] = 0$ *for* $d = x$. *For all* $d > x$, *his belief is such that* $E[U^c(d)] < 0$. *Hence, the agent exerts effort if and only if* $d \leq x$.

A somewhat surprising (but by no means novel) result is that a 'reversed' principal-agent problem emerges. Typically, the moral hazard in the principal agent problem is that the agent may shirk if he is not properly motivated to exert effort (either by rewarding him or monitoring him). Here, the principal has a moral hazard: he has an incentive to mislead the agent about his expected payoff.

For $\theta > x$, the marginal cost of deviating is $(x - \theta)^2$ while the benefit is K. Setting those equal yields that the principal is indifferent about deviating for

$$y = x + \sqrt{K}. \tag{3.11}$$

When the agent learns that $d = x$, his expected utility is given by $E[U^c(x) \,|\theta \in [x, y]] = \sum_{\theta \in [x,y]} U^c(\theta, x) / (y - x)$, which equals

$$E[U^c(x)] = \alpha K - \frac{1}{y - x} \int_x^y \left[(x - \theta)^2 + \theta^2\right] \partial\theta. \tag{3.12}$$

Computing this integral, we get that he is indifferent about exerting effort if

$$\alpha K = \frac{2\left(x^2 + y^2\right) - xy}{3},$$

and substituting y and solving for x gives

$$x = \left(\sqrt{\alpha - \frac{5}{12}} - \frac{1}{2}\right) \sqrt{K}. \tag{3.13}$$

Note that $x < \tau$, so deviating is effective: the probability of effort is increased.[4] The solution of x only exists for $x \geq 0$, i.e. $\alpha \geq 2/3$. For lower α, the agent mixes exerting effort for $d = 0$ such that y becomes sufficiently close to x. This must be bad for the principal. We can therefore restrict attention to $\alpha \geq 2/3$, because as we will see, centralisation is put to the test severely enough even then.[5]

3.3 Performance

From the principal's perspective, decentralisation dominates centralisation if $E\left[\pi^d(d, e)\right] > E[\pi^c(d, e)]$. The agent's decision making is first-best, so the question is really whether the possibility to deviate is beneficial for the principal. *Ex post*, centralisation is better if $\theta \in [\tau, y]$ because the principal was able to increase his profit by inducing effort, and it is worse if $\theta \in [x, \tau]$ because the agent would have taken a more efficient decision and exerted effort anyway. For all other θ, the choice was immaterial because both options would have lead to the same outcome. Furthermore, we have that $\pi^c(d) = U^c(d) + (1 - \alpha) K$ and $E[U^c(x)] = 0$, so $E[\pi^c(d) \,|\theta \in [x, y]] =$

[4] This is a result of assuming that the agent's choice of effort is binary.

[5] The next chapter contains an analysis of $x = 0$ in a modified model.

$(1-\alpha) K$. Using this, $E\left[\pi^d(d,e)|\theta \in [x,y]\right] > E\left[\pi^c(d,e)|\theta \in [x,y]\right]$ can be compactly written as

$$\frac{\tau - x}{y - x} K - E\left[\theta^2 | \theta \in [x,y]\right] > (1-\alpha) K. \tag{3.14}$$

Leaving calculations to the appendix, this inequality holds for all $\alpha \in [2/3, 1]$. We can now state the following proposition.

Proposition 3.1 *Suppose that $\alpha \in [2/3, 1]$.*

1. *HQ strictly prefers decentralisation for any α if the agent's decisions are first-best. The possibility to deviate is inefficient in the sense that it reduces the principal's expected payoff.*
2. *HQ's preference for decentralisation (and the inefficiency caused by deviation) increases in the relative difference between the principal's and agent's payoffs ($\partial E[\pi^c(d,e)]/\partial\alpha > \partial E\left[\pi^d(d,e)\right]/\partial\alpha$).*

Lemma 3.1 and proposition 3.1 imply that the principal increases the probability of effort by deviating under centralisation for all $\alpha > 2/3$, but that is not profitable on average. That is, deviating may be effective, but it is not efficient from the principal's point of view.

Furthermore, deviating becomes more inefficient as the difference between the project's returns for the principal and those for the agent increases. That is, as the principal's incentive to engage the agent becomes larger compared to the agent's willingness to participate, it becomes better to delegate. This result is similar to Harris and Raviv (2005), who also find that decentralisation can become a better option as agency problems increase. The reason behind their result is similar but different: in their model, the agency problem is that the agent has a bias towards certain decisions. As this bias increases, communication from the agent to the principal becomes harder. Delegating authority to the agent can prevent this. The result here is driven by the fact that as α decreases, the effect of the principal's incentive to deviate increases. That is, he needs to include more favourable d in his deviation strategy to make it work. That means that the cost of deviating remains the same, but its effectiveness decreases (y shifts left towards τ).

3.4 Inefficiency under decentralisation

If the agent's decision making is not first-best, there is a tradeoff between the inefficiencies under centralisation and decentralisation. This is, for example, the case in the two-agent model if the agents do not coordinate sufficiently. In a single-agent case, the agent may put less effort into finding out what the right decision is, or be less capable of taking the right decision. If the inefficiency under decentralisation is very large, centralisation may be better yet.

To clarify the tradeoff between centralisation and decentralisation, I add a simple measure of inefficiency to the agent's decision making in this model. In particular, I assume that the agent's decision making is flawed because his information is less accurate. To capture this, let his signal about θ be imperfect. His signal t is distributed symmetrically around θ with variance σ^2, and centralisation is the same as before. The variance has a specific meaning here, but σ^2 can be thought of as a measure of inefficiency under decentralisation in general.

The agent's optimal decision given his signal is $d^*(t) = t$, but this decision is expected to be inaccurate *ex post*. Because the agent expects his decision to be off his expected utility is lower, and therefore he requires a signal strictly lower than τ to exert effort. The noise in the agent's signal thus leads to a double inefficiency, which I will refer to as a *coordination loss* and a *motivation loss*. By the former, I mean the inefficiency of the agent being unable to take the exactly right decision (the name will make more sense in the following chapters). Together with the *deviation loss*, i.e. the decrease in efficiency under centralisation because of the principal's incentive to deviate, these two form the three quantities that are traded against each other when choosing between centralisation and decentralisation. Note that the motivation loss can be larger under centralisation than under decentralisation if the wedge between the principal's and the agent's incentives is large (recall that the agent starts mixing exerting effort for $\alpha < 2/3$). The coordination loss can actually consist of two components, one of which - the part due to inaccurate information - we see here. The other part is caused by disaligned incentives of the agent(s).[6]

To illustrate this tradeoff, let us return to the (adjusted) model. The agent's expected payoff given his signal under decentralisation is

$$\begin{aligned} E\left[U^d(d)\,|t\right] &= \alpha K - E\left[(t-\theta)^2 + \theta^2|t\right] \\ &= \alpha K - t^2 - 2\sigma^2, \end{aligned} \tag{3.15}$$

so his effort incentive constraint is

$$t \leq \sqrt{\alpha K - 2\sigma^2} \equiv \tau\left(\sigma^2\right). \tag{3.16}$$

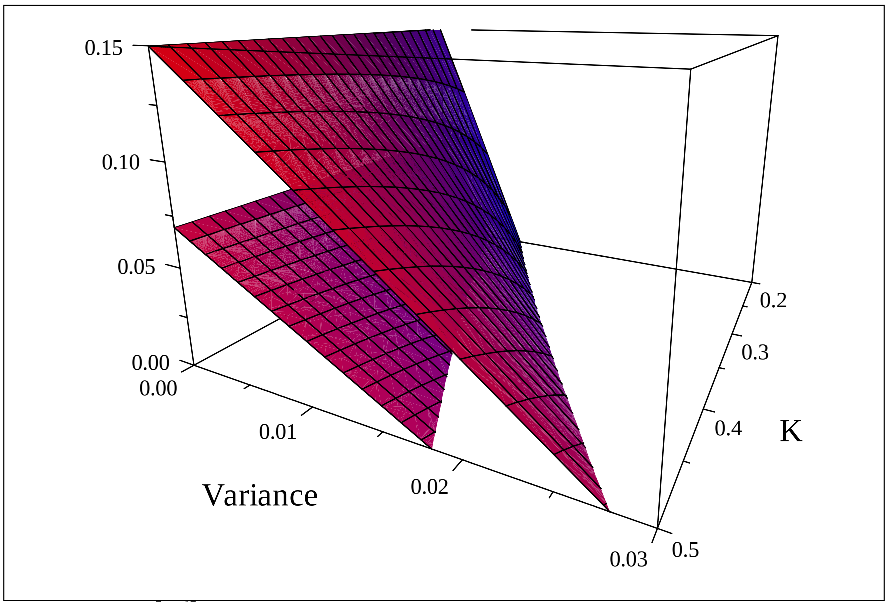
Since the distribution of t largely follows the distribution of θ, we assume that $\Pr(e=1) = \tau\left(\sigma^2\right)$.[7] HQ then prefers decentralisation if

$$\Pr(\theta \in [x,y]) \left(\frac{\tau\left(\sigma^2\right) - x}{y-x} K - E\left[\theta^2 | \theta \in [x,y]\right] \right) - \sigma^2 > \Pr(\theta \in [x,y])\,(1-\alpha)\,K. \tag{3.17}$$

Substituting and rewriting shows that this inequality holds for sufficiently high K/σ^2. That is, decentralisation is still better if the coordination loss is sufficiently small compared to the project's returns. Graph 3.4 shows the difference in performance for $\alpha = 2/3$ and $\alpha = 1$, where the (larger) upper plane represents the first case.

[6] The latter will play a larger role than the former in most of the later chapters, but the distinction is not that important for now.

[7] Ignoring θ close to 0 or 1 where the distribution of t is skewed for simplicity. One could assume that t is distributed such that the comparative statics are not affected.



Graph 3.4: $E\left[\pi^d\right] - E\left[\pi^c\right]$ for $\alpha = 2/3$ (upper plane) and $\alpha = 1$ (lower plane)

The following proposition summarises the tradeoff in a general way.

Proposition 3.2 *The principal prefers decentralisation if and only if*

$$DL > ML + CL,$$

where DL *is the deviation loss under centralisation,* ML *the motivation loss under decentralisation and* CL *the coordination loss under decentralisation. This is the case if the agent's decision making is sufficiently efficient compared to the principal's, and the project's returns are sufficiently high.*

This implies that decentralisation can also be the best option in a coordination problem if the agents can coordinate well enough (i.e. their decisions are efficient enough). It is reasonable to expect that this is the case as the agents care sufficiently about each other's payoff, and/or when the need for coordination is either very high or very low. As that need to coordinate grows larger, the agents work better together, and if it is very low, the penalty for not working together becomes very low. As especially chapter 5 shows, this intuition seems to hold pretty well.

3.5 Conclusions

The insights of this chapter are a stepping stone to the next chapters, but also have independent applications. The results so far show that the principal's incentive to induce effort from the agent under asymmetric information can be harmful to himself. For example, a firm's publicly visible decision to produce large quantities of a newly developed product can signal that the firm has private information about the market of the product's qualities that imply that the product will be a huge succes. This may draw investors, convince retailers to pre-purchase more and scare away competitors. The results of this chapter capture more examples that were mentioned in the introduction. Unlike in Bester and Krähmer (2008), decision making by the principal is less efficient than under delegation, as long as the agent's preferences are sufficiently aligned with the principal's and he is not otherwise unable to make efficient decisions.

When there is need for coordination between multiple agents or divisions, efficient decision making (from the principal's perspective) may not be possible under decentralisation. The model in this chapter was based on the assumption that the agent's preferences about decision making are equal to the principal's, but this assumption can be relaxed while leaving the key result intact. It is conceivable that letting the agent have different preferences would benefit decentralisation because the agent's motivation under centralisation would be reduced. The increased inefficiency of decision making by a biased agent under decentralisation is equivalent to the inefficiency that was already taken into account in section 3.4. The next chapter shows that decentralisation can indeed still be optimal in a model of coordination.

4 Coordination between two agents in an integer model

4.1 The coordination model

Let us now turn our attention to coordination between multiple agents. To do this, I use and modify the model of ADM. There is a firm with a headquarters (HQ) and two divisions, labelled 1 and 2. Both divisions are led by their own manager, so the game has three players: HQ, Manager 1 and Manager 2. At the beginning of the game, HQ must choose whether to centralise or decentralise its governance, which in the end is the decision of interest. After HQ makes its choice, Nature draws the state of the world $\theta = (\theta_1, \theta_2) \in \Theta^2$. The local states θ_1 and θ_2 are drawn independently from the same uniform distribution Θ, which is common knowledge.[8] That is, $\theta \sim U\left[\Theta^2\right]$. When the local states are drawn, they are revealed to HQ or the managers, depending on HQ's earlier choice. Under centralisation, HQ learns θ and the managers remain uninformed, and under decentralisation, the managers learn their own local state. In ADM, HQ can only allocate decision rights, and the local states are privately known by the managers (that is, only Manager i learns θ_i directly).

After θ is revealed, decisions are made for both divisions, possibly after communicating. The two decisions are denoted by $d = (d_1, d_2)$, and for clarity, decisions are restricted to Θ^2.[9] Under centralisation, HQ makes the decisions, which become common knowledge. That is, all players have complete information. Under decentralisation, the managers send each other a simultaneous cheap talk message $m_i \in \Theta$ about θ_i. After receiving the message from the other manager, each takes his decision d_i, which again becomes common knowledge. When decisions have been made, the agents can decide between contributing effort to the project and their outside option ω.

Like in ADM, the managers' payoff functions are a combination of the profitability of their own and the other Division. Their utility of the project is given by

$$U_i(d) = K - \lambda c_1 - (1-\lambda) c_2, \tag{4.1}$$

where c_i is the combination of the local adaptation and coordination costs. The latter are determined by the difference between the local decisions and multiplied by a parameter δ, which represents the relative importance of coordination. Let the local profits be given by

$$c_i(d) = (\theta_i - d_i)^2 + \delta (d_i - d_j)^2. \tag{4.2}$$

The managers choose their effort based on the expected returns of the project. Like in chapter 3, let

$$U_i(d, e_i) = e_i \left[K - \lambda c_1 - (1-\lambda) c_2\right] + (1-e_i)\,\omega \tag{4.3}$$

[8] At the end of chapter 5, I have to make stricter assumptions about Θ to avoid corner solutions.

[9] Imposing that $d \in \Theta^2$ ($D = \Theta$) rules out that HQ takes a decision that never is first-best to signal certain θ (i.e. a kind of money burning). For example, HQ could otherwise pick a d just outside of Θ^2 to signal that both θ_1 and θ_2 are close to a boundary of Θ.

map their utility, where K is the managers' private quasi-rent of the project. The managers' choice of effort is again binary and performance pay is impossible. The effort incentive constraint of the managers then is

$$e_i(d, \theta) = \underset{e_i \in \{0,1\}}{\arg\max} E[U_i(d, e_i) | d]. \tag{4.4}$$

Like in chapter 3, let $\omega = 0$, so that the managers exert effort if and only if $E[U_i(d) \geq 0]$.

Decision making by the managers is such that they maximise their utility of the project. Incentive pay is not possible, like in ADM. As a rule for the managers' decision making when they will not exert effort, I assume that they still make the decision that maximises $U_i(d)$. The managers still internalise a part of their utility from the project. That may well be the case if they cannot take their hands off the project completely. Choosing $e_i = 0$ then reflects that they minimise their engagement in the project, rather than pull out of it completely. This is captured by one additional assumption:

Assumption 5 *Under decentralisation, each manager makes the decision that maximises his utility of the project given the other manager's optimal decision.*

That is,

$$d_i(\theta) = \underset{d_i \in \Theta}{\arg\max} U_i(d_i, d_j(\theta)). \tag{4.5}$$

Headquarter's payoff consists of the combined profit of the divisions and the quasi-rents of effort:

$$\begin{aligned} \pi(d, e_1, e_2) &= (e_1 + e_2) K - c_1(d) - c_2(d) \\ &= (e_1 + e_2) K - (\theta_1 - d_1)^2 - (\theta_2 - d_2)^2 - 2\delta (d_1 - d_2)^2. \end{aligned} \tag{4.6}$$

Like in chapter 3, K can be seen as the quasi-rent of a manager's effort. To improve tractability, HQ's quasi-rent of effort equals that of the managers (that is, $\alpha = 1$). Note that it follows from proposition 3.1 that this favours centralisation.

ADM's original model uses a continuous support of Θ, but that has two serious drawbacks for my analysis. Firstly, there are very complex corner solutions, that make the model algebraically intractable. Secondly, the communication strategies of the managers are more complicated, which makes it impossible to analyse the managers' effort in a general way. Therefore, I start by assuming the support of Θ is $\{-1, 0, 1\}$. While making the model a bit crude at times, this assumption leaves the essential parts of the model intact, and allows it to be solved completely and in a tractable way. In chapter 5, I let the support of Θ be continuous, and show that the general results of chapter 3 and 4 hold.

The tradeoff between centralisation and decentralisation depends on the three factors that were identified in chapter 3: the deviation, coordination and motivation loss. In general, HQ has an incentive to 'overcoordinate' in order to hide that circumstances are bad. The managers value coordination relatively less than HQ, so they will *undercoordinate* under certain circumstances. This then causes a coordination loss, even if the managers' information is perfect (i.e. they communicate truthfully). The motivation loss is actually ambiguous throughout this chapter. For low K, the managers only exert effort if they have sufficient information. Because of that, the probability that they are motivated is often higher under decentralisation.

In the remainder of this chapter, I start by analysing centralisation, and then I analyse decentralisation and compare the two. The optimal decisions for HQ and the managers (i.e. how much they coordinate) depend on the parameters λ and δ. Therefore, I seperate two cases under centralisation and two under decentralisation. There is a bit of overlap when comparing those, but I will try to keep the analysis as clear as possible.

4.2 Centralisation

We start by analysing centralisation. To begin with, suppose that the managers always exert effort. HQ then makes the decision that is first-best from its own perspective, which is given by

$$d^* (\theta) \equiv \arg\min_d (c_1 + c_2) . \tag{4.7}$$

For $\delta \geq 1/2$, this decision always satisfies $d_1 = d_2$, because HQ puts more weight on perfect coordination than on local adaptation. For $1/8 < \delta < 1/2$, HQ will avoid $d_1 = -d_2$, but decide $d = \theta$ otherwise. Because the optimal decision rule changes at $\delta = 1/2$, we consider $\delta < 1/2$ and $\delta \geq 1/2$ seperately, starting with the former.

4.2.1 Local adaptation over coordination ($\delta < 1/2$)

Setting $\delta < 1/2$ resembles a situation where HQ values local success over coordination. It operates both divisions relatively independently, and its decision making is only different from complete independency if that would cause too heavy losses. To give a retailing example: it would let stores have different product lines based on the local market conditions, except if demand is too diverse. Another example would be that a car company allows its brands to make their own cars with their own specifications, but requires them to use the same chassis and engine. Building different interiors, using different suspension etc. would then represent a (relatively minor) '1-difference', whereas using a different chassis or engine would be a (major) '2-difference', because of heavy development costs and economies of scale. A '1-difference' is worth paying for because it increases sales, but a '2-difference' is too big to be compensated by a higher demand.

HQ's first-best decisions are given by

$$d^* (\theta_1 \neq -\theta_2) = (\theta_1, \theta_2) \tag{4.8}$$

and

$$d^* (1, -1) = \begin{cases} (1, 0) \\ (0, -1) \end{cases} \tag{4.9}$$

where $\theta = (1, -1)$ represents orthogonal local states. HQ only coordinates if the difference between the divisions is too big. To save on notation and make the analysis a bit more tractable, I focus on $\theta_1 = 0$ and $\theta_1 = 1$ and pick θ_2 according to my needs. This covers all possibilities, since the model is symmetrical.

If Manager 1 would exert effort for $d = (0, 1)$, decision making in equilibrium is first-best. To see this, note that no other d yields a lower expected utility, so HQ never has to deviate to induce effort. The fact that $d_1 \neq d_2$ means that $c_i \geq \delta$, and the fact that $d_1 = 0$ opens the possibility that $\theta = (-1, 1)$, in which case Division 1 also suffers a local adaptation loss. If HQ mixes its decisions from 4.9 with equal probability, we have that $E [U_1^c (0, 1)] = K - \delta - \lambda/3$. Hence, if $K < \bar{K}$ where $\bar{K} \equiv \delta + \lambda/3$, Manager 1 would not exert effort for $d = (0, 1)$. This gives HQ an incentive to deviate from its first-best decision rule, and set $d_1 = d_2$ even if it is not optimal. It does so with positive probability if and only if $K > 1 - 2\delta$. Deviating from the first-best decision rule could represent a firm pretending to have large synergies, while in fact, it does not. To turn back to our car manufacturer example, it could decide to impose drastic standardisation to convince investors that its brands are complementary, while in fact, they are not so much and it would have been better to let each brand develop its own car. Pretending to have synergies is obviously attractive, as it can drawn investments and drive up stock prices.

Returning to the model, consider HQ's devation strategy. When $\theta = (1, 0)$ or $(0, 1)$, HQ can choose to deviate to $(0, 0)$ or $(1, 1)$. When $\theta = (1, -1)$ or $\theta = (-1, 1)$, it can deviate to $(0, 0)$.

Deviating to $d = (1, 1)$ then (weakly) dominates deviating to $(0, 0)$ when $\theta = (1, 0)$ (or $(0, 1)$). To see this, first note that even if HQ only deviates to $(0, 0)$ if the states are orthogonal, the probability that $d = (0, 0)$ is a deviation is equal to the probability that $d = (1, 1)$ is a deviation (i.e. there is one θ for which it is optimal and two for which it is a deviation). Secondly, deviations to $(0, 0)$ imply a lower expected utility, because there is a double local adaptation loss. We therefore have that $E[U_i(1, 1)] \geq E[U_i(0, 0)]$, and we can establish the following lemma.

Lemma 4.1 *Suppose that $\delta < 1/2$. Under centralisation, HQ deviates from its first-best decision with positive probability for some θ if and only if $1 - 2\delta \leq K < \bar{K}$, where $\bar{K} = \delta + \lambda/3$. If $K > 1 - 2\delta$, HQ mixes deciding $d(1, 0) = (1, 1)$ and $d(1, 0) = (1, 0)$ with $p_a \equiv \Pr(1, 1)$, and mixes $d(1, -1) = (0, 0)$ and $d(1, -1) = (1, 0)$ with $p_o \equiv \Pr(0, 0)$.*

We then have that

$$E[U_i(1, 1)] = K - \frac{p_a}{1 + 2q_a} \tag{4.10}$$

and

$$E[U_i(0, 0)] = K - \frac{2p_o}{1 + 2p_o}. \tag{4.11}$$

If $K \geq 2/3$, the managers exert effort for any identical decision with any p, and so $p_a = p_o = 1$. As we will see later on, the outcome is then the same as with $\delta \geq 1/2$, because HQ coordinates perfectly. This is obviously not first-best here, since HQ deviates from its optimal decision rule with a high probability.

If $K \in \left[\frac{1}{3}, \frac{2}{3}\right)$ the managers always exert effort for $d = (1, 1)$, so we have that $p_a = 1$. HQ's mixing strategy p_o must be such that $E[U_i(0, 0)] = 0$, which gives

$$p_o = \frac{K}{2 - 2K}. \tag{4.12}$$

In that case HQ must be indifferent between the first-best decision and deviating. This is the case if and only if managers mix exerting effort for $\theta = (0, 0)$ such that HQ is exactly indifferent. Their mixing strategy with $r \equiv \Pr(e_i(0, 0) = 1)$ is

$$r = \frac{1 - 2\delta}{2K}. \tag{4.13}$$

Similarly, for $K \in \left[0, \frac{1}{3}\right)$, we have that

$$p_a = \frac{K}{1 - 2K}, \tag{4.14}$$

and the managers mix exerting effort for $d = (1, 1)$ with $\Pr(e_i(1, 1) = 1) = r$ as well. The following proposition summarises the equilibria of the game.

Proposition 4.1 (Centralisation with low δ) *Suppose that decision making and information are centralised, and that $\delta < 1/2$. HQ's expected profit is as in table 1.*[10]

1. *If $K < 1 - 2\delta$, decision making is first-best, but the managers do not always exert effort.*

[10] Conditional on intervals existing.

2. *If $K \in \left[1-2\delta, \bar{K}\right)$, HQ deviates from its first-best decision rule with non-zero probability, and the managers mix exerting effort for some decisions.*

3. *If $K \geq \bar{K}$, decision making is first-best and the managers always exert effort, and HQ (weakly) prefers centralisation.*

Table 1: Expected profit under centralisation

K		$E\left[\pi^c\right]$
From	To	
0	δ	$\frac{6K-2-12\delta}{9}$
δ	$1-2\delta$	$\frac{10K-2-12\delta}{9}$
$1-2\delta$	$\frac{1}{3}$	$\frac{1}{9}-2\delta$
$\frac{1}{3}$	$\frac{2}{3}$	$\frac{12K-5-6\delta}{9}$
$\frac{2}{3}$	$\delta+\lambda/3$	$2K-\frac{8}{9}$
$\delta+\lambda/3$	1	$2K-\frac{2+12\delta}{9}$

The plentiness of scenario's in table 1 may seem overwhelming, but all scenario's are actually based on two things: HQ's willingness to deviate and the managers' willingness to exert effort. What we see is that HQ's decision making is first-best if its quasi-rent of the managers' effort is so low that it does not want to deviate, and also if the managers' own quasi-rent of the project is so high that they always exert effort (I refer to these situations as 'low K' and 'high K'). In all cases inbetween ('moderate K'), HQ's incentive to induce effort reduces the efficiency of its decisions. For low and moderate K, decentralisation may be optimal. In the first case, the managers exert more effort if they can credibly learn when the state of the world is good ($\theta_1 = \theta_2$). In the second case, their decision making may also be more efficient. We will see this later on in the analysis of decentralisation.

4.2.2 Coordination over local adaptation ($\delta \geq 1/2$)

If $\delta \geq 1/2$, it is always best to coordinate decisions perfectly.[11] To illustrate this, let us use the car manufacturer example once again. Suppose that it is optimal to use the same basis for all cars. The different brands may then not know how well the design is suited to them (or rather to their fellow brands). Since HQ's decision is not very informative, it may be met with skepticism by the brand managers, who are not sure how well the design will work for them. It could then be better to let the brand managers decide on a design together, because they will know what they are in for.

In the model, a high need for coordination means that d^* always satisfies $d_1 = d_2$. Under centralisation, decision making can therefore be cloudy in the sense that HQ's decisions do not reveal much about the state of the world. Intuitively it can be expected that it may be more important to let the managers be informed if their expected returns are low on average. It can then be necessary to allow them to draw their own conclusions, and cherry pick and exert effort only when conditions are optimal.

[11] This leaves little room for deviating, which is a small drawback of the integer model. As we will see in chapter 5, $\delta \geq 1/2$ actually causes heavy overcoordination when the action space is continuous.

For identical states, HQ's decision is simple;

$$d^* (\theta_1 = \theta_2) = (\theta_1, \theta_2). \tag{4.15}$$

For orthogonal states the first-best decision is in the middle,

$$d^* (1, -1) = (0, 0), \tag{4.16}$$

and for different but adjacent states there are two first-best decisions:

$$d^* (1, 0) = \begin{cases} (1,1) \\ (0,0) \end{cases}. \tag{4.17}$$

Let HQ's strategy be to play $d(\theta) = d^*(\theta)$ and to mix $d(1,1) = (1,1)$ and $d(1,0) = (0,0)$ with probability $q \equiv \Pr(1,1)$. Using Bayes' rule, we get

$$E[U_i(1,1)] = K - \frac{q}{1+2q} \tag{4.18}$$

and

$$E[U_i(0,0)] = K - \frac{4-2q}{7-4q}. \tag{4.19}$$

HQ chooses q to maximise the probability that the managers exert effort, $e_i(d,q) = 1$:

$$q = \arg\max_q [q e_i(1,1,q) + (1-q) e_i(0,0,q)]. \tag{4.20}$$

We have that $E[U_i(1,1)] > E[U_i(0,0)]$ for all q. Clearly, 'extreme' decisions are a better sign than a 'moderate' one, because the latter can be a sign of clashing interests. If Manager 1 would exert effort for $d_1 = 1$ but not for $d_1 = 0$, then $d = (1,1)$ strictly dominates $d = (0,0)$ for $\theta = (1,0)$, and hence $q = 1$. This is the case if $\max_q E[U_i(0,0)] < 0 \leq \max_q E[U_i(1,1)]$, i.e. $K \in \left[\frac{1}{3}, \frac{4}{7}\right)$. If the project's returns are too low ($K < 1/3$), the managers never exert effort. On the other hand, if the project is sufficiently profitable ($K \geq 4/7$), HQ can choose $q \leq (7K-4)/(4K-2)$ such that the Manager always exerts effort. In that case, centralisation is (weakly) optimal.

Table 2: Optimal p

K		q
From	To	
0	$\frac{1}{3}$	$\in [0,1]$
$\frac{1}{3}$	$\frac{4}{7}$	1
$\frac{4}{7}$	$\frac{2}{3}$	$\leq \frac{7K-4}{4K-2}$
$\frac{2}{3}$	1	$\in [0,1]$

In any case, decision making is first-best. Suppose that $K \in \left[\frac{1}{3}, \frac{4}{7}\right)$, so HQ would like to avoid $d = (0,0)$. If it does so by playing $(1,0)$ for $\theta = (1,-1)$, the agents infer θ, and their utility of the project is strictly negative. Playing $(1,1)$ for $\theta = (0,0)$ would be too costly ($2K < 2$), so HQ has no reason to deviate from its first-best decision rule. The following proposition summarises the outcomes.

Proposition 4.2 (Centralisation with high δ) *Suppose that decision making and information are centralised, and that $\delta \geq 1/2$. Decision making is always first-best and the expected profit is as in table 3.*

1. *If $K < 1/3$, the managers never exert effort.*
2. *If $K \in \left[\frac{1}{3}, \frac{4}{7}\right)$, the managers exert effort except if $d = (0, 0)$.*
3. *If $K \geq 4/7$, HQ can steer to equilibria in which the managers always exert efforts, and HQ (weakly) prefers centralisation.*

Table 3: Expected profit under centralisation

K		$E[\pi^c]$
From	To	
0	$\frac{1}{3}$	$-\frac{8}{9}$
$\frac{1}{3}$	$\frac{4}{7}$	$\frac{12K-8}{9}$
$\frac{4}{7}$	1	$2K - \frac{8}{9}$

The results here, without deviating, are similar to those for $\delta < 1/2$. For low K, decentralisation may be better because the managers only want to exert effort when they know that the circumstances are good. For high K, there is no reason not to centralise. We now turn our attention to decentralisation in order to compare the two regimes.

4.3 Decentralisation

Under decentralisation, three things can be expected intuitively. Firstly, the managers may not always make the first-best decisions, because they value coordination less than HQ. Secondly, they each have imperfect information when they learn θ_i, and their communication may not always reveal the complete state of the world truthfully. These two things can lead to a coordination loss. Thirdly, the managers get more information than under centralisation, so they are better able to distinguish the cases in which they want to exert effort (or not).

4.3.1 Communication strategies

If information and decision making are decentralised, the managers have reason to coordinate their decisions to a certain degree, since their interests are at least partly aligned. In any case, it is in their mutual interest to avoid orthogonal decisions. If they value coordination more than local adaptation ($\delta > \lambda$), it is even in their interest to avoid dissimilar decisions altogether. In either case, the managers (simultaneously) send each other a message that maximises their expected payoff. This may mean that the managers try to influence each other by exaggerating their situation. Formally, Manager i's messaging strategy is

$$m_i(\theta_i) = \underset{m_i}{\arg\max} E\left[U_i^d(d) | \theta_i\right], \tag{4.21}$$

taking into account that

$$d_j(\theta_j, m) = \underset{d_j}{\arg\max} E\left[U_j^d(d) | \theta_j, m\right]. \tag{4.22}$$

For ‘extreme’ conditions, $\theta_i = 1$ and $\theta_i = -1$, there is no reason not to communicate truthfully while there is a benefit of coordination, so we assume that $m_i(1) = 1$ (thus ignoring babbling equilibria). It may, however, not be smart to reveal that local conditions are ‘average’, because that tells the other manager that the cost of taking an ‘extreme decision’ is limited. It could be better to exaggerate to convince the other manager to make a moderate decision to avoid a potential heavy coordination penalty. That is, $m_i(0) = 0$ can only be optimal if there is a positive probability that this message will change the other manager’s decision from $d_j \neq 0$ to $d_j = 0$.Otherwise, sending $m_i(0) = 0$ can be dominated by $m_i(0) = (-)\,1$, since that may convince the other manager to decide $d_j = 0$ when $\theta_j = -m_i$. It is straightforward to see that this is the case if $\lambda > \delta > 1-\lambda$, i.e. if the managers prefer local adaptation over coordination if their states are adjacent. For $\delta > \lambda$, the manager always value coordination over local adaptation, which means that they are able to tell the truth and cooperate, as we will see. We will first analyse this case and then turn attention to $\lambda > \delta$.

4.3.2 Local adaptation over coordination ($\delta < \lambda$)

If $\lambda > \delta$, the managers attach more weight to local adaptation than to coordination. Their incentive to coordinate is limited, and a predictable pattern under decentralisation is that the managers will often choose adaptation over coordination. That is problematic for HQ if it would like to see perfect coordination. Decentralisation with second-best decision making may still be better than centralisation with first-best decision making, but only if it is important to inform the managers about their payoff.

Since the managers only want to coordinate if their states are orthogonal, $m_1 = 0$ does not influence Manager 2’s decision in any case: it will then unavoidably be $d_2 = \theta_2$. However, receiving $m_1 = 1$ may induce him to decide $d_2 = 0$ if $\theta_2 = -1$, to avoid a big coordination loss. This would be beneficial for Manager 1 (if $\delta > 1-\lambda$), so sending $m_1(0) \neq 0$ may then dominate $m_1(0) = 0$.

If $\delta < 1-\lambda$, the managers value adaptation in the other division over coordination, and they message truthfully. Decision making is then first-best if $\delta \leq 1/2$. If $K > \delta$, the probability that the managers are motivated is then also strictly higher than under centralisation. It is clear that decentralisation then outperforms centralisation: it avoids a deviation loss, it increases motivation and there is no coordination loss.

The question when $\delta \in [1-\lambda, \lambda)$ is whether Manager 2’s decision can be influenced at all. When $m_1 = m_2$, Manager 2’s optimal decision is obviously $d_2 = \theta_2$. When m_1 and m_2 are orthogonal, the decision making subgame resembles a classic chicken game. In equilibrium, either one manager always caves (and strategies are pure) or the managers both mix their response. If strategies are mixed, the managers both mix $d_i = \theta_i$ and $d_i = 0$ for $m_1 \neq m_2$. While the pure equilibrium is *ex ante* pareto superior and it is reasonable to assume that the managers try to coordinate on that, it appears that it does not always exist. Also, the mixed equilibrium has the attractive features (with one eye already on the continuous model) that it is entirely symmetric and not completely efficient.

Pure strategies equilibrium To maintain some symmetry between the managers, we consider a pure equilibrium where the caving manager is selected based on the messages they sent (and hence on Nature’s draw of θ). Suppose that when $m_1 = -m_2$, the manager who sent $m_i = 1$ plays $d_i = \theta_i$ and the manager who sent $m_j = -1$ plays 0. This makes is strictly dominant to send $m_i = 1$ for $\theta_i = 0$, and we have that $\Pr(\theta_1 = 1|m_1 = 1) = \Pr(\theta_1 = 0|m_1 = 1) = 1/2$.

Manager j then optimally decides $d_j = 0$ if

$$\lambda + \frac{1}{2}\delta < \frac{1}{2} \cdot 4\delta + \frac{1}{2}\delta,$$

i.e. $\delta > \lambda/2$. If $\delta < \lambda/2$, pure strategies do not work and the equilibrium is mixed.

Mixed strategies equilibrium Now consider mixing. If Manager 1 mixes $m_1(0) = -1$ and $m_1(0) = 1$ with equal probability, Manager 2's beliefs are given by $\Pr(\theta_1 = 1|m_1 = 1) = 2/3$ and $\Pr(\theta_1 = 0|m_1 = 1) = 1/3$. If Manager 1's local state is 0, he always plays $d_1(0, m_2) = 0$. In an equilibrium where decisions are mixed, let his strategy for $\theta_1 = 1$ and $m_2 = -1$ be to mix $d_1(1, -1) = 1$ and $d_1(1, -1) = 0$ with $v \equiv \Pr(d_1(1, -1) = 1)$. If he mixes, he must be indifferent between these two decisions. Moreover, if $\theta_2 = -1$, Manager 2 should be indifferent and mix his strategies as well, since otherwise Manager 1 would not be indifferent. Since we have that $\Pr(\theta_2 = -1|m_2 = -1) = 2/3$ and Manager 2 mixes his response with the same probabilities as Manager 1 in that case, Manager 1 is indifferent if

$$\lambda + \frac{2}{3}(v\delta + (1 - v)(1 - \lambda)) = \frac{2}{3}(4v\delta + (1 - v)(\delta + 1 - \lambda)) + \frac{1}{3}\delta,$$

and solving this gives

$$v = \frac{3(\lambda - \delta)}{4\delta}. \tag{4.23}$$

We can now state the following proposition.

Proposition 4.3 (Decentralisation and performance for $\lambda > \delta$) *Suppose that $\lambda > \delta$ and $K < \bar{K}$. HQ (weakly) prefers decentralisation for given λ, δ if K is not too high.*

I. Pure equilibrium *In a pure decentralisation equilibrium the managers coordinate their response to orthogonal messages. This equilibrium exists if and only if $\delta > \lambda/2$. The expected costs are then*

$$E\left[c_1^d + c_2^d\right] = \frac{4 + 8\delta}{9}, \tag{4.24}$$

and the ex ante probability that manager i will exert effort is at least $2/3$ if $K > \delta$. For all $\lambda > \delta$, there exist K, λ, δ such that decentralisation strictly dominates centralisation:

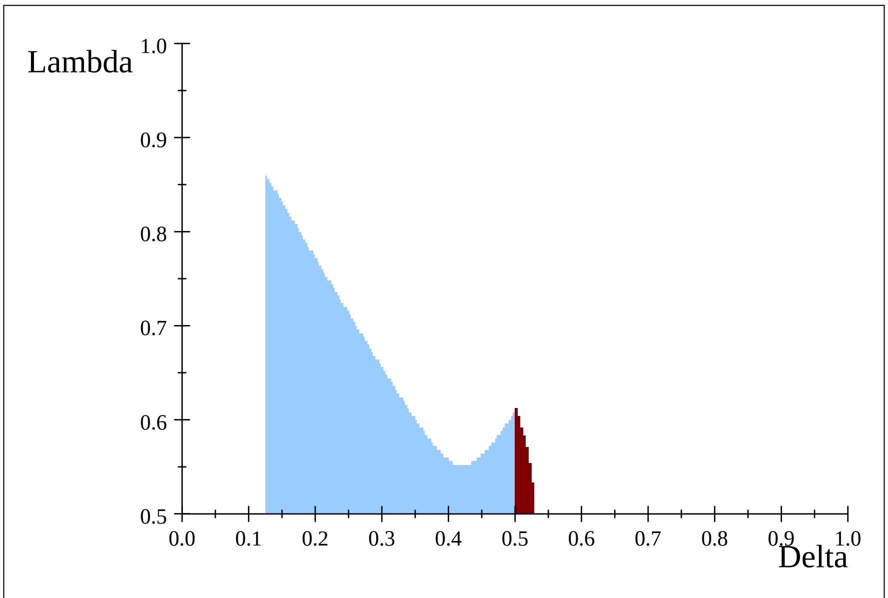
1. *If $\lambda > \delta \geq 1/2$, decentralisation is better if and only if K is not too low and not too high. That is, if*
   - *(a) $K \in \left[\frac{4\delta - 2}{3}, \frac{1}{3}\right)$ or*
   - *(b) $K \in \left[\lambda, \frac{2}{3}\right)$ and $\delta \to 1/2$.*
2. *If $\lambda > 1/2 > \delta$, the performance of both forms is the same for $K < \delta$, and decentralisation is strictly optimal for all $K \in \left[\frac{1}{3}, \bar{K}\right)$.*

II. Mixed equilibrium *In a mixed equilibrium the managers coordinate imperfectly. The expected costs are then*

$$E\left[c_1^d + c_2^d\right] = \frac{9\left(\lambda^2 - \lambda\right) - \delta^2 + 21\delta}{18\delta}, \tag{4.25}$$

and the probability that the managers exert effort depends on the probability that they coordinate sufficiently, which increases in δ and K and decreases in λ. For $K > \delta$, the probability of effort is at least $2/3$. Decentralisation still outperforms centralisation for sufficiently low λ and δ and moderate K.

This proposition gives a first part of the answer to my main question: decentralisation of information can be optimal when coordination is required if the agents' incentive to exert effort is not too strong. In other words, it confirms the intuition that decentralisation can be (weakly) optimal if K is not too high. The coordination loss under decentralisation can be outweighed by the deviation loss under centralisation (the role of motivation is ambiguous, but the result holds in cases where motivation is equal). This confirms and complements the result of chapter 3. The inequality plot is slightly inaccurate because it underestimates the probability of effort under decentralisation for some δ, λ, but even so it illustrates that there exist K, λ, δ such that decentralisation is the better option.[12]



Graph 4.1: Rough indication of $E\left[\pi^d\right] \geq E\left[\pi^c\right]$ with mixing for $\{\delta < 1/2, K \rightarrow \delta + \lambda/3\}$ (blue) and $\{\delta \geq 1/2, K \rightarrow 4/7\}$ (red)

4.3.3 Coordination over local adaptation ($\delta \geq \lambda$)

If $\delta \geq \lambda$, the managers would like to coordinate their decisions perfectly, so their incentives are perfectly aligned. Hence, they have reason to communicate their local state truthfully. There are three kinds of equilibrium candidates: truthtelling (perfect communication) with perfect coordination, truthtelling with imperfect coordination (mixing), and bluffing (imperfect communication, i.e. where $m_i(0) \neq 0$). If the first of the three can be sustained, it is reasonable to assume that the managers coordinate on that to avoid imperfect coordination and bluffing (which are inefficient).

In fact, it can be shown that truthtelling is only possible if coordination is perfect (i.e. strategies are pure). If truthtelling is to be an equilibrium strategy, there can be no reason to bluff if $\theta_i = 0$. This is the case if and only if the managers always 'cave' when their state is not zero and they learn that the other state is. Given that the other Manager's strategy is to decide 0 if $\theta_i = 0$, caving is optimal. That is, $d_1(1,0) = 0$.

If coordination is imperfect, the managers mix their response to $m_j = 0$. This uncertainty reduces the benefit of truthful communication to an insufficient level. It is then better to try to steer the other Manager rather than rely on his imperfect cooperation.

[12] The plot is inaccurate where both $\delta < 1/2$ and $\frac{\lambda}{3} > \frac{1-v}{2-v}(1-\lambda)$.

Lemma 4.2 *Suppose that $\delta \geq \lambda$. Under decentralisation, truthtelling can be sustained in equilibrium if and only if the managers coordinate their decisions perfectly. Decisions are then first-best and costs are the same as under centralisation.*

Proof. Suppose that communication is perfect, i.e. $m_i(\theta_i) = \theta_i$ for all $\theta_i \in \Theta$. If the managers do not coordinate their decisions perfectly but mix their response to $m_j = 0$, they must be indifferent between sticking to their own state and adapting to the other Division's state if $\theta_i = \theta_j \pm 1$. In equilibrium, Manager 2's belief about Manager 1's strategy must be such that

$$E\left[U_2^d(0)\,|\theta = (0,1), w\right] = E\left[U_2^d(1)\,|\theta = (0,1), w\right],$$

where $w \equiv \Pr(d_1 = 0|\theta = (0,1))$. Solving

$$-\lambda - (1-w)(1-\lambda+\delta) = -w\delta - (1-w)(1-\lambda)$$

gives $w = (\lambda+\delta)/2\delta$. Manager 1's expected payoff of $m_1(0) = 0$ is then

$$E\left[U_1^d(m_1 = 0)\,|\theta_1 = 0\right] = -\frac{\lambda^2 - \lambda + \delta^2 + \delta}{3\delta}.$$

His alternative is to lie and message $m_1(0) = 1$ (or its equivalent -1). If $m_1 = m_2$, Manager 2 will decide $d_2 = m_2$. In that case, Manager 1 should play $d_1 = m_1$ since $\delta \geq \lambda$. If $m_2 = 0$, Manager 1 optimally plays $d_1 = 0$ since $x \geq 1/2$. If $m_2 = -m_1$, Manager 1 and 2 both play $d_2 = 0$. Each scenario happens with equal probability, so Manager 1's expected payoff of lying is

$$E\left[U_1^d(m_1 = 1)\,|\theta_1 = 0\right] = -\frac{1}{3}\left(\frac{3}{2} + \frac{\lambda^2 - \lambda + \delta^2}{2\delta} - \lambda\right).$$

Lying then dominates telling the truth, as $E\left[U_1^d(m_1 = 1)\,|\theta_1 = 0\right] > E\left[U_1^d(m_1 = \theta_1)\,|\theta_1 = 0\right]$ for all $\delta \geq 1/2$. Therefore, truthtelling can only work if coordination is perfect, i.e. strategies are pure. ■

Table 4: Perfect communication equilibrium

θ_i	θ_j	d_i	$U_i(d)$	Likelihood
any	θ_1	θ_1	0	$1/3$
$-1 \vee 1$	$-\theta_1$	0	-1	$2/9$
$-1 \vee 1$	0	0	$-\lambda$	$2/9$
0	$-1 \vee 1$	0	$-(1-\lambda)$	$2/9$
Expectation			$-4/9$	

Suppose that the managers indeed coordinate on the truthtelling equilibrium. Since their decision making is then first-best, decentralisation is better for all $K < 1/3$, because there is a positive probability that the managers exert effort. For $\lambda \leq K < 4/7$, decentralisation dominates centralisation *ex ante* and *ex post* as well because there is a higher probability that the managers are motivated. For $K \geq 4/7$ centralisation is better because effort is exerted more often. It is then in the interest of HQ to let the managers not be perfectly informed, because that enables them to withdraw whenever the circumstances are unfavourable.

Proposition 4.4 (Decentralisation and performance for $\delta \geq \lambda$) *Suppose that $\delta \geq \lambda$. HQ prefers decentralisation if and only if the project's returns are sufficiently small ($K < 1/3$ or $K \in \left[\lambda, \frac{4}{7}\right)$) and the managers coordinate perfectly.*

Proposition 4.4 repeats the gist of proposition 4.3: for moderate K, HQ prefers decentralisation. The drivers behind this result are slightly different. For $\delta \geq 1/2$, HQ never deviates from its optimal decision path, but still decentralisation can be better. The effect we see here is purely caused by the fact that the managers are better informed and therefore more often willing to exert effort, because they are able to cherry pick the best cases. If that is necessary for them to be motivated, then decentralisation is better. A necessary condition for this result is that decision making under decentralisation is first-best, but such an equilibrium exists and is reasonably stable.

4.4 Conclusions

I can now answer my main question: decentralisation can indeed be better than centralisation if the project's payoff for the agents is not too high. This result has two major drivers. The first is that if the project's returns are low, the managers cannot be convinced to participate if they do not have accurate information about the costs. The average costs are then too high. The second driver is that HQ's incentive to deviate reduces efficiency. If the managers are able to coordinate on the first-best decision rule, decentralisation then also has the benefit that decision making is more efficient. Even if the managers do not always follow the first-best decision rule (but mix) decentralisation can outperform centralisation, because decision making is still more efficient. Another disadvantage of centralisation can be that while HQ's deviation strategy creates a positive probability that effort is exerted for some θ for which the managers would not exert effort if they were fully informed, the same strategy decreases the probability that they exert effort for some θ for which they would exert effort with perfect information (e.g. $d = (0, 0)$).

The result that the managers require exact information to exert effort for low K is a consequence of choosing an integer model. A similar result would have been obtained in chapter 3 for low values of α, but the question is whether it also holds in a continuous version of the coordination model. That, and the fact that almost all literature allows for a continuous decision space, are the motivations for the next chapter, in which I extend the model to a continuous version like in ADM.

5 Coordination in a continuous model

5.1 Introduction

The results of the previous two sections were obtained under specific assumptions. In the 'full', continuous model that resembles ADM, the result from chapter 3 that deviating is effective but decreases HQ's expected profit does not always hold. However, the result from chapter 4 that decentralisation can be better if the project's payoff is not too high holds.

The continuous model is the same as the one discussed in the last chapter, except of course for the fact that Θ is a continuous interval. Following ADM, let Θ be a continuous, compact range from $-s$ to s, so that $\theta_i \sim U[-s, s]$. For expositional simplicity, I assume that $s = 1$.[13] Analysing the continuous model still is a bit more complicated than the integer model, though. First of all, messaging under decentralisation becomes much more complex, and ADM show that it closely resembles the equilibrium in Crawford and Sobel (1982). Secondly, the managers' inferences from HQ's decisions become hard to capture at the boundaries of Θ. Therefore, it is useful to start

[13] The size of the support matters for the quantitative results if $\lambda > 1/2$. A larger support then favours centralisation, because the inefficiency of decentralisation is amplified. However, the qualitative results remain largely unchanged.

with the simplifying assumption that the states of the world are perfectly correlated: $\theta_1 = -\theta_2$. This assumption is dropped at the end of the chapter.

Assumption 6 *The states of the world are perfectly correlated and can be denoted by* $\theta \equiv \theta_1 = -\theta_2$*, where* $\theta \sim U[0,1]$.

This assumption has another useful property: all payoffs, for any θ, are a function of the absolute difference between the local states (as will be shown later on). By considering $\theta_1 = -\theta_2$ for $\theta_1 \in [0, s]$, we cover all possible $|\theta_1 - \theta_2|$. Hence, once the model is solved for $\theta_1 = -\theta_2$, the solution of an uncorrelated model under centralisation is not far away. Ignoring corner solutions, all that needs to be done is to attach probabilities to the possible outcomes (as larger $|\theta_1 - \theta_2|$ occur less often).

Assuming correlation is almost equivalent to assuming that the managers learn both local states under decentralisation. We can thus set a benchmark based on perfect information under decentralisation, which isolates the coordination loss. A limitation to the stand-alone meaning of the correlated model is that under the revelation principle, the managers could (and should) share their information truthfully with HQ, so that it can make the first-best decision. Neither of the managers has an incentive to lie, because by exaggerating their own state, they also exaggerate the other. However, firstly, the correlated model is a means to an end to gain insight in an uncorrelated world. Secondly, the qualitative results of the model hold if it is interpreted such that the managers both learn θ, but there is no pre-determined relation between θ_1 and θ_2. That is, the managers have perfect information but are unable to share it accurately with HQ (as in ADM).

Eventually, I am able to obtain some comparative statics in the continuous model under the assumption that the managers know the size of Θ, but not its exact boundaries. This seems like a serious limitation, and in a way, it is. However, ignoring corner solutions allows me to test the intuitions of chapter 3 and 4. Based on the 'botched' results I am also able to make some inferences about the comparative statics when Θ is common knowledge.

5.2 Analysis

Suppose that $\theta_1 = -\theta_2$. Since θ_1 and θ_2 are perfectly correlated, we can save on notation by denoting the state of the world with $\theta \equiv \theta_1$. We focus attention on Manager 1, who will be referred to as 'the Manager', and $\theta \geq 0$. From (4.6), we get that HQ's first-best decision is

$$d_1^*(\theta) = \frac{\theta}{1+4\delta} = -d_2^*(\theta), \tag{5.1}$$

and given that $d = d^*(\theta)$, the costs in one division are

$$c_i(\theta, d^*) = \frac{4\delta}{1+4\delta}\theta^2. \tag{5.2}$$

The project's returns K are assumed to be such that the Manager's effort incentive constraint is not satisfied for all $d_1^*(\theta)$, so $K < 4\delta/(1+4\delta)$.

The equilibrium under centralisation is similar to that in the model in chapter 3. The Manager will exert effort for all $d_1 \leq X$ and HQ will deviate to X for all $\theta \in [x, y]$, where $X \equiv d_1^*(x)$. Solving $\pi^c(x, 1) = \pi^c(y, 0)$ gives

$$y = x + \sqrt{(1+4\delta)K} \tag{5.3}$$

for all $x \leq 1 - \sqrt{(1+4\delta)K}$, and $y = 1$ otherwise. In the former case, solving $E[U_1^c(x)] = 0$ gives

$$x = \left(\sqrt{\frac{2-\delta}{3\delta}} - 1\right)\frac{\sqrt{(1+4\delta)K}}{2}. \tag{5.4}$$

We can then see that $x \leq 1 - \sqrt{(1+4\delta)K}$ is true for $K \leq \hat{K}$, where

$$\hat{K} = \frac{4}{(1+4\delta)\left(\sqrt{\frac{2-\delta}{3\delta}} + 1\right)^2}. \tag{5.5}$$

Such K exists if $\hat{K} \leq 4\delta/(1+4\delta)$, which is true if and only if $\delta > \hat{\delta}$, where $\hat{\delta} \approx 0.036$ is defined in the appendix. To simplify the analysis, assume that $K < \hat{K}$ and $\delta > \hat{\delta}$. In general, centralisation becomes more attractive as K is higher than $\hat{K}$, because the cost of deviating goes down, as y reaches its upper limit. This result is similar to what we saw in chapter 4: for high K, the managers are more willing to accept uncertainty, and centralisation becomes relatively better.

At the opposite side, we require $x \geq 0$. This is satisfied for all $\delta \leq 1/2$. For $\delta > 1/2$, equation 5.4 has no positive solution and we have that $x = 0$. Because the Manager must be indifferent for $x = 0$, y should then be closer to x. This implies that the Manager mixes exerting effort for $d_1 = 0$ so that HQ is indifferent about deviating for a lower θ, such that the Manager is indifferent about exerting effort for $d_1 = 0$. Hence, the Manager's strategy under centralisation is mixed for all $\delta > 1/2$. The intuition behind this is easy to see: if the need for coordination is low, deviating is relatively costly for HQ, which makes it effective. If the need for coordination is higher, deviating becomes cheaper, so HQ will deviate for more unfavourable values of θ. This decreases the expected payoff for the Manager, making him indifferent about the project at best. Note that this seems the opposite of what we saw in the last chapter, where HQ only deviated for $\delta < 1/2$. This is because overcoordination is not possible in the integer model. However, in the continuous version, it certainly is.

Parameters such that the agent would mix exerting effort were left out in chapter 3, because they only made centralisation worse. The same cannot be said here beforehand, since a higher δ also increases the coordination loss under decentralisation. We will therefore analyse both pure and mixed equilibria, starting with the former.

5.2.1 Pure equilibrium

Combining (5.3) and (5.4) yields the θ from whereon effort will be exerted in a pure equilibrium if $K \leq \hat{K}$ and $\delta < 1/2$:

$$y = \left(\sqrt{\frac{2-\delta}{3\delta}} + 1\right)\frac{\sqrt{(1+4\delta)K}}{2}, \tag{5.6}$$

which is larger than it would be if HQ did not deviate: $y \geq \sqrt{(1+4\delta)K/4\delta}$. Like in the one-agent model of chapter 3, deviating is effective if strategies are pure, and deviating for some d_1^* is always part of HQ's strategy in equilibrium. If $\delta \leq 1/2$ and $K \leq \hat{K}$, the *ex ante* probability that HQ deviates is given by

$$\Pr\left(\theta \in [X^c, Y] \,|K < \hat{K}\right) = \sqrt{(1+4\delta)K}. \tag{5.7}$$

Deviation becomes more likely as K increases and as the need for coordination does up. The intuition behind the former observation is obvious. The reason for the latter is that as the incentive to coordinate increases, setting d_1 closer to 0 (and hence d_2) becomes relatively less costly.

5.2.2 Mixed equilibrium

The Manager mixes exerting effort if HQ values coordination over local adaptation and the project payoff is not high enough to compensate for that ($\delta > 1/2$ and $K < 1/3$). If the Manager mixes, he is indifferent about exerting effort. Solving $E\left[U_1\left(0\right)|y\right] = 0$ gives

$$y_m = \sqrt{3K}. \tag{5.8}$$

In the equilibrium, the Manager exerts effort with probability $p \equiv \Pr\left(e_1 = 1|d_1 = 0\right)$ such that HQ is indifferent about deviating to zero and playing d_1^* for $\theta = y$. Solving $p\pi\left(0,1\right) + \left(1-p\right)\pi\left(0,0\right) = \pi\left(y,0\right)$ yields $y = \sqrt{\left(1+4\delta\right)pK}$, so we have that

$$p = \frac{3}{1+4\delta}. \tag{5.9}$$

The probability that deviating will work is inversely related to its cost, but it follows from y_m that deviation is equally likely for any $\delta > 1/2$. Hence, the effectiveness of deviation is declining in δ. The cheaper it is, the less the Manager is having of it. It can be shown that the probability that the Manager exerts effort with deviating equals the probability that he would exert effort under first-best decision making for $\delta \approx 0.899$. If δ is larger, deviating is then actually ineffective. Deviating to $d_1 = 0$ then is so cheap that it becomes counterproductive. Still, HQ needs to do it, because the Manager will not exert any effort otherwise. However, it would be optimal for HQ to commit itself to first-best decision making if it chooses centralisation, if it could. This also implies that for $\lambda \to 1/2$, the probability of effort is larger under decentralisation (ML then is negative).

The following statement characterises the centralisation equilibria and some comparative statics. Most of it summarises the text above, and the remainder is proven in the appendix.

Proposition 5.1 *Suppose that assumption 6 applies. Under centralisation, the Bayesian equilibrium of the correlated model is pure if and only if the need for coordination is relatively low ($\delta \leq 1/2$) or the project's payoff is high ($K \geq 1/3$). Deviation is then effective in the sense that it increases the probability that effort is exerted. The higher the need for coordination, the likelier HQ is to deviate. For $\delta > 1/2$ and $K < 1/3$, the equilibrium is mixed. HQ is then equally likely to deviate from the first-best decision for any δ, but as the need for coordination increases, the probability that effort is exerted decreases. Deviating is effective if and only if $\delta < 0.899$, but inefficient compared to first-best decision making for all $K < \hat{K}$.*

Next, I will sketch the (trivial) decentralisation equilibrium and evaluate the relative performance of centralisation and decentralisation when the states are correlated.

5.3 Decentralisation

The analysis under decentralisation is very straightforward. The managers have perfect information, so communication is not necessary.[14] The optimal decision for the Manager in equilibrium

[14] Note that this could be a result of experience, as discussed by Aoki (1988, 1990).

is given by

$$d_1(\theta) = \frac{\lambda}{\lambda + 2\delta}\theta, \tag{5.10}$$

which is equivalent to HQ's first-best decision rule if $\lambda \to 1/2$. As λ increases the managers coordinate less and their decisions diverge more from what would be ideal. Given θ and that decisions are (privately) optimal, the Manager's utility of the project is

$$U_1^d(d(\theta)) = K - \frac{4\delta\left(\lambda^2 + \delta\right)}{(\lambda + 2\delta)^2}\theta^2. \tag{5.11}$$

The Manager is then indifferent about exerting effort for $\theta = y^d$, where

$$y^d = \frac{\lambda + 2\delta}{2\sqrt{\delta\left(\lambda^2 + \delta\right)}}\sqrt{K}. \tag{5.12}$$

A consequence of using a continuous action space is that decentralisation never leads to first-best decision making, unless $\lambda = 1/2$. That is, there is always a (small) positive coordination loss compared to centralisation if $\lambda > 1/2$. It also appears that decision making under decentralisation then is never pareto optimal: first-best decision making (from HQ's perspective) leads to better outcomes for all parties. Each manager would prefer the decision for his division to be closer to the local state compared to the first-best decision while keeping the other decision fixed, but not while shifting the other decision towards the other local state as well. This follows from the fact that HQ maximises the joint utilities of the managers.[15]

5.4 Performance in the correlated model

To be complete, I here give the comparative statics of the correlated model. I will discuss the comparative statics when the states are not correlated in the next section.

From chapter 3, we have that decentralisation outperforms centralisation if $DL > ML + CL$. Define

$$\begin{aligned} DL &\equiv E[\pi(d^*)] - E[\pi^c(d_p(\theta))] && (5.13a) \\ ML &\equiv 2\left(py - y^d\right)K && (5.13b) \\ CL &\equiv E[\pi(d^*)] - E\left[\pi^d(d_a(\theta))\right], && (5.13c) \end{aligned}$$

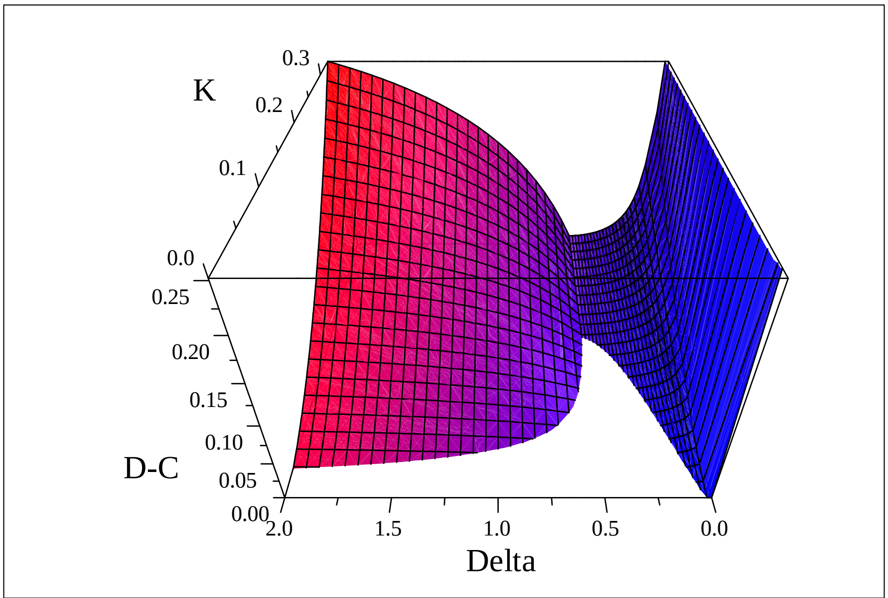
where $d_p(\theta)$ denotes HQ's equilibrium decisions (including deviation) and $d_a(\theta)$ the Manager's. To be able to evaluate $DL > ML + CL$ (which contains some lengthy expressions), it is quite useful to establish the following lemma first.

Lemma 5.1 *$DL > ML + CL$ has no or a single crossing point with respect to λ and becomes increasingly unlikely as λ increases.*

Proof. $\partial DL/\partial\lambda = 0$ and $\partial(ML + CL)/\partial\lambda > 0$, where DL, ML and CL are defined in the appendix. ■

[15] This is more apparent here than in the integer model. The reason is that decisions in the integer model were limited to a discrete interval, so it was impossible to share adaptation losses for adjacent states. That meant that the managers sometimes preferred no coordination over absolute coordination. In that case, the preferences of HQ and the managers could be different.

The performance of decentralisation relative to centralisation in the correlated model (that is, with a constant PDF, $\theta_1 = -\theta_2$ and the support of $\Theta = [-1, 1]$ is common knowledge) is illustrated in the graph below for $\lambda = 2/3$. For $\lambda = 1/2$, decentralisation dominates centralisation for all δ and K (proof is in the appendix). This shows that deviation is again inefficient compared to first-best decision making. If the inefficiency of decentralisation is small it is the better choice, because it protects HQ against itself. For any δ, it would be optimal for HQ to commit itself to first-best decision making, if it could. The result from chapter 3 that deviating decreases HQ's expected profit is duplicated the correlated coordination model. However, this result is not robust for any distribution of Θ, as will be shown in the next section. The appendix shows that even for $\lambda = 1$ there exist (high) K and δ such that HQ still prefers decentralisation. For any given λ and K, centralisation performs relatively better as δ is closer to $1/2$. The graph below illustrates this with a distinctive shark fin around $\delta = 1/2$.



Graph 5.1: $E\left[\pi^d\right] - E\left[\pi^c\right]$ in the correlated model for $\lambda = 2/3$.

The following proposition captures these results.

Proposition 5.2 *Suppose that the managers both learn θ_1 and θ_2 under decentralisation, and that all draws of $|\theta_1 - \theta_2|$ are equally likely. HQ would then prefer to commit to first-best decision making. In the absence of that possibility, it prefers decentralisation for sufficiently low λ, high K and δ far enough away from $1/2$.*

5.5 Translating the results to an uncorrelated world

The correlated model is 'flat' in the sense that each θ had an equal probability of happening. This assumption simplified solving the model significantly, but in ADM, higher differences between θ_1 and θ_2 have a lower probability of happening. To see this, note that there are only two unique combinations of θ_1, θ_2 for which $|\theta_1 - \theta_2| = 2$, but an infinite amount of combinations for which $\theta_1 = \theta_2$. To account for this, let the probability density function $f_{\theta_1 - \theta_2}(\theta)$ denote the likelihood of each θ. Since we have that θ corresponds to $(\theta_1 - \theta_2)/2$ in the flat model and the probability of $|\theta_1 - \theta_2|$ is decreasing linearly to zero in its outcome, $f_{\theta_1 - \theta_2}(\theta)$ is given by $f = 2(1 - \theta)$.[16]

[16]It can easily be seen that this PDF satisfies $f' < 0$, $\lim_{\theta \to 1} f = 0$ and $F(1) = 1$.

A more serious complication arises at the boundaries of Θ. If $d_i = X > 1 - (X - Y)$, there is a smaller area $[x', y']$ from which HQ could have deviated. This increases Manager i's expected utility keeping all other things constant constant., which implies that Manager i would exert effort for some d where $d_1 - d_2 > 2X$. In other words, HQ needs to deviate less. The solution of the managers' indifference conditions then turns out to be so intricate that it does not tell much. Calculating it would bring me no closer to my goal to gain insight in HQ's incentives to deviate versus the managers' imperfect coordination, so I admit defeat and opt to more or less ignore the corner solutions instead. Though I must apologise for being unable to solve the unsimplified model and for giving a technically incomplete analysis, I believe that I can still make a point about the tradeoff between centralisation and decentralisation if the corner solutions are omitted. I therefore make the following assumption to obtain the comparative statics of the model.

Assumption 7 *The managers cannot recognise corner solutions under centralisation.*

A technical workaround is to assume that the managers have imperfect information about the support of Θ under centralisation, so they cannot recognise corner solutions. Formally, suppose the support of Θ is a stochastic range $\left[\theta^-, \theta^+\right]$, where $\theta^-, \theta^+ \in \mathbb{R}$. The size of the support $|\Theta| = \theta^+ - \theta^-$ is common knowledge, but the location of the boundaries is drawn randomly at the start of the game. This is equivalent to assuming that it is common knowledge how close or far the divisions can be from each other, but there is uncertainty about the possible local circumstances. Note that this assumption is only relevant for draws of θ_1 and θ_2 that 1. are very close to 1, and 2. are such that HQ deviates. Its impact does not need to be big, and in my view, changes little to the qualitative results. The timeline is then as follows:

Timeline of the model

1. The principal decides who become(s) informed.
2. Nature
   (a) draws Θ,
   (b) draws θ,
   (c) sends a signal revealing θ (and if applicable Θ) to the informed party (parties).
3. The informed party (parties) make decisions $d_i, d_j \in \Theta$.
4. The agents choose $e_i \in \{0, 1\}$.
5. Payoffs are realised.

Suppose first that θ^- and θ^+ remain hidden for the managers even under decentralisation, so that truthful communication between the managers is possible. We will then examine what happens if we relax this assumption to allow that the managers learn $\left[\theta^-, \theta^+\right]$ under decentralisation. If the managers have no information about the boundaries of Θ they message $m_i(\theta_i) = \theta_i$, since $E\left[\left(\theta^+ + \theta^-\right)/2\right] = \theta_i$. That is, they do not know the relative position of θ_i in Θ, so they do not know how to influence the other manager in the right way.[17] We then have that

$$DL = \int_x^y [2(\pi(d^*) - \pi(d))(1-\theta)]\,\partial\theta \tag{5.14a}$$

$$ML = 2K\left(p\int_x^y 2(1-\theta)\,\partial\theta - \int_x^{y^d} 2(1-\theta)\,\partial\theta\right) \tag{5.14b}$$

$$CL = \int_0^1 \left[2\left(c^d(d) - c^d(d^*)\right)(1-\theta)\right]\partial\theta. \tag{5.14c}$$

Lemma 5.2 *Lemma 5.1 holds if assumption 6 is dropped (i.e. if $f_{\theta_1-\theta_2}(\theta) = 2(1-\theta)$ is imposed).*

Proof. We still have that $\partial(DL - ML - CL)/\partial\lambda < 0$, since $\partial DL/\partial\lambda = 0$, $\partial ML/\partial\lambda = 2K(2y_d - 2)(\partial y_d/\partial\lambda) > 0$, and $\partial CL/\partial\lambda > 0$ (specifications of DL, ML and CL are in the appendix). ■

We are now able to draw some conclusions about the conditions under which HQ prefers decentralisation. I limit myself further to the pure equilibrium, because the threshold of δ for which the equilibrium becomes mixed depends on K.

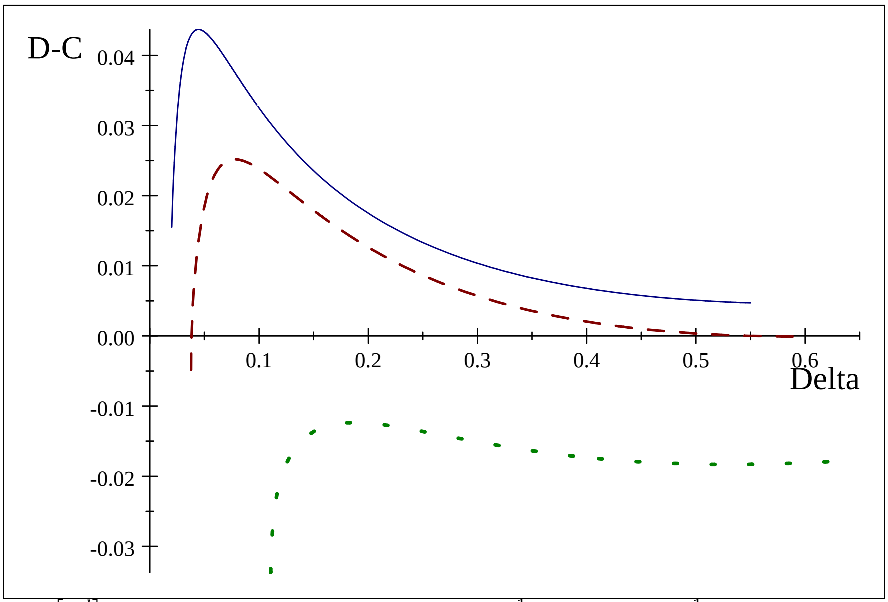
Proposition 5.3 *Suppose that assumption 7 applies. The equilibrium is pure if $\delta < \bar{\delta}(K)$, where $\bar{\delta}(K) \equiv \{\delta : x = 0\}$ and $\bar{\delta}'(K) > 0$. In the pure equilibrium, HQ prefers decentralisation if and only if λ is sufficiently low and the project's returns are not too low or high: $K \in [K^-, K^+]$ where*

1. *$K^-(\delta) > 0$ and*
2. *$K^+ < \kappa \equiv \{K : y = 1\}$.*

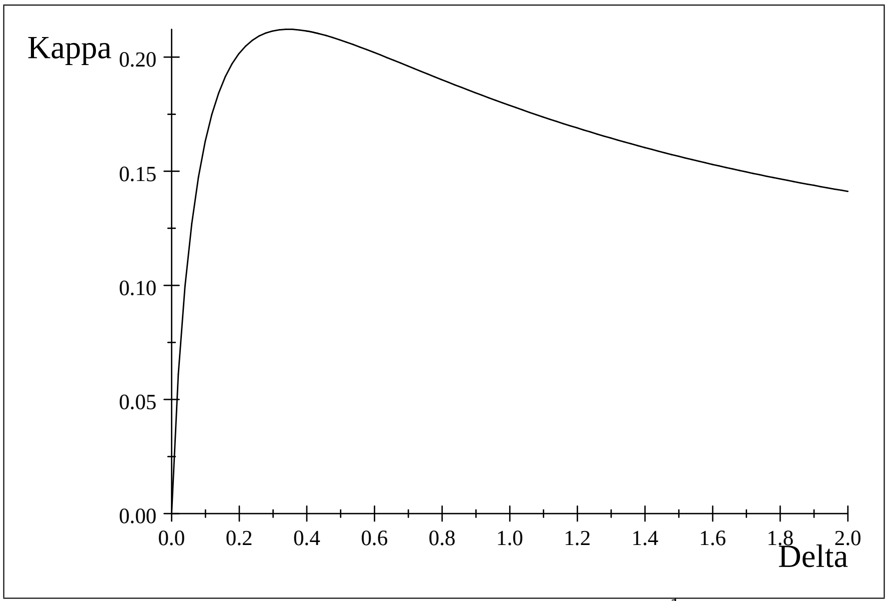
The most striking result is that as $K \to \kappa$ (the equivalent of $\hat{K}$ in the flat model), centralisation dominates decentralisation for all λ, δ (proof is in the appendix). This shows that deviating can actually be effective, as the result holds for $\lambda = 1/2$ (i.e. first-best decision making). The assumption that extreme states of the world become increasingly unlikely has an interesting effect: *for high K, deviating can be beneficial.* This is similar to the result in chapter 4, where not coincidentally, extreme states of the world (e.g. $\theta = (1,1)$) were also relatively less likely than more 'average' states (e.g. $\theta = (1,0)$). The intuition is simple: if it is relatively unlikely that HQ deviated from a value close to y given that it did deviate, the agent needs to be compensated less. That means that deviating can happen for more 'bad' values (for which the agent would not exert effort under optimal decision making), and needs to happen for fewer 'good' values (for which the agent would have exerted effort).

The graph below illustrates the tradeoff between centralisation and decentralisation under pure strategies for $\lambda = 1/2$, but it suffices to say that it holds for λ close enough to 1/2. It illustrates clearly that as K is lower (but not too low), decentralisation is more preferable. This is the opposite of what we saw in the flat model, where a higher $K < \hat{K}$ improved decentralisation. The intuition is again that deviating is more effective, and its gains increase with K. As for mixed equilibria, they occur when δ is relatively high compared to K, like in the 'flat' model. Based on the analysis of the flat model, it stands to argue that there will be $\delta > \bar{\delta}$ for which decentralisation regains the upper hand.

[17] This is equivalent to messaging for $\theta_i = 0$ in ADM.



Graph 5.2: $E\left[\pi^d\right] - E\left[\pi^c\right]$ in pure strategies for $\lambda = \frac{1}{2}$ and $K = \frac{1}{\beta^2(1+4\delta)}$, where $\beta = 2, 3, 4$ are dotted green, dashed red and solid blue



Graph 5.3: κ as a function of δ for $\lambda = \frac{1}{2}$

If the managers do learn $\left[\theta^-, \theta^+\right]$ before sending a message under decentralisation, decision making and messaging under decentralisation are as in ADM. From proposition 4 (p. 160) of their paper, we have that

$$E\left[c^d\right] = \frac{2}{3}(A + BS)$$

where

$$A = \frac{2\left(\lambda^2 + \delta\right)\delta}{\left(\lambda + 2\delta\right)^2} \qquad B = \delta^2 \frac{4\lambda^3 + 6\lambda^2\delta + 2\delta^2 - \lambda^2}{\left(\lambda + \delta\right)^2\left(\lambda + 2\delta\right)^2} \qquad S = \frac{b}{3 + 4b}$$

and

$$b = \frac{\left(2\lambda - 1\right)\left(\lambda + \delta\right)}{\lambda\left(1 - \lambda\right) + \delta}.$$

The coordination loss with strategic communication is strictly larger than with truthful communication. Furthermore, because decision making is less efficient, the managers could be expected to be motivated less often. However, this is not necessarily so. The extra coordination loss due to imperfect communication is largest when θ_i is small and θ_j is large, and communication is at its worst. The loss is smaller when θ_i and θ_j are closer to zero and closer to each other. There are even situations where imperfect communication leads to results that are closer to the first-best outcome, because the managers influence each other such that their decisions are closer. This happens if $\theta_{i,j}$ are as close to each other as possible within the borders of given messaging intervals. That is, if $\theta_i < \bar{m}_i$ and $\theta_j > \bar{m}_j$ where $\theta_i > \theta_j$. It is then obvious that the model is hard, if not impossible to solve generally. Proposition 4.3 showed that decentralisation may be better even if the managers do not communicate truthfully or coordinate perfectly, and the same may be true here, especially for low δ. If we assume that the motivation loss does not increase (much) under imperfect communication, we can examine performance, which gives a result that is similar to that of proposition 4.3. The following conjecture concludes this analysis.

Conjecture 5.1 *Proposition (5.3) holds for sufficiently low(er) λ if the probability that the managers are motivated does not change materially compared to truthful communication.*

5.6 Conclusions

The analysis in this chapter has shown that most qualitative results from chapter 4 hold in a continuous model. It is needless to say that the analysis in this chapter has its limitations. I had to make strict assumptions about the information of the managers about the game. Still, a number of results clearly holds. In the full model, HQ prefers decentralisation for moderate values of K. The ability to deviate then decreases HQ's payoff, so it would prefer to commit to efficient decision making. However, for high K, deviating can increase HQ's payoff on average. It is then preferable that the division managers remain uninformed. A bit like in Krähmer and Bester (2008), the ability to coordinate its decision with the managers' effort constraint makes it optimal not to delegate. Yet, this result only applies for high K, which implies that the conclusions of Bester and Krähmer do not always apply if only one party (or category) can be informed.

A final note is that I considered two extreme versions of centralisation and decentralisation. There exists a middle form, which ADM show to be sometimes optimal: decentralised information with centralised decision making. For the parameters for which centralisation was optimal in my analysis, it may in fact be optimal to decentralise information and centralise decision making. This adds an inefficiency compared to full centralisation, because HQ is unable to coordinate well. However, it can no longer deviate. For the parameters for which decentralisation is optimal, the mixed form of decentralisation may be better too. However, my analysis shows that it is not always optimal for HQ to be informed and make decisions itself, although that is often assumed in the coordination literature.

6 Final conclusions

It can be optimal to decentralise information in a multi-division firm that requires coordination. My analysis suggest that this is especially likely when the agents' incentive to exert effort is relatively weak. If the project choice is discrete, the principal can use information asymmetry to motivate the agents more often if their incentive to exert effort is relatively strong (K is high) - that is, if it is easy to motivate them. However, if the agents are hard to motivate (K is low), it is better to let them be fully informed about the profitability of the project. In both cases, the increased probability that the agents exert effort can outweigh the loss caused by less efficient decision making. If the project choice is not discrete but from a continuous interval, and favourable states of the world are equally likely as unfavourable ones, the possibility to deviate is always bad for the principal. Decentralisation of information is then better if the agents care enough about maximising total surplus and the need for coordination is either low or high. If favourable states are more likely than unfavourable ones, as is the case in ADM, the possibility to deviate can be beneficial for the principal if the agents are easy enough to motivate. The intuition behind this result is that deviating is less often necessary and therefore also more effective. As the agents become harder to motivate, deviating is necessary more often and the balance between motivation and inefficiency tips. It would then be good for the principal to commit himself to first-best decision making. Alternatively, decentralisation is better than centralisation without first-best decision making if the agents care enough about maximising total surplus and the need for coordination is low or high.

My result qualifies the idea from most coordination literature (of which I featured ADM prominently) that the centralisation of information would be optimal. This notion is not always true if centralisation means that the agents remain uninformed and if they have an outside option. Asymmetric information combined with an agent's effort incentive constraint can thus be crucial for the question whether centralisation is efficient. To put it more generally, it is not always optimal for the principal to allocate information and decision rights to himself if there is a risk that he will use his position to induce effort from the agents by making decisions that look good, but are in fact bad. It is sometimes better to let the agents be informed and let them make decisions, rather than the principal.

One implication of my results is that managers should be reluctant with patronising employees. It can be optimal to let employees gather information themselves, rather than centralise information and try to steer the workers' beliefs. The latter is not a sustainable (cost-free) practice, because employees become reluctant to believe a manager who has an incentive to motivate them by pretending all is well. If this is true, my results predict that there are firms where unverifiable information is decentralised (or delegated), even if centralised information would be optimal.

If information is verifiable, firms can commit to first-best decision making (which is often optimal) and maximise effort by sharing information with employees. That is, managers should explain their decisions (in a verifiable manner), even if the employee does not need the explanation to do his job well. This would improve the worker's productivity on average, especially his task is enjoyable or inviting (i.e. when it can be assumed he exerts effort). A potentially empirically testable hypothesis is that a worker's average productivity should be correlated with whether he is informed about the point of his tasks. That is, managers who take time to explain why they give certain tasks to employees show a higher productivity under their responsibility. In an ideal field study, employees would have some sort of outside option, i.e. an alternative task to spend their time on. For instance, employees who have multiple principals who assign tasks to them and a tight time constraint have to choose between multiple tasks, and therefore the principals have an incentive to make their task look more important.

As a possible (theoretical) extension, it would be interesting to see what happens if variable wages are introduced to the model of chapter 3. Suppose that under delegation the principal would offer a pay that is based on the agent's expected utility given his decision. There would then be a continuous tradeoff between taking a optimistic decision and paying a lower wage on the one hand, and the inefficiency of such a decision on the other hand. The equilibrium would be as in Crawford and Sobel (1982), and probably be more efficient than in my analysis, because effort can always be induced against limited costs (if it is efficient). Under centralisation, a fixed wage may be optimal to avoid that the agent biases his decision (however, this is not necessarily so, if the agent cares sufficiently about the project's payoff). It would be interesting to see whether a variable wage leads to better or worse outcomes than a fixed wage, considering the parties' incentives to take suboptimal decisions.

In conclusion, principals sometimes have an incentive to deceive their agents, and that can give rise to reverse principal-agent problems. If an agent needs information about the situation to make his choice between participating and walking away, it is therefore often better to let him collect that information himself. Otherwise, the principal has an incentive to make bad decisions. If the minister of information tells you that you have nothing to fear and you should carry on as usual, it may be wise to take a look out the window to judge for yourself. In a firm, the mechanism is much the same: a leader who needs to motivate employees is not entirely trustworthy when it comes to (implicitly) telling how well everything is going. If he can communicate that in a costly (and therefore somewhat credible) way with his decisions, it may be better to shut him up and let others make the calls.

A Appendix to chapter 3

Proof of lemma 3.1. Most of the proof follows easily from the text and payoff functions. To see that the principal's strategy cannot be mixing, consider the following. Suppose that the principal does not always deviate to the same value, but deviates to $d \in [X_a, Y_a]$ for $\theta = a$ with some probability distribution over those values. Since he mixes, he must be indifferent between all $d \in [x_a, y_a]$. This can only be true if the agent exerts effort with some probability $p(d)$ that decreases in d, such that deviating more increases the probability of effort, which cancels the increasing cost. Suppose that the agent's strategy is as such. HQ then mixes if and only if $(\partial p(z)/\partial d) K = -\partial \pi(a,z)/\partial d$ for all $z \in [x_a, y_a]$. Now consider $\theta = b = a + \eta$ where $\eta \to 0$. In a mixing equilibrium we should then also have that $(\partial p(z)/\partial d) K = -\partial \pi(b,z)/\partial d$ for all $z \in [x_b, y_b]$. For any $z \in [x_a, y_a] \cap [x_b, y_b]$ we must then have that $\partial \pi(a,z)/\partial d = \partial \pi_1(b,z)/\partial d$. However, that cannot be true, as $\partial^2 \pi / \partial d^2 < 0 \forall d < d^*$. Therefore, if the Manager's mixing strategy is such that HQ is indifferent about deviating to any $[x_a, y_a]$ for a $\theta = a$, HQ must strictly prefer playing $d = x_b$ for all $b < a$. Hence, HQ's strategy must be pure. ■

Proof of proposition 3.1 (I). We have that

$$E\left[\theta^2 | \theta \in [x,y]\right] = \frac{1}{y-x} \int_x^y \theta^2 \partial \theta = \frac{x^2 + xy + y^2}{3}. \tag{A.1}$$

Substituting in (3.14) and multiplying by $(y-x)$ yields

$$(\tau - x - (1-\alpha)(y-x)) K > \frac{y^3 - x^3}{3}, \tag{A.2}$$

and substituting τ, x and y yields

$$\left(\sqrt{\alpha}-\left(\sqrt{\alpha-\frac{5}{12}}-\frac{1}{2}\right)-(1-\alpha)\right)K^{3/2}>\left(\alpha-\frac{1}{3}\right)K^{3/2}, \tag{A.3}$$

which is true for all $\alpha\in[2/3,1]$. ■

Proof of proposition 3.1 (II). We have that

$$E\left[\pi^{c}(d,e)\right]=xK+(y-x)(1-\alpha)K-\frac{1-x^{3}-y^{3}}{3}, \tag{A.4}$$

and its derivative to α can be written as

$$\begin{aligned}\frac{\partial E\left[\pi^{c}(d,e)\right]}{\partial\alpha} &= \frac{\partial x}{\partial\alpha}\left(K+y^{2}-x^{2}\right)-K^{3/2}\\ &= \sqrt{\frac{3}{12\alpha-5}}K^{3/2},\end{aligned} \tag{A.5}$$

since $\partial y/\partial x=1$. Comparing this with

$$\frac{\partial E\left[\pi^{d}(d,e)\right]}{\partial\alpha}=\frac{K^{3/2}}{2\sqrt{\alpha}} \tag{A.6}$$

shows that $\frac{\partial E[\pi^{c}(d,e)]}{\partial\alpha}>\frac{\partial E\left[\pi^{d}(d,e)\right]}{\partial\alpha}$. ■

Expected utility. We have that $E\left[(t-\theta)^{2}|t\right]=\sigma_{t}^{2}$ by definition, and $E\left[\theta^{2}|t\right]=t^{2}+\sigma_{t}^{2}$. ■

Proof of proposition 3.2. Decentralisation is dominant if

$$\tau(\sigma)K-\sigma^{2}>xK+(y-x)(1-\alpha)K+\frac{y^{3}-x^{3}}{3}, \tag{A.7}$$

which can be rewritten to

$$\left(\sqrt{\alpha K-2\sigma^{2}}-\left(\sqrt{\alpha-\frac{5}{12}}-\frac{1}{2}\right)\sqrt{K}-(1-\alpha)\sqrt{K}\right)K>\left(\alpha-\frac{1}{3}\right)K^{\frac{3}{2}}+\sigma^{2}. \tag{A.8}$$

This gives

$$\sqrt{\alpha-\frac{2\sigma^{2}}{K}}-\sqrt{\alpha-\frac{5}{12}}>\frac{1}{6}+\frac{\sigma^{2}}{K^{3/2}}, \tag{A.9}$$

which is true for sufficiently low σ^{2}/K. The second part of proposition 3.1 also holds, since for all $\sqrt{\alpha-\frac{2\sigma^{2}}{K}}-\sqrt{\alpha-\frac{5}{12}}>0$, the partial derivative of the left hand side to α is negative. ■

B Appendix to chapter 4

Proof of proposition 4.1. For $0<K<1-2\delta$, decision making is first-best and HQ does not deviate. We then have that $E\left[\pi_{i}^{c}(d^{*})\right]=-\left(\frac{1}{3}\cdot 0+\frac{4}{9}\delta+\frac{2}{9}(\delta+1/2)\right)=-\frac{1+6\delta}{9}$. For $K<\delta$, the managers only exert effort if $d_{1}=d_{2}$, which happens with probability 1/3. For $\delta\leq K<\min\{1-2\delta,\delta+\lambda/3\}$, they exert effort for all $d_{i}\neq 0$ as well, which increases the probability of effort to 5/9.

If the managers mix exerting effort, the expected profit for all decisions for which HQ would deviate is equal to the profit under first-best decision making without K. For $1-2\delta \leq K < 1/3$, we have that $E\left[\pi^{c}\left(d^{*}\right)\right] = -2\left(\frac{1}{3}\cdot 0 + \frac{4}{9}\delta + \frac{2}{9}\left(\delta + \frac{1}{2}\right)\right) + \frac{2}{3}rK = \frac{1}{9} - 2\delta$. For $1/3 \leq K < 2/3$, we have $E\left[\pi_{i}^{c}\left(d^{*}\right)\right] = -\left(\frac{1}{3}\cdot 0 + \frac{2}{9}\cdot 1 + \frac{2}{9}\left(\delta + 1/2\right)\right) + \left(\frac{2}{9} + \frac{4}{9} + \frac{1}{9}r\right)K = \frac{12K-5-6\delta}{18}$.

For $2/3 \leq K < \delta + \lambda/3$, the managers always exert effort but also always deviate such that $d_1 = d_2$. For $K \geq \delta + \lambda/3$, decision making is first-best and the managers always exert effort. ■

Proof of proposition 4.3 (I). All possible outcomes of the game (which happen with equal probability) are in the following table.

Table 5: Pure strategies equilibrium

θ_i	θ_j	d_i	d_j	$U_i(d)$	Effort if $K > \delta$
-1	-1	-1	-1	0	✓
-1	0	0	0	$-\lambda$	
-1	1	0	1	$-(\lambda+\delta)$	
0	-1	0	0	$-(1-\lambda)$	✓
0	0	0	1	0	✓
0	1	0	0	$-\delta$	✓
1	-1	1	0	$-(1-\lambda+\delta)$	
1	0	1	0	$-\delta$	✓
1	1	1	1	0	✓
Expectation				$-\frac{2+4\delta}{9}$	$2/3$

■

Proof of proposition 4.3 (II). We have that $E\left[c_1^d + c_2^d\right] = \frac{1}{3}\cdot 0 + \frac{4}{9}\left(\frac{1}{2}\cdot 2\delta + \frac{1}{2}\left(2v\delta + (1-v)\right)\right) + \frac{2}{9}\left(v^2\cdot 8\delta + 2v(1-v)(1+2\delta) + 2(1-v)^2\cdot 1\right) = \frac{9\left(\lambda^2-\lambda\right)-\delta^2+21\delta}{18\delta}$. Manager i exerts effort when $d_i = d_j$, and if $K > \delta + \frac{1-v}{2-v}(1-\lambda)$ also for all $d_i = \theta_i = d_j \pm 1$. The probability of effort is then $\frac{1}{3} + \frac{2}{9} + \frac{2}{9}\left(\frac{1}{2} + v\right) = \frac{1}{2} + \frac{\lambda}{6\delta}$. If $\delta + \frac{1-v}{2-v}(1-\lambda) > K > \delta$, the manager does not exert effort for $\theta_i = 1$ and $m_j = -1$, and the probability of effort is $\frac{1}{3} + \frac{2}{9} + \frac{1}{2}\cdot\frac{2}{9} = \frac{2}{3}$. ■

C Appendix to chapter 5

Strategies for deviation. Since the managers have complete information when they decide their effort (i.e. d is visible), deviating is only effective if it is symmetrical. When HQ decides $d_1 = X$, we have that

$$c_1(X,\theta) = (\theta - X)^2 + 4\delta X^2. \tag{C.1}$$

$\pi^c(x,1) = \pi^c(y,0)$ becomes

$$-\frac{8\delta}{1+4\delta}y^2 = 2K - 2(y-X)^2 - 8\delta X^2, \tag{C.2}$$

and solving this gives

$$\begin{aligned} y &= (1+4\delta)X + \sqrt{(1+4\delta)K} \\ &= x + \sqrt{(1+4\delta)K}. \end{aligned} \tag{C.3}$$

We then have that

$$E\left[U_1\left(X\right)\right] = K - \frac{1}{y-x}\int_x^y \left[\left(\theta - X\right)^2 + 4\delta X^2\right]\partial\theta \tag{C.4}$$

$$= K - \frac{\left(1+4\delta\right)\left(x^2+y^2\right) + 4\delta xy - 2xy}{3\left(1+4\delta\right)} \tag{C.5}$$

and substituting y and setting this equal to zero gives

$$x = \left(\sqrt{\frac{2-\delta}{3\delta}} - 1\right)\frac{\sqrt{\left(1+4\delta\right)K}}{2}. \tag{C.6}$$

■

Existence of $K < \hat{K}$. There exist $K < \hat{K}$ if

$$\frac{4}{\left(1+4\delta\right)\left(\sqrt{\frac{2-\delta}{3\delta}}+1\right)^2} < \frac{4\delta}{1+4\delta}$$

$$1 < \delta\left(\sqrt{\frac{2-\delta}{3\delta}}+1\right)^2 \tag{C.7}$$

which is true for $\delta \leq 1/2$ if and only if

$$\delta > \frac{7-3\sqrt{5}}{8} \equiv \hat{\delta}. \tag{C.8}$$

■

Proof of proposition 5.1 (I). Most follows from the text, which I will not repeat. I provide proof for the claim that the equilibrium is pure for $K > 1/3$ here. If $K \geq \hat{K}$, we have that $y = 1$ if the equilibrium is pure. We get

$$x = \frac{1 - 2\delta + \sqrt{3\left(1+4\delta\right)^2 K - 12\left(1+\delta\right)\delta}}{1+4\delta}, \tag{C.9}$$

which is larger than 0 for all $\delta \leq 1/2$. For $\delta > 1/2$, x is positive if and only if $K \geq 1/3$. This threshold is not random, but equal to the variance of θ.[18] This is intuitive, since that is the expected value of θ^2 (i.e. the adaptation loss) if Manager has no information about θ. ■

Proof of proposition 5.1 (II). With regard to effectiviness and efficiency, define

$$\tau \equiv \left\{\theta : U_1^c\left(d_1^*\right) = 0\right\}$$

$$= \sqrt{\frac{1+4\delta}{4\delta}K}.$$

Deviating is *effective* if it increases the *ex ante* probability of effort. For all $\delta \leq 1/2$ we have that $y > \tau$, so this is true. For $\delta > 1/2$, the probability that effort is exerted is py_m, which is larger than τ for all $\delta \in (1/2; 0.899)$. Deviating is *inefficient* if the expected value of the extra effort is smaller than the expected deviation loss, so if $\left(py - \tau\right)K < \int_x^y \left[c_i\left(x\right) - c_i\left(d^*\right)\right]\partial\theta$. The integral is given by

$$\frac{x-y}{3\left(1+4\delta\right)^2}\left(192x^2\delta^3 + 96x^2\delta^2 + 20x^2\delta - x^2 + 2\left(1+4\delta\right)xy - \left(1+4\delta\right)y^2\right). \tag{C.10}$$

[18] It can be shown that the threshold is σ_θ^2 for any $\Theta = [-s, s]$.

Computing this inequality for $\delta \leq 1/2$ and for $\delta > 1/2$ with corresponding x, y and p shows that it always holds for $K < \hat{K}$. ■

Proof of proposition 5.2.

Pure equilibrium Suppose that $\delta \leq 1/2$ and $K < \hat{K}$. We get

$$DL = \frac{2K\sqrt{(1+4\delta)K}}{3} \tag{C.11}$$

$$ML = \left(\left(\sqrt{\frac{2-\delta}{3\delta}}+1\right)\sqrt{1+4\delta} - \frac{\lambda+2\delta}{\sqrt{\delta\left(\lambda^2+\delta\right)}}\right)K\sqrt{K} \tag{C.12}$$

$$CL = \frac{8\left(2\lambda-1\right)^2\delta^2}{3\left(1+4\delta\right)\left(\lambda+2\delta\right)^2}. \tag{C.13}$$

$DL > CL + ML$ can then be rewritten to

$$\left(\frac{\lambda+2\delta}{\sqrt{\delta\left(\lambda^2+\delta\right)}} - \sqrt{1+4\delta}\left(\frac{1}{3}+\sqrt{\frac{2-\delta}{3\delta}}\right)\right)K\sqrt{K} > \frac{8\left(2\lambda-1\right)^2\delta^2}{3\left(1+4\delta\right)\left(\lambda+2\delta\right)^2}. \tag{C.14}$$

For $\lambda = 1$ we get

$$\left(\frac{1+2\delta}{\sqrt{\delta\left(1+\delta\right)}} - \sqrt{\frac{(1+4\delta)(2-\delta)}{3\delta}} - \frac{\sqrt{1+4\delta}}{3}\right)K\sqrt{K} > \frac{8\delta^2}{3\left(1+4\delta\right)\left(1+2\delta\right)^2}. \tag{C.15}$$

This condition has solutions if the project payoff is high and the need for coordination is low. In general it can be shown that as δ gets closer to 1/2, centralisation becomes relatively more efficient. For $K \to \hat{K}$, decentralisation is more efficient than centralisation if $\delta < 0.144$.

Mixing equilibrium Suppose that $\delta > 1/2$ and $K < \sigma^2$. We get

$$DL = \frac{2K\sqrt{3K}}{1+4\delta} \tag{C.16}$$

$$ML = \left(\frac{6\sqrt{3}}{1+4\delta} - \frac{\lambda+2\delta}{\sqrt{\delta\left(\lambda^2+\delta\right)}}\right)K\sqrt{K}, \tag{C.17}$$

and CL is obviously the same as before. $DL > ML + CL$ can then be written as

$$\left(\frac{\lambda+2\delta}{\sqrt{\delta\left(\lambda^2+\delta\right)}} - \frac{4\sqrt{3}}{1+4\delta}\right)K\sqrt{K} > \frac{8\left(2\lambda-1\right)^2\delta^2}{3\left(1+4\delta\right)\left(\lambda+2\delta\right)^2}. \tag{C.18}$$

For $\lambda = 1$, this is true if $K \to \sigma^2$ and $\delta > 0.657$. In general, a higher need for coordination increases the relative efficiency of decentralisation, *ceteris paribus*.

■

Proof of proposition 5.3. Regardless of Θ and $f_{\theta_1-\theta_2}(\theta)$, HQ deviates for $y = x + \sqrt{(1+4\delta)K}$. Taking into account the PDF, we have that

$$\begin{aligned} E[U_1(y)] &= \frac{\int_x^y U(y) f(\theta) \partial\theta}{\int_x^y f(\theta)\partial\theta} \\ &= \frac{\int_x^y 2U(y)\partial\theta - \int_x^y 2\theta U(y)\partial\theta}{(2y-y^2)-(2x-x^2)}. \end{aligned} \tag{C.19}$$

From (C.4) we have that

$$\int_x^y U(y)\partial\theta = (y-x)\frac{(1+4\delta)\left(x^2+y^2\right)+4\delta xy-2xy}{3(1+4\delta)} \tag{C.20}$$

and computing

$$\int \theta U(y)\partial\theta = \frac{\theta^2\left(3\theta^2-8x\theta+12\theta^2\delta+6x^2\right)}{12(1+4\delta)} \tag{C.21}$$

shows that Manager 1 is indifferent about exerting effort for $d_1 = x$ if

$$K = \frac{x^2y-5xy^2-16x^2\delta+12x^3\delta-16y^2\delta+12y^3\delta+8xy-4x^2+x^3-4y^2+3y^3-16xy\delta+12xy^2\delta+12x^2y\delta}{6(1+4\delta)(x+y-2)}. \tag{C.22}$$

Performance for moderate K Suppose that $K = \frac{1}{\beta^2(1+4\delta)}$ and $\lambda = \frac{1}{2}$, so $CL = 0$. Decentralisation outperforms centralisation if

$$\frac{2\sqrt{(1+4\delta)K}}{3} > \sqrt{(1+4\delta)K}\frac{4x+3\sqrt{(1+4\delta)K}}{6}+2y-y^2-\sqrt{\frac{1+4\delta}{\delta}}\sqrt{K}+\frac{1+4\delta}{4\delta}K. \tag{C.23}$$

$\beta = 2$ Suppose that $\beta = 2$, such that $y = x + \frac{1}{2}$. Manager 1 is then indifferent about exerting effort for $d_1 = x$ if

$$\frac{1}{4(1+4\delta)} = \frac{5(1+4\delta)-8x+96x\delta+96x^2\delta-384x^3\delta}{288\delta-96x-384x\delta+72} \tag{C.24}$$

which can be rewritten to

$$\delta\left(384x^3-96x^2-96x-20\right)-16x+13=0. \tag{C.25}$$

The solution for x is given by $x = x_1$ for all $\delta < .41$ and $x = x_2$ for $\delta > .41$, with

$$x_1 = -\frac{13\delta-24\delta A+13i\sqrt{3}\delta+144\delta A^2+2i\sqrt{3}-144i\sqrt{3}\delta A^2+2}{288\delta C} \tag{C.26}$$

$$x_2 = -\frac{13\delta-24\delta A-13i\sqrt{3}\delta+144\delta A^2-2i\sqrt{3}+144i\sqrt{3}\delta A^2+2}{288\delta C} \tag{C.27}$$

where

$$A = \sqrt[3]{\frac{1}{6912\delta}\left(256\delta+\delta\sqrt{\frac{1}{\delta^3}\left(30\,384\delta^3-69\,984\delta^2+8529\delta-128\right)}-105\right)}. \tag{C.28}$$

$\beta = 3$ Suppose that $\beta = 3$, such that $y = x + \frac{1}{3}$. We then have that

$$\frac{1}{9\left(1+4\delta\right)} = \frac{3 + 12\delta - 4x + 96x\delta + 216x^2\delta - 432x^3\delta}{360\delta - 108x - 432x\delta + 90} \tag{C.29}$$

which can be rewritten to

$$\frac{7 - 12\delta - 216x^2\delta + 432x^3\delta - 8x(1+12\delta)}{(-5+6x)(1+4\delta)} = 0. \tag{C.30}$$

The solution for x is given by $x = x_3$ for all $\delta < .177$ and $x = x_4$ for $\delta > .177$, with $x_3 = \frac{1}{6} + \frac{1}{2}i\sqrt{3}\left(B - C\right) - \frac{1}{2}\left(B + C\right)$ and $x_4 = \frac{1}{6} - \frac{1}{2}i\sqrt{3}\left(B - C\right) - \frac{1}{2}\left(B + C\right)$, where

$$B = \sqrt[3]{-\frac{17}{2592\delta} + \sqrt{-\frac{427}{629\,856\delta} + \frac{1897}{60\,466\,176\delta^2} - \frac{1}{4251\,528\delta^3} + \frac{397}{1259\,712}} + \frac{1}{27}} \tag{C.31}$$

and

$$C = \frac{\frac{1}{162\delta} + \frac{11}{108}}{\sqrt[3]{-\frac{17}{2592\delta} + \sqrt{-\frac{427}{629\,856\delta} + \frac{1897}{60\,466\,176\delta^2} - \frac{1}{4251\,528\delta^3} + \frac{397}{1259\,712}} + \frac{1}{27}}}. \tag{C.32}$$

$\beta = 4$ Suppose that $\beta = 4$, such that $y = x + \frac{1}{4}$. We then have that

$$\frac{1}{16\left(1+4\delta\right)} = \frac{13\left(1+4\delta\right) - 16x + 576x\delta + 1920x^2\delta - 3072x^3\delta}{2688\delta - 768x - 3072x\delta + 672} \tag{C.33}$$

which can be rewritten to

$$\delta\left(3072x^3 - 1920x^2 - 576x - 52\right) - 32x + 29 = 0. \tag{C.34}$$

The solution for x is given by $x = x_5$ for all $\delta < .098$ and $x = x_6$ for $\delta > .099$, with

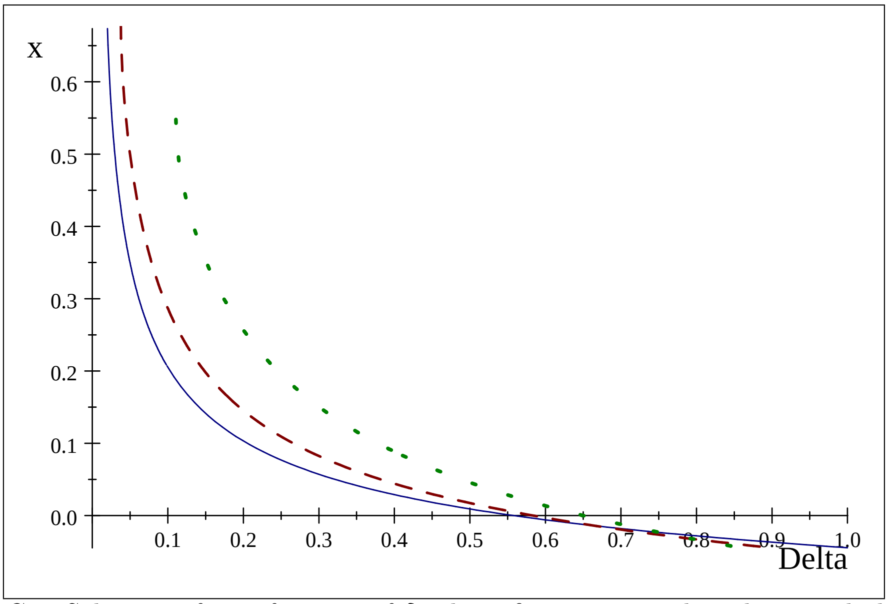
$$x_5 = -\frac{61\delta - 240\delta D + 61i\sqrt{3}\delta + 576\delta D^2 + 2i\sqrt{3} - 576i\sqrt{3}\delta D^2 + 2}{1152\delta D} \tag{C.35}$$

$$x_6 = -\frac{61\delta - 240\delta D - 61i\sqrt{3}\delta + 576\delta D^2 - 2i\sqrt{3} + 576i\sqrt{3}\delta D^2 + 2}{1152\delta D} \tag{C.36}$$

where

$$D = \sqrt[3]{\frac{1}{55\,296\delta}\left(2048\delta + \delta\sqrt{\frac{1}{\delta^3}\left(562\,608\delta^3 - 1180\,512\delta^2 + 28\,689\delta - 128\right)} - 201\right)}. \tag{C.37}$$

The following graph shows where the solutions for x become 0 and therefore cease to exist in a pure equilibrium. For higher δ, the equilibrium is mixed.



Graph C.1: Solutions of x as function of δ, where $\beta = 2, 3, 4$ are dotted green, dashed red and solid blue

High K For $\kappa \equiv K$ such that $y = 1$, we get

$$\kappa = \frac{1 + 4\delta - 2x + 8x\delta + 12x^2\delta + x^2}{6(1 + 4\delta)} \tag{C.38}$$

and substituting $x = 1 - \sqrt{(1 + 4\delta)\kappa}$ yields

$$\begin{aligned} \kappa &= \frac{\kappa + 24\delta + 16(1 + 3\delta)\kappa\delta - 32\delta\sqrt{(1 + 4\delta)\kappa}}{6(1 + 4\delta)} \\ &= \frac{8\left(112\delta^3 + 88\delta^2 - 8\sqrt{2}\sqrt{-64\delta^6 + 208\delta^5 + 116\delta^4 + 15\delta^3} + 15\delta\right)}{2304\delta^4 - 768\delta^3 - 416\delta^2 + 80\delta + 25}. \end{aligned} \tag{C.39}$$

We then have that the deviation loss is

$$\begin{aligned} DL &= \frac{4\kappa\sqrt{(1 + 4\delta)\kappa}}{3} + \frac{(1 + 4\delta)\kappa^2 - 4\kappa\sqrt{(1 + 4\delta)\kappa}}{3} \\ &= \frac{(1 + 4\delta)\kappa^2}{3}, \end{aligned} \tag{C.40}$$

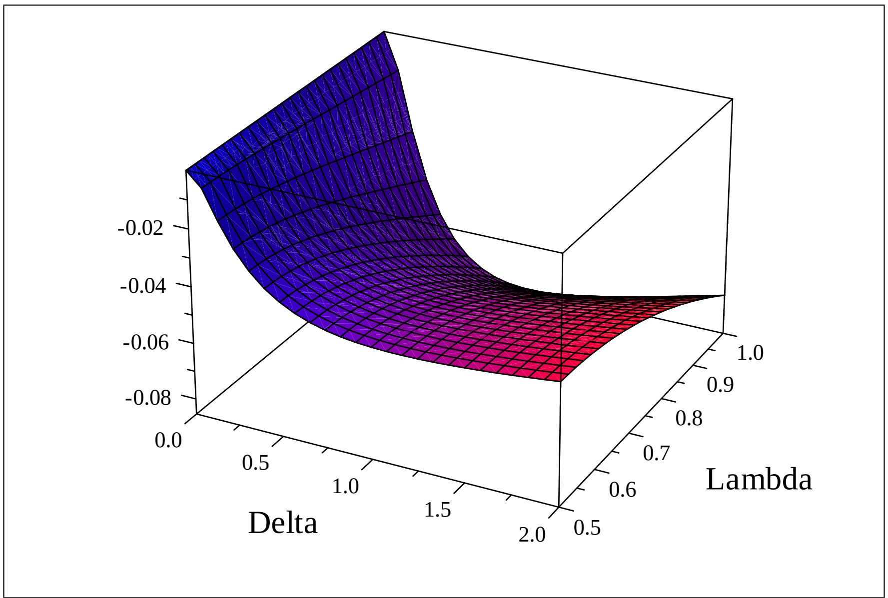
and the motivation loss

$$ML = 2\kappa\left(1 - \frac{\lambda + 2\delta}{\sqrt{\delta(\lambda^2 + \delta)}}\sqrt{\kappa} + \left(\frac{\lambda + 2\delta}{2\sqrt{\delta(\lambda^2 + \delta)}}\sqrt{\kappa}\right)^2\right), \tag{C.41}$$

while the coordination loss is as before. Decentralisation outperforms centralisation if

$$\frac{(1 + 4\delta)\kappa^2}{3} > 2\kappa\left(1 - \frac{\lambda + 2\delta}{\sqrt{\delta(\lambda^2 + \delta)}}\sqrt{\kappa} + \left(\frac{\lambda + 2\delta}{2\sqrt{\delta(\lambda^2 + \delta)}}\sqrt{\kappa}\right)^2\right) + \frac{4(2\lambda - 1)^2\delta^2}{3(1 + 4\delta)(\lambda + 2\delta)^2}, \tag{C.42}$$

which never holds, as the plot below illustrates.



Graph C.2: $E\left[\pi^d\right] - E\left[\pi^c\right]$ for $K = \kappa$

Meanwhile it can be verified that $\kappa < \frac{4\delta}{1+4\delta}$ and that $x > 0$. ■

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