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Essays on Organizational Design, Performance Measurement, and Incentives

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1 Introduction

Incentive problems may (...) be important determinants of organization structure.[1]

The choice of its organizational structure is critical to a firm's survival and success (Burton/Obel 1998). Constant technological progress, accelerating changes in demand and increasingly strong competition are forcing firms to adopt organizational structures, which allow them to compete successfully (Acemoglu et al. 2007). Frequently, firms are forced to undergo several organizational changes in a short period of time in order to adapt to a changing environment.[2] As the success of any organization is contingent on the performance of its staff, firms need to motivate their employees to breathe life into the organizational structure and contribute to the firm's success (Porter 1998; Shaw/Schneier 1995). In other words, they have to provide efficient incentives to make their organization work. This, in turn, necessitates the measurement of employees' performance to form the basis for the provision of incentives. Based on this rationale, the present dissertation analyzes the endogenous choices of organizational design, performance measurement, and incentives, and takes a detailed look at the interdependencies between these choice variables.

From a practical perspective, the existence of the above-mentioned interdependencies is well-established and supported by recent evidence. For example, the Royal Dutch/Shell Group

[1] Harris/Raviv (2002), p. 854.

[2] For example, the electric utility *E.ON* changed its organization in 2010 from a market-orientation towards an organization along businesses reacting to growing competition. Two years later, another change was necessary due to unforeseen challenges in the conventional generation business. This time, the organization was geared towards greater decentralization.

changed its organizational structure due to massive turbulences regarding their industry environment. This included redesigning the internal system of coordination and control and, as a consequence, redesigning the incentive system (Grant 2007). Likewise, Citibank jointly adjusted its organizational design[3] and corporate incentives to emphasize its focus on customers rather than on regions (Baron/Besanko 2001). Another example relates to GlaxoSmithKline, which reorganized its R&D department in order to be more effective in developing new drugs and to improve their well-established drugs at the same time. The accordant organizational changes were accompanied by an adjustment of performance measurement and incentives (Garnier 2008). Finally, in an attempt to expand their penetration of national accounts, UD Trucks combined local branch offices into regions and established national account teams. To maximize the benefits from this restructuring, performance measurement and incentives were adjusted to fit the new structure (Blenko et al. 2010). In addition to this anecdotal evidence, empirical studies have demonstrated an interrelation of organizational design and incentives for the banking sector (Nagar 2002) and, more broadly, based on survey data comprising firms from different industries (Wulf 2007; Baiman et al. 1995).

Despite the overwhelming evidence, relatively little is known about the interdependence of organizational design and incentives from a theoretical point of view. This is quite surprising, given that research on organizational design evolved almost eighty years ago and is at the heart of economic research (Chandler 1992). Beginning with the seminal study of Coase (1937), various determinants of organizational design have been subject to extent analyses. The path-breaking work of Chandler (1962) analyzes the early 20th's century trend to change organizational design from a functional orientation (U-form) towards a divisionalized organization (M-form), which

[3] Consistent with prior literature (e.g., Harris/Raviv 2002; Maskin et al. 2000), the terms organizational form, organizational design and organizational structure are used interchangeably within this dissertation.

focuses on products or regions. He stresses that strategic considerations form a key element of organizational design choices and are critical for a firm's success. Whereas Chandler's findings are based on case studies on General Motors, DuPont, Sears, and Standard Oil, Williamson (1975) takes the analysis a step further and provides a general formulation of the arguments. He claims that one of the main concerns of organizational design relates to efficient coordination. Hence, firms must be organized in a way that allows them to efficiently coordinate their employees in order to achieve their strategic goals. Most notably, he argues that organizations differ with respect to the extent to which they delegate decision rights. This, in turn, has consequences for the effectiveness of coordination caused by the loss of control associated with different organizational forms, because greater decentralization is frequently associated with a greater loss of control if employees have discretion over their decision. Williamson (1967) shows that the loss of control is closely related to the size of the firm in the sense that it is more difficult to observe employees' decisions in larger firms.[4] This is due to the distance between the observing party (e.g., board of directors, firm owners) and the observed party (e.g., employees), which is increasing with firm-size. Consequently, a firm's optimal organizational design frequently trades off the costs of reduced control against the benefits of an improved strategic fit. Blau/Schoenherr (1971) and Child (1973) show that firms often react to this trade-off through the allocation of responsibilities. Particularly, firms use job responsibilites as a tool to regulate the loss of control by hiring specialists with very few responsibilites rather than generalists, who are responsible for a wide range of tasks. This naturally gives rise to various organizational structures, which have been established in practice.

Unfortunately, since these basic findings were established in the 1960's and 1970's, the aca-

[4] See also Keren/Levhari (1989) and Rosen (1982) for further literature along these lines.

demic literature has not made much progress when it comes to explaining the determinants of organizational design (Acemoglu et al. 2007; Harris/Raviv 2002). Facing the spread of more complex and sophisticated organizational structures and in the light of increasing pressure by the business press and management consultants to explain the determinants of these structures, researchers have recently begun to enhance efforts (Liang et al. 2008). Studies concerned with the impact of information processing (Bolton/Dewatripont 1994; Radner 1993), coordination and expertise (Hart/Moore 2005; Harris/Raviv 2002; Garicano 2000) and, more broadly, the general concept of the modern firm (Roberts 2004), have contributed to a better understanding of organizational design choices.

This progress, however, does not spill over to a significant increase of knowledge with regard to the interdependence of organizational design and incentives. This is quite surprising, as the impact of organizational design on incentives has been acknowledged as early as Williamson (1975) and is considered common knowledge nowadays (e.g., Clegg/Hardy 1998; Argyres 1995). The same applies to the opposite relation, that is, various studies assert that incentive considerations have an influence on organizational design choices (e.g., Tirole 2003; Harris/Raviv 2002). Yet, they usually do not account for their impact.[5]

The present dissertation aims to narrow this gap by taking an integrative approach to analyze the interdependencies between organizational design, performance measurement, and incentives. In this respect, it contributes to the sparse but growing literature in this field. Particularly, the choice of optimal incentives and performance measurement systems is at the heart of accounting research (Christensen et al. 2010). Thus, it is perspicuous to build on the findings presented

[5] An exemption from the rule are Fama/Jensen (1983a) and (1983b), who stress the relevance of residual claims for organizational design. In their studies, residual claims capture the difference between the firm's cash inflow and contract payments.

above to analyze the link between organizational design and incentives from an accounting perspective.

Virtually all accounting research on incentives (including this dissertation) is based on agency theory (Jensen/Meckling 1976). This theory builds on the assumption that a principal (e.g., an entrepreneur or firm-owners) contracts with one or several agents (e.g., managers) and delegates certain actions to them that she cannot take herself (e.g., exert productive effort).[6] The agents' actions cannot be contracted upon, for example, because they are not perfectly observable or verifiable. In this respect, agency theory builds on the theory of incomplete contracts (Coase 1937). Hence, agents have some discretion over their actions which they can use to their own advantage, that is, they behave opportunistically. If the actions preferred by the agents differ from those preferred by the principal, the latter faces a *moral hazard* problem, which she can mitigate through the design of the *incentive contract*, which serves to motivate the agents to take actions that are in the principal's interest. The incentive contract specifies state-contingent payments (i.e., incentives) from the principal to the agents dependent on the realization of one or more *performance measures*, which are part of the contract. In practice, these measures often take the form of accounting metrics, such as firm profit or divisional profits (Murphy 1999).

The description of agency theory presented above provides the definitions of *performance measurement* and *incentives*, which are underlying all subsequent analyses. Hence, it only remains to define the concept of *organizational design*, which is employed within this dissertation. This definition makes use of the key elements of organizational architecture, which are established by Brickley et al. (2009). They refer to a "three-legged stool", where the three legs are performance

[6]Throughout this dissertation the feminine gender is used for the principal, masculine nouns refer to the agents.

measurement, rewards, and the allocation of decision rights.[7] Thus, the allocation of decision rights determines a firm's organizational design. This concept is not only commonly accepted in the literature (Hall 2006), but it also allows for a comprehensive analysis of organizational design choices. In particular, accounting research has examined different aspects of organizational design, which can all be traced back to the allocation of decision rights. Typically, decision rights are captured by agents' responsibilities for tasks, that is, the allocation of decision rights is tantamount to the assignment of responsibility for one or several tasks (e.g., productive effort or contract design). The respective literature can be broadly subdivided into four different streams, which can be distinguished by their assumptions regarding the total number of tasks for the agents (fixed versus variable) and the number of tasks per agent (endogenous versus exogenous).

The first stream of literature allows for a variable total number of number of tasks and an endogenous decision on the number of tasks per agent. Studies within this stream are typically concerned with questions regarding the delegation of decision-making authority from the principal to the agents. The principal's choice in these cases is twofold; first, she decides whether or not to assign decision rights to lower levels (total number of tasks). Second, she decides whom to assign the decision right (number of tasks per agent). The main purpose of these studies is to analyze the benefits of delegation and the effects that delegating authority to agents has on their respective incentives. Predominantly, the focus has been on delegating contracting authority to lower hierarchical levels, which affects the depth of the hierarchy. More precisely, literature on delegated contracting typically assumes that the principal contracts with an agent, who in turn contracts with another agent, thus creating a three layer hierarchy. From a theoretical standpoint, delegating contracting authority exacerbates incentive problems because the decentralized

[7] See also Jensen/Meckling (1995) and Milgrom/Roberts (1992) for the importance of these three features in organizations.

contract between agents usually differs from the centralized contract the principal would offer *both* agents (Melumad et al. 1995). Particularly, it has been shown that delegating contracting authority is often tantamount to collusion between agents and therefore detrimental to the principal (Feltham/Hofmann 2007; Macho-Stadler/Pèrez-Castrillo 1998). On the other hand, benefits from delegation arise from the principal's ability to reduce the burden of communicating with each agent (Melumad et al. 1995) or from allowing her to elicit (part of) the agents superior decentralized knowledge (Feltham/Hofmann 2009). Consequently, the basic-trade off with respect to organizational design (delegation versus centralization) critically depends on incentives; whereas delegation introduces additional frictions due to the deviation of decentralized from centralized contracts, it also allows for enhancing the information available to the principal (be it through communication or stochastic effects), thereby improving the efficiency of *all* incentive contracts.

The second stream of literature is concerned with the size of the firm. These studies allow for a variable number of tasks within the firm while holding the number of tasks per agent constant. As an example, each agent is responsible for sales of laptops and printers on a single market and firm-size captures the number of markets to sell the products on. The critical assumption in the second category is that increasing size is associated with an increased loss of control. In other words, incentive problems are more severe in larger firms. The literature thus builds on the findings of Williamson (1967) and additionally devotes attention to optimal incentives. In particular, several studies have analyzed the joint nature of size, incentives, and monitoring technology. Most notably, monitoring agents' efforts has been established as a means to reduce (Liang et al. 2008; Ziv 2000 and 1993; Qian 1994) or even eliminate (Calvo/Wellisz 1978) the limiting impact of the control loss. The insights of these studies have contributed to the understanding of incentives in hierarchies of different width (number of agents on a given hierarchical level) and depth (number of hierarchical levels).

Contrary to the literature on size, the third stream takes the number of tasks as exogenously given but allows for an endogenous determination of the number of agents to cover these tasks. For instance, laptops and printers are sold only in Germany and France, so the principal might hire a single agent to sell both products on both markets, or she might decide to hire four agents, each of which sells a single product on a single market, and so forth. Hence, these studies implicitly include the principal's choice of firm-size, but set an exogenous limit to it (determined by the number of tasks, which is four in the example). The basic idea of these studies is that organizational design not only impacts on control, but also on the firm's productive efficiency, an aspect that is widely accepted but has hardly been analyzed (Aghion/Tirole 1995). The trade-off between productive efficiency and control uses of accounting information (Christensen/Feltham 2003; Christensen/Demski 2002) then determines the optimal number of agents to allocate a given number of tasks. For example, hiring a small number of agents might be beneficial because it allows to capitalize on complementary effects and is therefore benefical regarding the productive efficiency (Nikias et al. 2005). On the other hand, incentive problems might be exacerbated if agents perform several tasks due to the *loss from noncongruity*, which arises if the allocation of efforts chosen by an agent differs from the one preferred by the principal (Feltham/Xie 1994). Moreover, hiring an additional agent might introduce an additional incentive problem while at the same time alleviating incentive problems for the remaining agents (Hofmann/Rohlfing 2012). These studies combine two elements, which help to limit the loss of control in firms, namely the assignment of job responsibilites (as in Blau/Schoenherr 1971 and Child 1973), and the design of optimal incentives. In addition, they bridge the third and the fourth stream of literature, which analyzes how tasks are allocated to agents, once the optimal number of agents is determined.

This aspect is the main scope of the literature on task assignment, which is the fourth stream of accounting literature on organizational design. The key characteristic of these studies is that the number of agents and tasks are held constant, but the assignment of tasks to agents is varied. For example, the principal assigns one agent responsibility to sell laptops and printers in France and another agent responsibility for the German market. Alternatively, one agent is responsible to sell laptops in France and Germany, whereas the other agent sells printers on both markets. The seminal study on task assignment is Holmström/Milgrom (1991), who establish that it is never beneficial to assign several agents to the same task, thus, necessitating a distinct assignment of tasks to agents. In addition, they claim that tasks should be grouped such that easy to measure tasks are assigned to one agent who receives relatively strong incentives, whereas the difficult to measure tasks are assigned to another agent. This result has attracted considerable interest by numerous subsequent studies, which analyze optimal task assignment in more detail and (in part) find deviating results. In particular, in the context of multi-task agents, it is often beneficial to assign a fraction of easy and difficult to measure tasks to each agent (Corts 2007; Besanko et al. 2005). Critical to these deviating results is the nature of performance measurement. Predominantly, prior studies analyze how the assignment of tasks to agents changes the informativeness of *given* performance measures. A joint analysis of performance measurement, task assignment, and incentives, in contrast, has hardly been undertaken.

This dissertation comprises three different essays to analyze the allocation of decision rights, performance measurement, and incentives on the common ground of agency theory. It builds on the studies summarized above and adds several aspects, which are novel to the literature. Before turning to the detailed description of the essays and their particular contributions, the following table shows how the different essays fit into the streams of literature and how they relate to selected analytical accounting literature on organizational design.

		Number of Tasks per Agent	
		exogenous	endogenous
Total Number of Tasks	fixed	Essay I	Essay II
		Corts (2007)	Essay III
		Besanko et al. (2005)	Hofmann/Rohlfing (2012)
		Hughes et al. (2005)	Nikias et al. (2005)
		Zhang (2003)	Indjejikian/Nanda (1999)
		Maskin et al. (2000)	
		Hemmer (1995)	
		Itoh (1991)	
		Holmström/Milgrom (1991)	
	variable	Liang et al. (2008)	Feltham/Hofmann (2009)
		Ziv (2000)	Macho-Stadler/Pèrez-Castrillo (1998)
		Qian (1994)	Mookherjee/Reichelstein (1997)
		Ziv (1993)	Melumad et al. (1995)
		Calvo/Wellisz (1978)	Villadsen (1995)
			Itoh (1994)
			Melumad et al. (1992)

Table 1.1: Selected theoretical work on organizational design, performance measurement, and incentives.

Essay I analyzes the interdependence of optimal incentives and the choice between organizational M-form and U-form against the background of accounting aggregation. The study considers a firm which comprises two functions (production and sales) related to two products (cars and trucks), each of which is associated with specific shocks (e.g., an increase of labor costs reflects a shock to production). Within a three-tier hierarchy, there is a single *top-level* agent (CEO) and four *bottom-level* agents (unit managers), each being responsible for a single product-function combination (e.g., production of cars). The grouping of these units on the *middle-level* determines the firm's organizational form. With M-form (divisional organization), units are grouped according to products and the middle-level agents (division managers) are responsible for cars and trucks, respectively. In contrast, a U-form structure (functional organization) foresees a grouping by functions, such that each middle-level agent is responsible for a single function related to both products (e.g., department manager sales). The remaining agents' responsibilities are unaffected by organizational design. Agents' compensation is based on performance measures, which are aggregated dependent on the firm's accounting system. With *disaggregated information*, performance measures are available for each product-function combination (e.g., revenue from car sales), whereas with *fully aggregated information*, only a single performance measure is available (e.g., firm profit). Finally, the intermediate case relates to *partially aggregated information*. The key assumption is that accounting information is aggregated according to the internal structure of the firm, that is, with partial aggregation, incentives are based on *divisional* performance measures with M-form (e.g., earnings from cars) whereas they are based on departmental measures with U-form (e.g., overall revenue from sales). The key trade-off between organizational forms is that the M-form lumps together product-related shocks, which are thus emphasized in the performance measures, whereas the U-form emphasizes function-related uncertainty. As the analysis assumes risk-averse agents, the principal prefers the organizational form, which burdens the agents with less risk.

Although accounting standards for segmental reporting (SFAS 131, IFRS 8) stipulate a provision of accounting information in line with the internal structure of the firm (as described above), this aspect has not yet been subject to formal analysis. Essay I addresses this point and reveals that organizational design and incentives are independent for all agents if information is fully aggregated. Given that compensation is based on firm profit, the underlying organizational design does not have an impact on performance measurement and, consequently, does not affect incentives. The independence of organizational design and incentives holds for the top and bottom-level agents if disaggregated information is considered, whereas incentives for middle-level agents are dependent on organizational design. In contrast, incentives for *all* agents differ dependent on the organizational form with partially aggregated information. Hence, the study establishes that the extent of accounting aggregation significantly impacts the interdependence of organizational design and incentives. This finding is of particular interest for accounting practice, where aggregation is commonplace (Demski 2008; Arya et al. 2004). Accountants thus need to consider incentive effects when designing accounting systems with respect to the extent of aggregation.

The study then takes a closer look at optimal incentives with partially aggregated information to provide insights into the impact of organizational design on the effectiveness of RPE. It is shown that the opportunities to use firm-internal measures for RPE are restricted for the CEO, such that the principal needs to resort to external measures to filter risk from the CEO's compensation. The risk that needs to be filtered then depends on the organizational form. In contrast, the M-form enables the principal to filter function-related uncertainty from lower level agents' compensation, whereas the U-form allows for filtering product-related uncertainty. Again, the risk that remains to be filtered through external measures depends on the organizational form. Following Albuquerque (2009), empirical research on RPE frequently fails to determine well-specified peer-groups to provide external measures. The results of the first essay imply that organizational design poses an important factor for the choice of peer-groups and thus should be accounted for in future studies. Finally, the results of the study provide a novel rationale for a positive relation between risk and incentives. In particular, considering organizational design as a choice variable might help to explain this theoretically puzzling result and might strengthen the results of empirical compensation studies (Prendergast 2002). The distinction between organizational M-form and U-form gives empiricists an opportunity to control for organizational design by including the job responsibilities of middle managers as a proxy variable.

Essay II delineates the principal's decisions on organizational design and performance measurement and analyzes these choices separately. Thus, it considers a firm that has more degrees of freedom because it does not need to abide by the accounting standards for segmental reporting. In the study, an entrepreneur (the principal) hires a group of identical agents to sell two products on a given number of markets. Initially, a *bundled* organization is assumed, in which each agent sells both products on a single market. Efforts are associated with a task complementarity in the sense that effort exerted on the sales of one product increases the marginal productivity of selling-effort on the other product. Importantly, this effect arises only if products are sold by the same agent. For example, if an agent puts a lot of effort in the establishment of a good relationship to his customers when selling one product, this likely has a positive impact when he wants to sell another product to the same customers. To measure the performance of her sales staff, the principal chooses between two distinct measurement systems. With *aggregate* performance measurement, group output is tracked, that is, the revenues from sales of both products across all markets. In contrast, an *individual* measurement system captures revenues for every single product on every market, so it provides task-specific information. The installation of both systems is prevented by limited resources, e.g., because the principal lacks the time and money to install several measurement systems.

The advantage of individual measures is that they allow to induce effort on each task separately. This *fine-tuning advantage* enables the principal to limit the loss from noncongruity, which arises if agents perform several tasks (as mentioned above). The disadvantage is that the measurement of task-specific outcomes requires a greater utilization of resources, because more information must be processed. As there are often limits to the amount of information that can be processed (Fellingham/Schroeder 2007; Marschak/Reichelstein 1998), it is assumed that the measurement of individual signals is noisier than aggregate measurement. Moreover, the precision decreases with the number of observations (number of markets/group-size) due to an increasing amount of information that must be processed with given resources (Liang et al. 2008; Ziv 2000). The principal thus trades off the fine-tuning advantage against the costs of less precise information when she decides on the performance measurement system.

After the analysis of this basic trade-off, the assumption of a bundled organization is relaxed and the principal can decide to employ an *unbundled* organization, where she hires one agent per task. On the one hand, unbundling destroys complementary effects because tasks are performed by different agents (Nikias et al. 2005; Zhang 2003), on the other hand, there is no loss from noncongruity if each agent performs only a single task.

As an obvious result, the analysis shows that aggregate measurement is preferred in larger groups. Moreover, the likelihood that aggregate measurement is employed increases if the principal's decision on organizational design (bundling versus unbundling) is taken into account. The consideration of these factors might thus help to explain the mixed evidence regarding the use of individual and aggregate performance measures in practice (Hwang et al. 2009). In particular, the decision on organizational design critically depends on complementary effects, such that different structures point towards differences in the productive efficiency between firms. The common practice of empirical studies to compare firms within the same industry (e.g., measured by SIC codes, Davis/Thomas 1993) can then go into insufficient depth if these firms exhibit different structures, which in turn implies that different measurement systems are optimal. Another important result of the study relates to the alleged benefit of individual measures to allow for a fine-tuning of incentives in the presence of multi-task agents (Corts 2007). The analysis reveals that the principal always avoids a loss from noncongruity with individual measures if complementary effects are absent. Including task complementarities in the analysis, however, changes the results significantly. Most importantly, the loss from noncongruity strictly increases as complementarities become stronger when individual measures are employed, whereas the opposite result applies to aggregate measurement. Consequently, the ubiquity of complementary effects in modern organization (Brickley et al. 2009; Milgrom/Roberts 1992) implies that there might often be no trade-off between risk and congruity when choosing between aggregate and individual measurement. Instead, it is frequently the case that *both* effects favor the use of aggregate measures. This rationale supports the widespread use of aggregate signals in practice and adds a novel aspect to analytical accounting, as it changes the commonly known results regarding congruity with aggregate performance measurement.

Finally, essay III puts further emphasis on the allocation of decision rights and refrains from a distinct analysis of performance measurement. The main purpose of the study is to determine the optimal organizational design with respect to the allocation of the decision right on task assignment and to analyze how this choice affects optimal incentives. The principal hires two agents (production and sales manager) to perform three tasks (production, sales, and product innovation). Contrary to the prior essays, the principal cannot completely decide on the assignment of tasks to agents, e.g., because she lacks knowledge with regard to the day-to-day business or due to large geographical dispersion between her and the agents. Instead, each agent is specialized in a single task and both agents are similarly capable of performing the third task (product innovation). The principal then allocates the right to decide on the assignment of product innovation to the *senior agent*, who either takes the task himself, or assigns it to the *junior agent*. The case where the senior agent assigns the task to the junior agent is referred to as *split responsibility*, meaning that the senior agent has *formal* authority (the right to decide) whereas the junior agent has *real* authority (the actual control over decisions, Baker et al. 1999; Aghion/Tirole 1995). The opposite case is referred to as *unified* responsibility. The analysis focuses on the principal's preference with regard to formal authority (which is a direct allocation) and real authority (which is made through the design of incentive contracts) and it combines these decisions to determine the optimal organizational form. In addition, it takes a closer look at the impact of the organizational design choice on optimal incentives. Interestingly, the hierarchical disentanglement of contract design (centralized) and task assignment (delegated) is commonplace in practice (Milgrom 1988), but it has not yet been analyzed theoretically.

The results of the study can be summarized as follows. First, delegating formal authority impacts the incentives of *all* agents, regardless of the authority they exercise. In particular, the delegation of formal authority establishes a link between agents' incentives, because agent 1's incentives are dependent on agent 2's characteristics (productivities, sensitivities, effort costs), and vice versa. Empiricists should thus be careful when developing hypotheses in a multi-agent context based on findings from single-agent analyses (e.g., Abernethy et al. 2004; Keating 1997), where mutual dependence of incentive rates is precluded and thus is out of scope in the analysis. Second, the impact of the senior agent on incentives is higher than that of the junior agent. The decision on formal authority is thus more important for the determination of optimal incentives than the decision on real authority. This finding is meaningful for practitioners dealing with the promotion of employees, as the promotion of a very productive agent increases the incentives of all agents down the hierarchy, even if there are no productive links between the agents (e.g., synergies). Third, the analysis reveals that it is never beneficial to unify responsibility at a single agent. This is due to the fact that the senior agent's impact on incentives becomes too high if he also has real authority. Consequently, formal and real authority typically lie with different agents, such that empirical studies should separate between the two to account for their impact. Prior studies have either focused only on one type or have proxied both types of authority by a single variable (e.g., Wulf 2007; Nagar 2002), which bears the risk that the full impact of authority on incentives cannot be captured. Most notably, the essay shows that one agent's incentives often increase in another agent's effort costs as a result of organizational changes undertaken by the principal. This result stands in contrast to the commonly known comparative static results and thus supports the reasoning that the analysis of authority is important to gain a thorough understanding of the joint decision on organizational design and optimal incentives.

The final chapter of the dissertation summarizes the three essays and provides concluding remarks.

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2 Essay I: Organizational Form, Aggregation of Performance Measures, and Incentives

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2.1 Introduction

The choice of its organizational form is one of the most important decisions every firm must take. Prior studies emphasize the influence of strategy (Chandler 1962), technology (e.g., synergies and economies of scale), coordination (Williamson 1975; Harris/Raviv 2002) and incentives (Fama/Jensen 1983a, 1983b) on a firm's optimal organizational form.[1] We contribute to this literature by considering the effect a firm's accounting system has on the optimal organizational form.

Early seminal work by Williamson (1975) established the interdependence between organizational design and the provision of incentives. Along these lines, a key characteristic of organizational design is the information structure that it gives rise to (Arrow 1974; Maskin et al. 2000) which forms the basis for the provision of incentives. We extend this view by arguing that a firm's accounting system can affect this relation by providing aggregate information for performance evaluation, where the aggregation follows along the internal structure of the firm.[2]

Following Demski (2008), aggregation is ubiquitous in accounting. More specifically, accounting standards for segmental reporting stipulate aggregation of information in line with the internal structure of the firm. For example,

> "(...) segments are evident from the structure of the enterprise's internal organization (...)" (SFAS 131);
>
> "[r]eportable segments are operating segments or aggregations of operating segments (...)" (IFRS 8).

The standards imply that as the organizational form of the firm changes, the firm's accounting

[1] Roberts (2004) provides an overview of research on organizational design choices.
[2] Relatedly, Arya et al. (2004) consider incentives for a sequential production setting.

system will generate different segmental reports. Anecdotal evidence related to companies such as British Gas, Neste Oil Corporation, and Pfizer is consistent with this view.[3]

In addition, vast empirical and anecdotal evidence suggests an interdependence between organizational form and incentives. For example, changes of organizational structure at Citibank (Baron/Besanko 2001), the Royal Dutch/Shell Group (Grant 2007) and UD Trucks (Blenko et al. 2010) were accompanied by adjustments of incentives for the respective managers.[4] Moreover, anecdotal evidence suggests that the firm's information system can be an important determinant of the organizational design choice. For example, Scapens/Jazayeri (2003) report that BM (Europe) implemented an ERP-software (SAP), which led to a reorganization within the firm. Likewise, according to Davenport (1998), Applied Materials gave up on the implementation of an ERP-system due to the need for substantial organizational changes.

In our study, we consider an agency setting with agents on three hierarchical levels (top, middle, bottom). We distinguish between organizational M-form and U-form. The firm uses two functions (e.g., production and sales) for two products (e.g., cars and trucks). With M-form, agents are grouped according to products and the middle-level agent is responsible for a specific product (e.g., a division manager cars). With U-form, agents are grouped according to functions and the middle-level manager is responsible for a specific function (e.g., a production manager). We distinguish three types of accounting systems, which differ with respect to the extent of aggregation: With *disaggregated information*, performance measures originate at the bottom-level

[3]In 2007, British Gas split up its industrial sales and wholesale segment into a Power generation segment and an industrial and commercial segment. In 2009, the Neste Oil Corporation reorganized its structure around three business areas. In the same vein, Pfizer's 2009 reorganization established three new operating divisions that were scattered around various divisions. In all cases, the change of the organizational structure was reflected by the reports generated by the respective firm's accounting system.

[4]Citibank underwent strategic changes and restructured its global corporate banking, thereby changing the incentives of its top management. Likewise, Royal Dutch/Shell changed its organizational form due to an increasingly turbulent industry environment, adjusting its managers' incentives accordingly.

for each function/product-combination. The polar case relates to *fully aggregated information*, where the performance measures are fully aggregated, e.g., to firm profit. An intermediate aggregation relates to *partially aggregated information*, where the performance measures are aggregated on the middle-level, generating, e.g., information for the car division or the production department.

We consider the interrelation between the extent to which performance measures are aggregated and the firm's optimal organizational form. With disaggregated information, following Maskin et al. (2000), the choice between M-form and U-form depends only on the incentives for middle-level managers. On the other hand, with fully aggregated information, we find that the provision of incentives is unaffected by the choice of the firm's organizational form. In contrast, with partially aggregated information, the organizational form affects the incentives on all hierarchical levels. While there are settings where a specific organizational form is optimal for all hierarchical levels, this is generally not the case. Consequently, when choosing the optimal organizational form, the principal has to trade off the benefits of improved incentives for agents on some hierarchical levels against the cost of worsened incentives for agents on other hierarchical levels.

With disaggregate information, grouping agents according to products (M-form) enables the principal to apply relative performance evaluation (RPE) to remove function-related uncertainty from the division managers' performance assessment. In contrast, grouping agents according to functions (U-form) enables the principal to use RPE to remove product-related uncertainty from the department managers' performance assessment. Intuitively, the principal prefers M-form over U-form if function-related uncertainty is sufficiently large relative to product-related uncertainty, and vice versa. With fully aggregated information, the firm's organizational form does not affect the available performance measure. Having only a single performance measure bars the principal from using RPE. Finally, with partially aggregated information, information is only available for each division (M-form) or department (U-form). Similar to the case of disaggregated information, with M-form (U-form), the principal can use RPE to remove function-related uncertainty (product-related uncertainty) from the performance assessment of each agent grouped into a division (department). Consequently, she prefers M-form over U-form if function-related uncertainty is sufficiently large relative to product-related uncertainty, and vice versa.

We use the insights from the comparison in efficiency of M-form versus U-form to derive implications for setting managerial incentives. Generally, with partially aggregated information, organizational form and incentives are interdependent for all hierarchical levels, suggesting to include the organizational form as a control variable in empirical compensation studies. In particular, we find that agents' incentives can increase in the noisiness of a performance measure as a consequence of changes in the organizational form. Neglecting this relation in empirical compensation studies may result in a correlated omitted variable bias. In this regard, we contribute to empirical research on the trade-off between risk and incentives. Prendergast (2002), among others, states that the lack of evidence for this theoretically well recognized trade-off can (partly) be explained by correlated omitted variables such as organizational form. We support this argument and provide a rationale for the increase of incentives in risk. Moreover, we contribute to empirical research on RPE by deriving implications for the choice of peer-groups. Following Albuquerque (2009), empirical studies frequently rely on market-based or industry indices and fail to choose well-specified peer-groups. Our results imply that firms within the same index are not necessarily suitable for RPE as long as a firm's organizational structure is not taken into account.

Our study is related to Corts (2007) and Besanko et al. (2005). Similar to their studies, the organizational form affects the availability of action- and insurance-informative performance measures if we consider disaggregated information. However, with partially aggregated information, assuming that the aggregation follows the internal structure of the firm, the organizational form affects the noise inherent to the performance measures. Unlike Hemmer (1995) and Hughes et al. (2005), we neglect the possibility that different organizational forms exhibit different production functions, e.g., because of synergies or complementarities.

The remainder of the paper is organized as follows. In Section 2.2, we lay out the basic model. In Section 2.3, we derive conditions for optimal organizational form with disaggregate information. Sections 2.4 and 2.5 extend the analysis to fully aggregated information and partially aggregated information. Section 2.6 considers consequences of the organizational form for managerial incentives. Section 2.7 concludes.

2.2 The Model

At date 0, the principal, acting on behalf of the firm's risk-neutral owners, contracts with the firm's managers (i.e., agents) to provide effort at date 1 in return for compensation at date 2. We consider a firm that uses two functions, $i \in \{1, 2\}$, related to two products, $r \in \{\text{A,B}\}$; the firm consists of four operating units, one unit for each function-product combination (i.e., 1A, 1B, 2A, 2B). For example, if functions are production ($i = 1$) and sales ($i = 2$), and products are cars ($r =$A) and trucks ($r =$B), then operating unit 1A produces cars and unit 2A sells cars.

There are two types of *shocks*: function-related shocks θ_i that hit all operating units performing function i and product-related shocks δ_r that hit all operating units related to product r.

Following Maskin et al. (2000), we suppose that shocks are assigned to managers, and these managers are responsible to take actions (i.e., exert effort) to prevent the shocks from having detrimental consequences for the outcome of the operating units they hit.[5] More precisely, a manager's effort prevents the outcome's mean from falling too far as a reaction to the shock, whereas the outcome's variance is independent of the actions undertaken. Assigning shocks to managers gives rise to the firm's organizational form.

In line with standard textbook descriptions (e.g., Milgrom/Roberts 1992; Brickley et al. 2009), operating units are combined into divisions or departments (Figure 2.1). With an organization along divisional lines (M-form or multi-divisional form), units related to the same product are combined to a division (i.e., operating units $1r$ and $2r$ constitute division r, r=A,B). The M-form emphasizes product-related shocks; accordingly, responsibility is assigned to *middle-level managers* to take steps against product-related shocks. For example, shocks to product A could be interpreted as shifts in the demand for cars due to the customers' increased environmental concern. The division manager cars (i.e., agent A) is charged with the responsibility to deal with these shocks (i.e., δ_A). Specifically, he might conceive of and implement a program that improves quality (e.g., reduces gas consumption) and boosts car sales. These steps are complemented by measures taken by *bottom-level managers* who are responsible for the division's operating units (i.e., agents $1r$ and $2r$ in division r, r=A,B). For example, a production manager cars (i.e., agent 1A) is assigned shocks related to the production of cars (i.e., θ_1 and δ_A); consequently, he might work out a plan to increase the productivity of the car manufacturing process.

[5] Our assumptions about the number of agents, agents' actions, and disaggregated performance measures are identical to Maskin et al. (2000); in later sections, our analysis differs when we consider (fully and partially) aggregated performance measures.

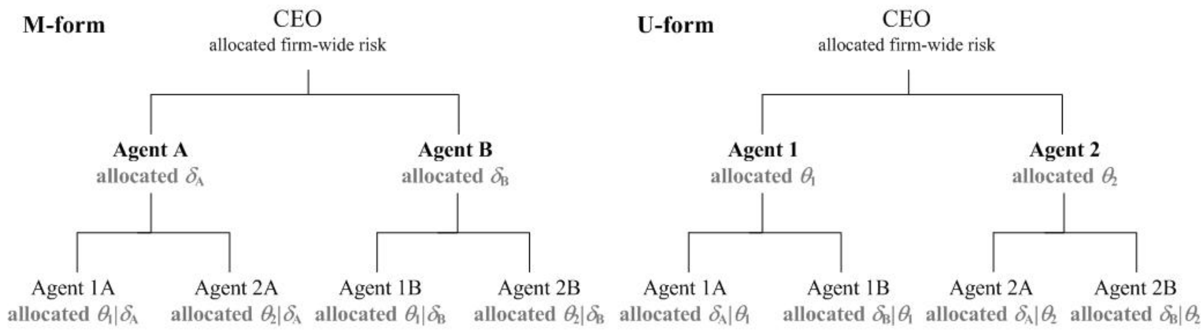

Figure 2.1: Organizational Form

Alternatively, with an organization along functional lines (U-form or unitary form), units performing the same function are combined into a department (i.e., operating units iA and iB constitute department i, i=1,2). Now, function-related shocks are emphasized and middle-level managers are assigned responsibility to deal with these shocks. For example, a production manager (i.e., agent 1) is responsible for changes in the cost of labor (i.e., θ_1). Accordingly, he might plan steps such that less labor is required for production. Similar to the M-form, these steps are complemented by the steps of bottom-level managers. With U-form, however, it is managers responsible for the *department's* operating units who complement the steps implemented by the *department manager* (i.e., agents iA and iB complement agent i's actions, i=1,2). Finally, divisions or departments are combined into the firm, and a *top manager* (i.e., CEO) is responsible for the firm.[6]

The actions undertaken by agent $j \in J^s, s \in$ {M,U}, to dampen the consequences of as-

[6]Conceptually, the CEO is assigned firm-wide shocks that hit all operating units. For example, a new regulation might alter the production and distribution of the firm's products and the CEO is supposed to lobby against new regulation. For simplicity, we chose to neglect firm-wide shocks. However, we included the CEO's action to keep our results comparable to Maskin et al. (2000). Given disaggregated information, we will establish in Proposition 0 their benchmark result, i.e., the organizational form impacts only the incentives for middle-level managers and has no effects on the incentives of bottom-level managers and the top manager. To the contrary, with partially aggregated information, we find that the organizational form affects the incentives of all agents in the agency.

signed shocks are represented by the effort expended in his task, denoted $a_j \in \mathbb{R}$, and $J^M = \{c,\mathrm{A},\mathrm{B},1\mathrm{A},1\mathrm{B},2\mathrm{A},2\mathrm{B}\}$ ($J^U = \{c,1,2,1\mathrm{A},1\mathrm{B},2\mathrm{A},2\mathrm{B}\}$) denotes the set of agents employed under M-form (U-form).[7] Agent j's preferences are characterized by a negative exponential utility function $u_j(w_j^s, a_j) = -\exp\{-\rho(w_j^s - \kappa_j(a_j))\}$, where $\kappa_j(a_j) = 1/2\ a_j^2$ is the agent's cost of effort and ρ denotes his absolute risk aversion. Hence, agents are effort- and risk-averse and must be compensated for their productive effort and any risk they bear. Compensation is denoted by w_j^s and the principal chooses the organizational form $s \in \{\mathrm{M,U}\}$ and contract parameters such that she maximizes the expected value of non-contractible gross payoff $x^s = \sum_{J^s} a_j$ net of agents' compensation, i.e., she maximizes

$$\Pi^s = x^s - \sum_{J^s} \mathrm{E}[w_j^s], \qquad s \in \{\mathrm{M,U}\},$$

subject to the constraints that each agent's effort choice maximizes his ex ante utility and that compensation provides him at least with his reservation wage, which is scaled to equal zero without loss of generality. In order to determine the principal's choice of the organizational form independently of a particular compensation scheme, we apply the concept of *sufficient statistics*. Following Holmström (1979), using a sufficient statistic for contracting rather than the basic signals does not entail a loss to the principal, regardless of a particular incentive scheme. Consequently, if either organizational form is superior to the other based on a comparison of sufficient statistics, its superiority holds for any given incentive scheme.

Given that output is non-contractible, compensation must be based on performance measures

[7] For each organizational form, there are 7 agents. It is evident from Figure 2.1 that this is the minimum number of agents to model a symmetric firm organized along functions (U-form) or product lines (M-form). Exploring the consequences of different levels of aggregation for incentive purposes requires that we consider the actions chosen by the agents. Also, the organizational form not merely implies a specific combination of operating units, but rather results in a distinct impact of the middle-level managers' actions on the performance of the operating units. Finally, we assume that aggregation is executed along the internal structure of the firm, thus affecting the incentives for managers on all hierarchical levels.

provided by the firm's accounting system. Initially, we consider accounting system η_d that generates one performance measure y_{ir} for each operating unit ir (i =1,2 and r =A,B). A key assumption linking organizational form (implied by the assignment of shocks to managers) and the available performance measures is that a manager's actions affect the outcome of all operating units under him. In other words, in line with Demski (2008), we assume that the performance of each bottom-level agent is informative with respect to the actions of his direct and indirect superiors. For example, while the CEO's actions, a_c, affect the outcome of all four operating units, the production manager's actions, a_1, assuming U-form, only affect the outcome of the two production units 1A and 1B.[8] Importantly, M-form and U-form differ with respect to the characteristics of the available performance measures.

With M-form, the outcome of operating unit ir is

$$y_{ir}^M = a_c + a_r + a_{ir} + \theta_i + \delta_r, \qquad i \in \{1,2\} \text{ and } r \in \{\text{A,B}\}, \tag{1a}$$

where $a_c \in \mathbb{R}$ represents effort exerted by the CEO, $a_r \in \mathbb{R}$ is effort exerted by divisional manager r, and $a_{ir} \in \mathbb{R}$ is effort exerted by unit manager ir. For simplicity, we consider unit sensitivities. We assume that the shocks are normally distributed and uncorrelated, i.e., $\theta_i \sim N(0, \sigma_i^2)$, $\delta_r \sim N(0, \sigma_r^2)$, and $\text{Cov}[\theta_1, \theta_2] = \text{Cov}[\delta_A, \delta_B] = \text{Cov}[\theta_i, \delta_r] = 0$, $i \in \{1,2\}$ and $r \in \{\text{A,B}\}$.

With U-form, the outcome of operating unit ir is

$$y_{ir}^U = a_c + a_i + a_{ir} + \theta_i + \delta_r, \qquad i \in \{1,2\} \text{ and } r \in \{\text{A,B}\}, \tag{1b}$$

where $a_i \in \mathbb{R}$ is effort exerted by department manager i. For M-form and U-form, comparing (1a)

[8] As another example, suppose the products are sold in North America (r =A) and Europe (r =B). The outcome of operating units 2A and 2B relate to revenue accrued in North America and Europe, respectively. Sales unit managers (i.e., agents 2A and 2B) sell goods on their respective markets, whereas the sales department manager (i.e., agent 2) is responsible, e.g., for international key account management. Most likely, the actions taken by the sales department manager have consequences for the revenues accrued in North America and Europe.

and (1b), the performance of operating unit ir shows the same influence of the CEO's actions, the actions of the operating unit managers, and the consequences of product- and function-related shocks. However, the measures differ with respect to the influence of the middle-level managers, thereby indicating divergent *spheres of influence* (Maskin et al. 2000) implied by M-form and U-form.

2.3 Optimal Organizational Form with Disaggregated Information

We first consider the optimal organizational form, assuming that the firm's accounting system releases disaggregated information, i.e., one performance measure y_{ir}^{s} for each operating unit ir ($i \in \{1,2\}$ and $r \in \{A,B\}$).[9] We assume that the agents act non-cooperatively when choosing their actions.[10]

M-form and U-form differ with respect to the characteristics of the available performance measures. Specifically, the metrics reflect differences in the spheres of influence of the middle-level managers. However, given disaggregated information, it turns out that these differences do not affect the incentives for top and bottom-level managers. Rather, differences in the spheres of influence only impinge on the incentives for middle-level managers[11]:

Proposition 0: With disaggregated information,

(1) Optimal incentives for top and bottom-level managers do not depend on the organizational form;

(2) To provide effort incentives for middle-level managers, the principal strictly

[9] Maskin et al. (2000) confine their analysis to this setting.

[10] Holmström/Milgrom (1990) and Ramakrishnan/Thakor (1991), among others, consider settings in which the agents mutually observe each others' efforts. In these settings, the agents cooperatively select their actions.

[11] Proposition 0 is similar to Propositions 1 and 2 in Maskin et al. (2000).

prefers M-form over U-form if product-related shocks are less volatile than function-related shocks, i.e., if

$$\min\{\sigma_A, \sigma_B\} < \min\{\sigma_1, \sigma_2\}$$

and

$$\max\{\sigma_A, \sigma_B\} < \max\{\sigma_1, \sigma_2\}.$$

All results are proven in the Appendix A.

Intuitively, from the perspective of top and bottom-level managers, differences in the spheres of influence of middle-level managers have a mean effect on the performance measures. Given that agents act non-cooperatively, any change in the mean can be taken care off by an appropriate adjustment of compensation, i.e., the principal can simply increase or reduce compensation by a fixed amount. Moreover, the shocks inherent to the performance measures are independent of the organizational form, implying that the principal uses the same information with M-form und U-form to provide incentives for top and bottom-level managers. More generally, performance measures with M-form constitute an *equivalent incentive statistic* for performance measures with U-form (in the sense that any U-form incentive scheme can be replicated by an M-form incentive scheme that results in the same incentives for the agents and the same cost to the principal, and vice versa; Amershi and Hughes, 1989).

Contrary to top and bottom-level managers, the organizational form, i.e., differences in the spheres of influence, affects the incentives for middle-level managers. For each middle-level manager and both organizational forms, there are two action-informative performance measures and two insurance-informative performance measures. For example, for agent A under M-form, y_{1A}^M and y_{2A}^M are action-informative signals (i.e., $\partial \mathrm{E} y_{iA}^M / \partial a_A \neq 0, i =$1,2), whereas y_{1B}^M and y_{2B}^M are insurance-informative signals (i.e., $\partial \mathrm{E} y_{iB}^M / \partial a_A = 0$ but $\mathrm{Cov}[y_{iA}^M, y_{iB}^M] \neq 0, i = 1{,}2$). In contrast, for agent 1 under U-form, y_{1A}^U and y_{1B}^U are action-informative signals, whereas y_{2A}^U and y_{2B}^U are insurance-informative signals. Generally, insurance-informative performance measures are valuable for relative performance evaluation (i.e., RPE) purposes (Holmström/Milgrom 1987). With M-form, the principal can use the insurance-informative signals to filter function-related shocks from the performance assessment of the middle-level managers, whereas, with U-form, she can use the insurance-informative signals to filter product-related shocks. Intuitively, if function-related shocks are more volatile than product-related shocks, filtering function-related shocks via M-form is more valuable to the principal than filtering product-related shocks via U-form, and vice versa.

More precisely, the *conditional variance*, i.e., the residual noise in the performance of middle-level managers after all means to filter noise have been exhausted, differs dependent on the organizational form.[12] For example, if function-related shocks are more volatile than product-related shocks, the conditional variance with U-form is larger than the conditional variance with M-form, implying that the performance measurement of division managers A and B (under M-form) is less noisy than the performance measurement of department managers 1 and 2 (under U-form). Consequently, any incentive scheme under U-form can be replicated by an incentive scheme under M-form at the same cost, but *not* vice versa. Thus, given that M-form (U-form) enables filtering of function-related (product-related) shocks, M-form dominates U-form from an incentive perspective if function-related shocks are more volatile than product-related shocks (i.e., if $\min\{\sigma_A, \sigma_B\} < \min\{\sigma_1, \sigma_2\} \ \wedge \ \max\{\sigma_A, \sigma_B\} < \max\{\sigma_1, \sigma_2\}$). In turn, U-form

[12]Throughout the paper, the conditional variance is expressed by the variance of the sufficient statistic of the basic signals. As the sufficient statistic contains the same information as the basic signals (Holmström 1979), insurance-informative signals are weighted such that the risk an agent is exposed to is minimized for arbitrary incentive schemes.

dominates M-form if product-related shocks are more volatile than function-related shocks (i.e., if $\min\{\sigma_A, \sigma_B\} > \min\{\sigma_1, \sigma_2\} \ \wedge \ \max\{\sigma_A, \sigma_B\} > \max\{\sigma_1, \sigma_2\}$).

While Proposition 0 yields an incomplete ranking of organizational forms, it establishes that the principal's choice of the organizational form hinges on the incentives for middle-level managers. In turn, Proposition 0 implies that variations in the organizational form do not affect the incentives provided to the top manager and to bottom-level managers. The latter result implies that empirical compensation studies of incentives provided to the CEO do not need to control for the organizational form.[13] However, the subsequent analysis shows that this implication does not hold true in general for different levels of aggregation.

2.4 Fully Aggregated Information

Subsequently, we extend the previous analysis by assuming that the principal only contracts on aggregate performance. In settings where the principal incurs a cost for separately identifying the operating units' performance, the principal will refrain from contracting on the units' performance if the cost is sufficiently large. Rather, the accounting system will be designed to generate aggregate measures, i.e., individual performance is not tracked, and the principal will contract on the aggregate measure (Nikias et al. 2005). The optimal level of aggregation depends on the trade-off between identification costs and the benefits from discriminating between the performance measures, e.g., discriminating may enable the principal to remove noise from a manager's performance evaluation. Alternatively, the principal will de facto contract on aggregate performance measures if the managers can transfer entries between accounts and the principal is unable

[13] Whereas the results of Proposition 0 do not depend on a particular incentive scheme, the separability of performance measures in agents' efforts is critical because it disentangles the agency problems and dissociates the choice of the organizational form from incentive considerations for top and bottom-level managers.

to detect these transfers (Holmström/Tirole 1991). With fungible accounts, any difference in the variable parts of an agent's compensation creates an opportunity for arbitrage, essentially implying that the principal contracts on an aggregate performance measure. It is noteworthy that, for both cases, unit weights are applied when aggregating the individual performance measures.

In this section, we consider the benchmark case where the performance of the operating units is fully aggregated, e.g., because of sufficiently large identification costs. Then, the aggregate measure is given by

$$y_f^s = y_{1A}^s + y_{2A}^s + y_{1B}^s + y_{2B}^s, \qquad s \in \{\text{M,U}\}, \tag{2}$$

and we interpret y_f^s as a measure of firm profit.

Given that the aggregate performance measure is additively separable and because agents act non-cooperatively, it is straightforward that the choice of the organizational form does not affect the agents' incentives.

Proposition 1: With fully aggregated information, the optimal incentives of top, middle-level, and bottom-level agents are all independent of whether the M-form or the U-form is employed.

From the perspective of a focal agent, whereas the actions chosen by other agents have a mean effect on the aggregate performance measure, any variation in the mean that is not related to the focal agent's action does not affect the incentives provided to this agent. Consequently, for top and bottom-level agents, the aggregate measure under M-form, y_f^M, is an equivalent incentive statistic to the aggregate measure under U-form, y_f^U. Hence, the organizational form does not affect the choice of optimal incentives for top and bottom-level agents.

Whereas the spheres of influence of the middle-level agents differ under U-form and M-form, these differences are not captured by the aggregate performance measure. More specifically, the actions of division manager r with M-form and department manager i with U-form have the same impact on the fully aggregated performance measure (i.e., $\partial \mathrm{E} y_f^M / \partial a_r = \partial \mathrm{E} y_f^U / \partial a_i, r$=A,B, i=1,2). As the signal's variance is also unaffected by the organizational form, the principal sets identical optimal incentives for both organizational forms.

2.5 Optimal Organizational Form with Partially Aggregated Information

2.5.1 Organizational Form and Sufficient Performance Statistics

Based on the results of the previous sections we may presume that the impact of the organizational form on incentives decreases with the extent of aggregation. While independency has been shown to apply to top and bottom-level agents throughout, the interdependence of organizational form and incentives for middle-level agents no longer holds once we turn from disaggregated to fully aggregated information. To explore the influence of aggregation in more detail, we now turn to the case of partially aggregated information. For example, the principal may find it beneficial to contract on partially aggregated performance measures if identification costs are relatively low.[14]

Within the framework of our model, partial aggregation is tantamount to an aggregation of operating units' outcomes on the middle-level. The key aspect with respect to aggregation is that it follows the internal structure of the firm.[15] Therefore, the middle-level managers' divergent spheres of influence with M-form and U-form imply that the organizational form affects the

[14]Even if identification costs are absent, the principal might prefer to contract on partially aggregated information rather than on disaggregated information. Although more precise information is generally beneficial, basing compensation on too many performance measures might dilute incentives (Moers 2006).

[15]For instance, accounting standards for segmental reporting (SFAS 131, IFRS 8) stipulate aggregation of reports in line with the internal structure of the firm.

aggregation of performance measures.

Consider first an organization along divisional lines (M-form), where division managers j=A,B are assigned responsibility to take steps against product-related shocks. With aggregation along divisional lines, the partially aggregated performance measures for each division r are characterized by

$$\begin{aligned} y_r^M &= y_{1r}^M + y_{2r}^M \\ &= 2a_c + 2a_r + a_{1r} + a_{2r} + \theta_1 + \theta_2 + 2\delta_r, \quad r \in \{\text{A,B}\}. \end{aligned} \tag{3a}$$

We interpret these measures as divisional profits.[16] From (3a) it is evident that both performance measures are action-informative for the top manager. In contrast, for bottom-level and middle-level agents within division r=A,B, the respective divisional profit is action-informative, whereas the other division's profit is an insurance-informative signal.

With a U-form organization, operating units are combined into functional departments and performance measures are aggregated accordingly, yielding

$$\begin{aligned} y_i^U &= y_{iA}^U + y_{iB}^U \\ &= 2a_c + 2a_i + a_{iA} + a_{iB} + 2\theta_i + \delta_A + \delta_B, \quad i \in \{1, 2\}. \end{aligned} \tag{3b}$$

We interpret these measures in terms of functional outcome; e.g., y_1^U measures the cost of production for both products and y_2^U captures overall revenue from sales.[17] Similar to the M-form, both measures are action-informative for the top manager, whereas for bottom-level and middle-

[16] The use of such measures for incentive design in practice is commonplace. See, for example, Bushman et al. (1995).

[17] Murphy (1999) provides evidence that executive compensation is frequently based on several performance measures. In particular, compensation often depends on a mixture of fully aggregated metrics, such as firm profit, and partially aggregated metrics, such as sales. In the previous section, the former has been shown to be independent of organizational design. Hence, in order to analyze whether organizational design has an impact on optimal incentive contracts that are based on a mixture of fully and partially aggregated performance measures, it suffices to focus on the latter.

level agents, the focal department's performance is action-informative whereas the performance of the other department is insurance-informative.

Comparing (3a) with (3b) establishes that the shocks inherent to the signals clearly depend on the organizational form. Consequently, the informativeness of the performance measures under M-form differs from the informativeness of the signals under U-form. To assess whether this difference will affect optimal incentives, we compare the sufficient statistics of the performance measures generated under M-form and U-form. We characterize the sufficient statistics ψ_j^s by their *signal-to-noise ratio*, $\phi_j^s = \partial \mathrm{E}\psi_j^s / \partial a_j \cdot \mathrm{Var}[\psi_j^s]^{-1}$. It is noteworthy that the sufficient statistics depend on the organizational form $s \in \{M, U\}$ and differ between agents. The following Proposition summarizes the results.

> **Proposition 2:** Suppose that the outcome of operating units is partially aggregated along the internal structure of the firm;
>
> (1) Sufficient statistics for agents $j \in J^s$ are given by Table 2.1;
>
> (2) The incentives of top, middle-level, and bottom-level agents are all dependent on the choice between M-form and U-form.

With partially aggregated information, the interdependence of organizational form and incentives extends to all hierarchical levels. Intuitively, aggregation along the internal structure of the firm implies that the divisional performance measures under M-form reflect distinctly different shocks than the departmental performance measures under U-form. For example, with M-form, each divisional performance measure is afflicted by shocks related to both functions but only to shocks to a single product. In contrast, each departmental performance measure under U-form contains shocks related to both products but only shocks to a single function. More precisely, for each agent, the sufficient statistics with both organizational forms have the same sensitivity to the agent's action (i.e., $\partial \mathrm{E}\psi_j^M/\partial a_j = \partial \mathrm{E}\psi_j^U/\partial a_j$, $j \in J^s$); generally, however, the sufficient statistics differ with respect to their conditional variance (i.e., $\mathrm{Var}[\psi_j^M] \neq \mathrm{Var}[\psi_j^U]$, $j \in J^s$). Hence, agent j's effort has the same mean effect with M-form and U-form, but the provision of effort incentives is associated with divergent noise. Consequently, given partially aggregated information along the internal structure of the firm, the incentives for agents on all hierarchical levels differ between the organizational forms.

2.5.2 Local Optimal Organizational Form

With partially aggregated information, the optimal organizational form follows a multi-level comparison. In this subsection, we consider the local (level-specific) optimal organizational form. While Subsection 2.5.2.1 considers the optimal organizational form to set incentives for the top manager, Subsection 2.5.2.2 explores the optimal organizational form at the bottom-level and middle-level. Subsection 2.5.3 combines the analyses by considering the global (firm-wide) optimal organizational form and subsection 2.5.4 provides an example to illustrate the results.

2.5.2.1 Optimal Organizational Form for Top Manager

From the previous analysis, with either organizational form, both performance measures (i.e., divisional performance or departmental performance) are action-informative regarding the top manager's effort. It turns out that this action-informativeness of both signals regarding the top manager's effort yields a simple condition to determine the optimal organizational form on the top level.

Corollary 1: With partially aggregated information, to set incentives for the top manager, the principal prefers M-form over U-form if the volatilities of product-related shocks differ sufficiently more than the volatilities of function-related shocks, i.e., if

$$\frac{(\sigma_A^2 - \sigma_B^2)^2}{\sigma_A^2 + \sigma_B^2} > \frac{(\sigma_1^2 - \sigma_2^2)^2}{\sigma_1^2 + \sigma_2^2},$$

and U-form over M-form otherwise.

With M-form, each divisional performance measure is afflicted by shocks related to both functions and by shocks to a single product (i.e., $\text{Var}[y_r^M] = 4\sigma_r^2 + \sigma_1^2 + \sigma_2^2, r{=}\text{A,B}$). Hence, the measures differ only with respect to product-related shocks whereas the impact of function-related shocks is identical for both divisional performance measures. As both measures are action-informative for the CEO, the principal has a high precision and a low precision metric available to incentivize the CEO, i.e., y_A^M is more precise than y_B^M if shocks to product B are more volatile than shocks to product A, and vice versa. As agents are risk-averse, the principal puts greater weight on the high precision metric when incentivizing the CEO, as this reduces the risk-premium she needs to pay the agent. Moreover, the advantage of emphasizing the high precision metric is greater the more the volatilities of shocks to products differ. Of course, the reverse relation applies to the U-form, that is, the advantage of emphasizing the high precision metric increases with the difference between volatilities of shocks to functions, whereas the difference of product-related volatilities does not play a role because the latter affect both performance measures with U-form in exactly the same way (i.e., $\text{Var}[y_i^U] = 4\sigma_i^2 + \sigma_A^2 + \sigma_B^2, i{=}1{,}2$).

Overall, to set incentives for the CEO, the principal prefers the organizational form which provides her with the means to set incentive at lower risk premium payments, which is affected by two factors. First, the difference between volatilities drives the advantage of the high over the low precision metric, as described above. Second, the total levels of product-related and function-related volatilites have a bearing on the principal's choice of organizational design, as the M-form emphasizes the former, whereas the U-form emphasizes the latter. Hence, if the advantage of the high precision metric with M-form is great (i.e., $(\sigma_A^2 - \sigma_B^2)^2$ is large) but product-related shocks are very volatile (i.e., $\sigma_A^2 + \sigma_B^2$ is large), the principal might still be better off employing the U-form, as this burdens the CEO with lower risk and therefore causes lower risk premium payments.

2.5.2.2 Optimal Organizational Form for Bottom-level and Middle-level Agents

Contrary to the top level, the choice of the optimal organizational form is more subtle for lower hierarchical levels. For both, M-form and U-form, and for each agent $j \in J^s/c$ of lower hierarchical levels, the partially aggregated accounting system generates one action-informative signal and one insurance-informative signal. Moreover, given M-form (U-form), the signals serve the same purpose for all agents of a specific division (department). For example, with M-form, performance measure y_A^M is action-informative for division manager A and unit managers 1A and 2A whereas y_B^M is insurance-informative for these agents. However, middle-level agents differ from bottom-level agents with respect to the sensitivity of the action-informative signal to the actions of the respective agents. Generally, the action-informative signal is more sensitive to the action of higher-level agents.

A straightforward implication of this observation is that the condition for the optimal organizational form will be highly similar for agents on lower hierarchical levels. Using the sufficient statistics as outlined in Table 2.1, we are able to establish the following result regarding the optimal organizational form for lower hierarchical levels.

Corollary 2: With partially aggregated information, to set incentives for bottom-level and middle-level managers, the principal prefers M-form over U-form if function-related shocks are sufficiently volatile, i.e., if

$$\sigma_{\underline{i}} > \sigma_{\underline{i}}^{bm} \qquad \text{where} \qquad \sigma_{\underline{i}} = \min\{\sigma_1, \sigma_2\},$$

and U-form over M-form if $\sigma_{\underline{r}} > \sigma_{\underline{r}}^{bm}$, where $\sigma_{\underline{r}} = \min\{\sigma_A, \sigma_B\}$.

The key to Corollary 2 is that the organizational forms enable the filtering of different shocks under M-form and U-form. With M-form, only function-related shocks can be filtered. Consequently, contracting on the insurance-informative signal (i.e., y_l^M for agent $r \neq l$) enables the principal to filter function-related shocks from the performance evaluation of agent $j \in J^M/c$. For example, if the principal uses the action-informative signal y_A^M to motivate agent A to exert effort, the agent is burdened with shocks related to product A and to both functions (i.e., $\text{Var}[y_A^M] = 4\sigma_A^2 + \sigma_1^2 + \sigma_2^2$). Additionally using y_B^M allows the principal to filter function-related uncertainty from agent A's performance evaluation, thereby reducing the risk premium she needs to pay the agent.[18] On the other hand, U-form enables the principal to filter shocks to products, implying that the conditional variance of the sufficient statistic exhibits less product-related noise.

Thus, it is straightforward that U-form is detrimental relative to M-form if function-related shocks are sufficiently volatile. Moreover, in line with the intuition presented above, the cut-off value $\sigma_{\underline{i}}^{bm}$ increases with the volatility of product-related shocks (σ_r, r=A,B) and decreases as

[18] In particular, using the insurance-informative signal y_B^M in addition to the action-informative signal y_A^M yields a conditional variance of $\text{Var}[\psi_A^M] = 4\Big(\sigma_A^2 + \dfrac{(\sigma_1^2+\sigma_2^2)\sigma_B^2}{\sigma_1^2+\sigma_2^2+4\sigma_B^2}\Big)$, which is lower than $\text{Var}[y_A^M] = 4\sigma_A^2 + \sigma_1^2 + \sigma_2^2$ due to the filtering of function-related shocks.

shocks to the other function become stronger (i.e., $\max\{\sigma_1, \sigma_2\}$ increases). The inability of the U-form to filter function-related shocks gives it a disadvantage compared to the M-form which becomes more severe the greater the volatility of function-related shocks is.[19]

2.5.3 Global Optimal Organizational Form

The level-wise analyses imply that the choice of the optimal organizational form is rather intricate with regard to the whole firm because the principal needs to consider trade-offs between hierarchical levels. Still, Proposition 3 establishes a simple condition to ensure that the choice of the optimal organizational form is aligned over all hierarchical levels.

> **Proposition 3:** With partially aggregated information, to set incentives for top, middle-level and bottom-level managers, the principal prefers M-form over U-form for strong function-related shocks, i.e., if
>
> $$\sigma_{\underline{i}} > \sigma_{\underline{i}}^{firm}, \qquad \text{where} \qquad \sigma_{\underline{i}} = \min\{\sigma_1, \sigma_2\}$$
>
> and U-form over M-form if $\sigma_{\underline{r}} > \sigma_{\underline{r}}^{firm}$, where $\sigma_{\underline{r}} = \min\{\sigma_A, \sigma_B\}$.

Corollary 2 establishes that the M-form is preferred on the bottom-level and middle-level if $\sigma_{\underline{i}}$ is sufficiently large, which is due to the inability of the U-form to filter function-related shocks. Moreover, it is obvious from Corollary 1 that an increase of $\sigma_{\underline{i}}$ also yields an advantage of M-form over U-form on the top level because it decreases the difference between volatilities of shocks to functions and therefore reduces the advantage of emphasizing the high precision metric. Taken together, the M-form is preferred on all hierarchical levels and therefore optimal on the firm-level if function-related shocks are sufficiently volatile.

[19] Due to the symmetry of our model, the intuition for the advantage of U-form over M-form dependent on product-related noise is similar. To keep the analysis tractable, we refrain from describing both cases separately and instead limit the analysis in this and the following section to the advantage of M-form over U-form.

While Proposition 3 is intuitively appealing, it remains rather subtle to determine the global cut-off value. Especially, the key to the local optimal organizational form on the top level is the difference between volatilities, driven by the action-informativeness of both signals for the CEO, which gives the principal an advantage from emphasizing the high precision metric. In contrast, only one signal is action-informative for agents on lower levels and therefore the principal's benefits from either organizational form stem from the ability to filter risk from the agents' performance evaluation. Hence, there might be a tension between benefits on the top level and on lower levels, as big differences between volatilities do not necessarily coincide with better means to filter risk, given that only the sum of product-related (U-form) and function-related (M-form) shocks can be filtered from bottom-level and middle-level agents' compensation (i.e., $\mathrm{Cov}[y_1^U, y_2^U] = \sigma_A^2 + \sigma_B^2$ and $\mathrm{Cov}[y_A^M, y_B^M] = \sigma_1^2 + \sigma_2^2$). Simplifying the analysis by assuming identically distributed noise-terms, however, allows to derive the following condition regarding the global cut-off value.

Corollary 3: With partially aggregated information and identical product-related and function-related shocks, the principal (weakly) prefers M-form over U-form on the firm-level if

$$\sigma_F \geq \sigma_R,$$

and U-form otherwise (where $\sigma_1 = \sigma_2 \equiv \sigma_F$ and $\sigma_A = \sigma_B \equiv \sigma_R$).

With the assumptions of Corollary 3, performance measures with M-form and U-form constitute equivalent incentive statistics for the top manager. As established in Proposition 2, the principal puts equal weights on both performance measures regardless of the organizational form if function-related and product-related noise-terms are identically distributed. Hence, the CEO's compensation is effectively based on the same single aggregate performance measure with M-form and U-form (i.e., $\text{Var}[y_A^M + y_B^M] = \text{Var}[y_1^U + y_2^U]$ and effort sensitivities are identical). In contrast, agents on lower hierarchical levels are exposed to less risk with M-form if function-related shocks are more volatile than product-related shocks. Again, the main driver for this result is the fact that the M-form provides the principal with the means to shield bottom-level and middle-level agents against the detrimental impact of high functional risk by using the insurance-informative signal, which is not possible for the top level agent.

Despite the simplifying assumptions, Corollary 3 underlines the intricacy of determining the firm-wide cut-off value, because the global optimal organizational form is not beneficial on all hierarchical levels (due to the indifference on the top level). Moreover, if the conditions of Corollaries 1 and 2 do not coincide, the global cut-off value is often determined based on a trade-off between the costs of worsened incentives and benefits from improved incentives across hierarchical levels. For example, if the volatility of either product-related shock increases ceteris paribus, then the M-form becomes advantageous on the top level due to an increasing difference of product-related volatilities. On lower levels, however, increasing product-related risk favors the U-form due to the ability to filter the increasing noise. The following subsection provides an example to illustrate this point.

2.5.4 Example: Optimal Organizational Form with the LEN-model

To emphasize the intricacy of finding the cut-off value for $\sigma_{\underline{i}}^{firm}$ and to illustrate the inherent trade-offs, we solve for closed-form solutions within the LEN-framework. Using a numerical example, we compare the principal's expected net payoff under M-form and U-form.[20] For the sake of tractability, we assume that function-related shocks are identically distributed ($\sigma_1 = \sigma_2 \equiv \sigma_F$).[21] Consequently, the cut-off value $\sigma_{\underline{i}}^{firm}$ as established in Corollary 2 simplifies to σ_F^{firm}. Figure 2.2 depicts the optimal organizational form dependent on the volatility of function-related shocks, $\sigma_F \in [0, 10]$, and, without loss of generality, the volatility of shocks to function A, $\sigma_A \in [0, 10]$. Moreover, $\rho = 0.1, \sigma_B = 5$.

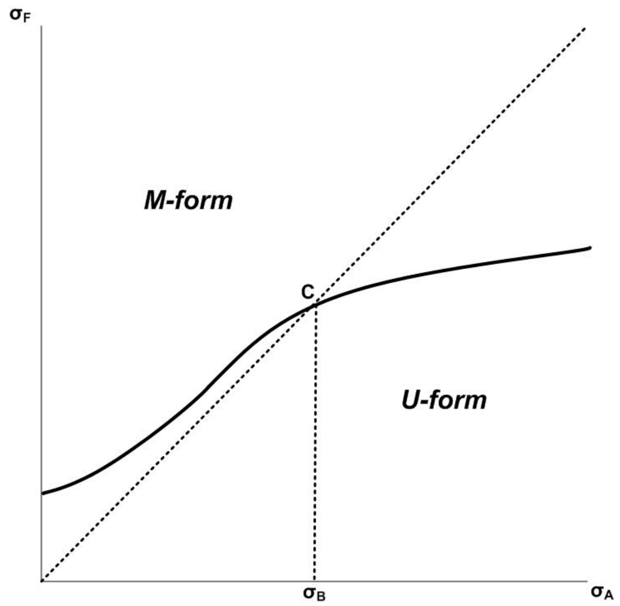

Figure 2.2: Global Optimal Organizational Form within the LEN-model

The dotted vertical line in figure 2.2 depicts the point where shocks to product A and to product B have the same volatility (i.e., $\sigma_A = \sigma_B$) and C depicts the point where shocks to functions have the same volatility, too (i.e., $\sigma_A = \sigma_B = \sigma_F$). Moreover, above the angle bisector, shocks

[20]The optimal incentive rates and the principal's expected net payoff under U-form and M-form can be found in Appendix B. Inspection of the closed-form solutions reveals that solving the principal's payoff for $\sigma_{\underline{i}}^{firm}$ requires the solution to a fifth order polynomial.

[21]Given the symmetry of the model, we would obtain opposite results but the same basic intuition if we would assume identically distributed shocks to products (rather than shocks to functions).

to functions are more volatile than shocks to product A (i.e., $\sigma_F > \sigma_A$). Finally, the solid line depicts the cut-off value σ_F^{firm}, hence, the principal prefers the M-form for all combinations of σ_F and σ_A which lie above the solid line, and prefers U-form otherwise.

The figure shows that for low values of σ_A (left of C) the M-form is preferred only if shocks to functions are sufficiently more volatile than shocks to product A, which is reflected by the „gap“ between the solid line and the angle bisector. As shocks to product A become stronger, this gap becomes smaller which means that the U-form is favored by an increase of σ_A. The reason for this is twofold. First, the principal prefers the M-form on the top level unless $\sigma_A = \sigma_B$ (from Corollary 1). Second, the principal prefers the U-form on lower levels even for weak shocks to product A because this exposes the agents to lower risk compared to the M-form. This is due to the detrimental impact of shocks to function B, which are on a constant high level. Consequently, shocks to functions need to be sufficiently strong such that the detriment of worsened incentives on lower levels with M-form is reduced and can be overcome by improved incentives for the top level agent. In addition, as σ_A increases left of C, the benefits on the top level are diminished because the difference between volatilities of shocks to products decreases. Likewise, stronger shocks to product A increase the detriment of the M-form to set incentives for bottom-level and middle-level agents. Overall, an increase of σ_A yields an even larger increase of the cut-off value σ_F^{firm}, that is, shocks to functions need to be strong such that the detriment of the M-form on lower levels is smaller than the benefit of the M-form to set incentives for the top level agent.

Once σ_A reaches C, the principal is indifferent between organizational forms, as all performance measures with M-form and U-form constitute equivalent incentive statistics for all agents, as has been shown in Corollary 3. Finally, for very volatile shocks to product A (right of C), the cut-off value σ_F^{firm} is almost invariant to changes in σ_A. Contrary to the previous case (left of C), greater values of σ_A mean that the benefits of the M-form to set incentives for the top level agent are increased. This effect counterveils the detriment on the bottom-level and middle-level caused by the fact that a higher volatility of shocks to product A exposes the agents to more risk with the M-form as opposed to the U-form.

To summarize, figure 2.2 shows that the U-form can be the global optimal organizational form although it is never beneficial on the top level. This illustrates the trade-off between the benefits from improved incentives for bottom-level and middle-level agents against the costs of worsened incentives for the top level agent. Importantly, notwithstanding the fact that the above analysis was framed within the LEN-model for illustration purposes, this result is valid for arbitrary incentive schemes. In the next section, we further investigate how the trade-off between hierarchical levels impacts optimal incentives.

2.6 Organizational Form and Incentives

2.6.1 Impact of Organizational Form on Effort Incentives

The subsequent analysis focuses on partially aggregated information, as this enables us to analyze the impact of the principal's organizational design choice on incentives across all hierarchical levels. Particularly, the previous analysis has shown that the firm-wide optimal organizational form is frequently detrimental on the top level. For instance, if shocks to both functions are similarly weak, Corollary 1 shows that the M-form might be preferred on the top level even for strong product-related shocks, whereas Corollary 2 implies that weak shocks to functions favor the U-form on lower levels. Altogether, the principal only prefers the M-form to set incentives for all agents if function-related shocks are sufficiently volatile (i.e., if $\sigma_{\underline{i}} > \sigma_{\underline{i}}^{firm}$). Hence, increasingly volatile shocks to functions might yield an alignment of optimal organizational forms on all hierarchical levels. Based on this finding, we establish the following result.

> **Corollary 4:** With partially aggregated information, if the local optimal organizational forms differ, stronger shocks (to functions or products) frequently yield stronger incentives for the top level agent.

Following Prendergast (2002), a positive relation between risk and incentives is frequently observed empirically, but stands in sharp contrast to conventional wisdom in analytical accounting, which finds the opposite relation. Hence, the result of Corollary 4 might serve as one possible rationale to narrow the gap between empirical findings and analytical results as the treatment of organizational design as a choice variable yields analytical results which are in alignment with empirical observations. Likewise, Corollary 4 implies that a firm's organizational structure should be included as a control variable in empirical compensation studies, e.g., by taking into account whether a firm is organized along functions or along products/markets.

To illustrate the rationale presented in Corollary 4, we again provide a numerical example within the LEN-model. The following figure 2.3 shows the principal's choice of organizational design (in terms of expected profits, Π^s) and the CEO's effort incentives (expressed by his effort choice a_c^M (a_c^U)). We assume that $\sigma_1 = \sigma_2 \equiv \sigma_F$ and vary $\sigma_F \in [5, 8]$ for $\sigma_A = 8, \sigma_B = 5, \rho = 0.1$, i.e., the underlying parameter values are identical to Figure 2.2.

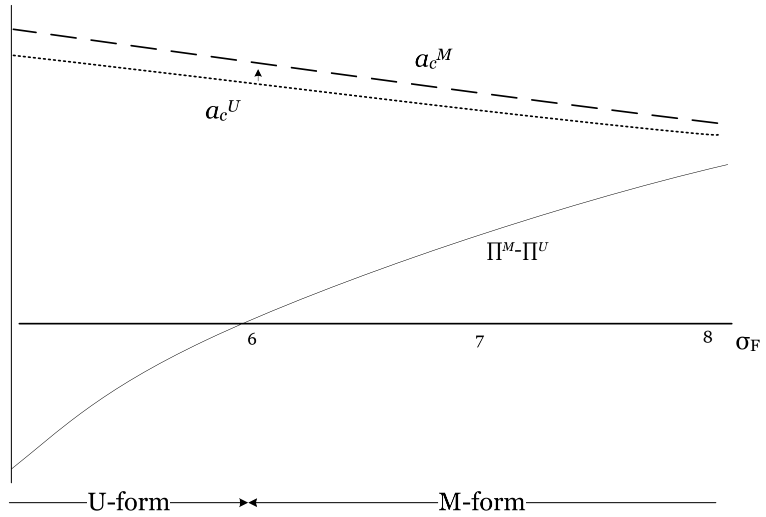

Figure 2.3: CEO Incentives and Global Optimal Organizational Form

Within the example, the M-form is strictly beneficial on the top level because shocks to functions have the same volatility, which precludes the principal from emphasizing the high precision metric with U-form. Consequently, incentives for the CEO are constantly higher with M-form than with U-form, that is, the dashed line (a_c^M) is on a higher level than the dotted line (a_c^U). However, the CEO only receives the weaker incentives with U-form if the functional organization is optimal on the firm-level, which is the case as long as the solid curve is below the abscissa. In this case, shocks to functions are weak such that the benefits of the U-form on the bottom-level and middle-level are greater than the disadvantage on the top level. As functional shocks become stronger, the benefits on lower levels are diminished, eventually yielding an advantage of the M-form on the firm-level. As a result, the CEO receives the stronger incentives with M-form, i.e., his incentives „jump“ from the dotted to the dashed line. Thus, increasingly volatile shocks to functions make it worthwile for the principal to change organizational design from U-form to M-form, which gives her the opportunity to set stronger effort incentives for the CEO.

2.6.2 Relative Performance Evaluation

The previous analysis has shown that a firm's organizational structure has a great bearing on the risk that agents are exposed to. Therefore, we subsequently take a closer look at the principal's means to shield the risk-averse agents against uncertainty by using relative performance evaluation (RPE), that is, by comparing agents' outcomes (i.e., performance measures) which share common shocks. Importantly, organizational design affects performance measures within the firm, hence, it affects the ability to filter shocks from agents' compensation through „internal" RPE. To account for differences between hierarchical levels, we proceed by analyzing RPE on the top level first before we turn to the bottom-level and middle-level.

I.) RPE on the top level

The analysis of RPE on the top level has been subject to various empirical studies (e.g., Jensen/Murphy 1990; Aggarwal/Samwick 1999), which rely on the use of external (e.g., market-based) measures to filter uncertainty from top managers' compensation. This is consistent with our model, as the principal cannot employ internal measures for RPE because both performance measures with either organizational form are action-informative for the CEO. More precisely, divisional (departmental) outcomes with M-form (U-form) have a strictly positive covariance, which means that the principal needs to put negative weight on either measure to filter common noise.[22] However, putting negative weight on an action-informative signal reduces the agent's effort incentives. It follows that the principal needs to resort to external measures if she wants to filter risk from the CEO's compensation.

Furthermore, the organizational form has an impact on the risk that needs to be filtered through external RPE, because product-related shocks are emphasized with M-form whereas

[22]See the proofs of Propositions 0 and 2 for technical details.

function-related shocks are emphasized with U-form. Thus, a firm's organizational form influences the choice of external measures that are used for RPE, as those measures either serve to filter shocks to products (M-form) or shocks to functions (U-form).

This result has an important implication for empirical studies on RPE. Despite vast research on this topic, prior studies failed to provide consistent evidence for the use of RPE in practice. Albuquerque (2009) states that this might be due to misspecified peer-groups as *„(...) the challenge in choosing a RPE peer group is to identify the set of firms that are exposed to common shocks (...)"*. Frequently, empirical studies use all firms within a market index (e.g., S&P 500) or within an industry index as a peer group. Our results indicate that this might be a reason for their inconsistent results, as even firms within the same industry are not necessarily suitable for RPE if they exhibit distinct organizational structures. As the shocks that need to be filtered from executive compensation are (among other factors) determined by the internal structure of the firm, empirical studies should account for this factor in order to obtain a well-specified peer-group.

II.) RPE on the bottom-level and middle-level

Contrary to the top level, the principal is able to apply internal RPE to agents on lower hierarchical levels. Given that only one signal is action-informative for each agent $J \in J^s/c$, the insurance-informative signal can be used to shield the agents from risk associated with their compensation without reducing effort incentives. Generally, the principal could completely filter functional (product) risk from the agents' compensation with M-form (U-form) if she puts exactly negative weights on the performance measures (i.e., if the weights L and M applied to the insurance-informative and action-informative signal, respectively, are chosen such that $\frac{L}{M} = -1$). However, as established in Proposition 2, it is not in the principal's interest to do so. The reason is that the insurance-informative signal is associated with risk that the agent would not be exposed to without RPE. For example, the insurance-informative signal for division manager A with M-form is y_B^M. Using this metric in agent A's compensation exposes him to shocks to product B which he would not be exposed to if compensation was based solely on the action-informative signal y_A^M. Overall, with M-form, the principal trades off the benefits from filtering shocks to functions against the costs from additional product-related shocks, and vice versa for the U-form.

There are two straightforward consequences of this argument. First, the organizational form affects the risk that needs to be filtered from the agents' compensation. In this respect, the result is similar to the top level. Second, however, the application of RPE substantially differs across hierarchical levels. Although the M-form (U-form) always emphasizes shocks to products (functions) on all hierarchical levels, the uncertainty that needs to be filtered through external measures is not the same because part of the uncertainty on the bottom-level and middle-level can be filtered through internal RPE. This view is in line with empirical evidence from the banking sector (Blackwell et al. 1994), where RPE for agents on lower hierarchical levels is based on internal measures, as opposed to the top level, where external measures are dominant. Thus, empirical studies below the executive level should consider internal RPE before focusing on market-based metrics. Given the conjecture that the scarcity of empirical research in this field is (partly) due to the lack of available market-based information (Blackwell et al. 1994), our results imply that it might be worthwile to gear empirical analyses towards firm-internal information. Especially, basing future research on case studies (rather than on field studies) might help to gain a deeper understanding of RPE for managers below the executive level.

2.7 Concluding Remarks

In this paper we analyze the impact of organizational form on incentives dependent on the firm's accounting system. We assume that different organizational forms give rise to different information structures, thereby changing the foundation on which agents' incentives are based. In this respect, our work is related to research on organization design, such as Arrow (1974) and particularly Maskin et al. (2000), who set up the framework on which we built our analysis. Our main finding is that posing limits on the aggregation of information alters the organizational form's impact on incentives. This relates our paper to accounting research analyzing the aggregation of accounting information and the appendant consequences. Moreover, this result extends the findings of Maskin et al. (2000) within their framework and has several implications for empirical accounting research.

Distinguishing between M-form and U-form organization, we find that with fully aggregated information, organizational form and incentives are independent. Hence, if agents are remunerated based on fully aggregated accounting measures, such as firm profit, organizational structure does not have an impact and can therefore be omitted in empirical compensation studies.

In contrast, we find that with partial aggregation, the information on which to base incentives differs for all agents dependent on the organizational form. In this case, the principal frequently trades off the benefits from improved incentives on lower levels against the costs of worsened incentives on the top level. The firm-wide optimal organizational form is therefore often detrimental to the top level agent (CEO), unless function-related (product-related) shocks are sufficiently volatile such that the M-form (U-form) is preferred on all levels. Hence, increasingly strong shocks to functions (products) yield an alignment of optimal organizational forms across hierarchical levels and result in stronger incentives for the CEO. This result provides a possible rationale for a positive relation between risk and incentives and implies that empirical compensation studies should include a firm's organizational structure (e.g., measured by functional or product/market-oriented managerial responsibilities) as a control variable to capture its impact on incentives.

Furthermore, we find that organizational design has a great bearing on relative performance evaluation (RPE). We show that the principal cannot use firm-internal performance measures for RPE on the top level and, thus, needs to resort to external (market-based) measures. Moreover, the shocks that need to be filtered depend on organizational design, which implies that the firm's organizational structure affects the choice of external measures that are used for RPE. This result is particularly helpful for the choice of peer-groups in empirical studies on executive RPE, as the inconsistent empirical evidence is (in part) due to misspecified peer-groups (Albuquerque 2009). Taking a firm's organizational structure into account can help to avoid a misspecification of peer-groups, e.g., arising from the use of an industry index, where firms exhibit different organizational forms and are therefore potentially unsuitable as peers for RPE.

Whereas the results in this paper are derived independently of specific incentive schemes, they are nonetheless subject to some simplifying assumptions and should be understood as a basis for further exploration. For example, more complex hierarchies could be considered, such as the matrix structure (see, e.g., Harris/Raviv 2002), or aggregation of reports might be subject to additional measurement errors, e.g., through flaws in the accounting system. Yet, we think that the parsimonious structure of our model suffices to provide some new insights into the interdependence of organizational form and incentives when aggregated accounting metrics are used for manager compensation.

Table 2.1: Sufficient Statistics with Partially Aggregated Information

Unit Managers

$$\phi_{km}^{M} = \frac{1}{4\Big(\sigma_m^2 + \dfrac{(\sigma_1^2+\sigma_2^2)\sigma_n^2}{\sigma_1^2+\sigma_2^2+4\sigma_n^2}\Big)} \qquad \phi_{km}^{U} = \frac{1}{4\Big(\sigma_k^2 + \dfrac{(\sigma_A^2+\sigma_B^2)\sigma_l^2}{\sigma_A^2+\sigma_B^2+4\sigma_l^2}\Big)}$$

Division Managers **Department Managers**

$$\phi_{m}^{M} = \frac{2}{4\Big(\sigma_m^2 + \dfrac{(\sigma_1^2+\sigma_2^2)\sigma_n^2}{\sigma_1^2+\sigma_2^2+4\sigma_n^2}\Big)} \qquad \phi_{k}^{U} = \frac{2}{4\Big(\sigma_k^2 + \dfrac{(\sigma_A^2+\sigma_B^2)\sigma_l^2}{\sigma_A^2+\sigma_B^2+4\sigma_l^2}\Big)}$$

$$k, l \in \{1,2\}, k \neq l$$

$$m, n \in \{A,B\}, m \neq n$$

CEO

$$\phi_{c}^{M} = \frac{2}{\sigma_1^2+\sigma_2^2+\dfrac{4\sigma_A^2\sigma_B^2}{\sigma_A^2+\sigma_B^2}} \qquad \phi_{c}^{U} = \frac{2}{\sigma_A^2+\sigma_B^2+\dfrac{4\sigma_1^2\sigma_2^2}{\sigma_1^2+\sigma_2^2}}$$

$\phi_j^s = \partial \mathrm{E}\psi_j^s/\partial a_j \cdot Var[\psi_j^s]^{-1}$

Appendix A: Proofs

For ease of presentation, we first introduce some additional notation.

The *sensitivity* μ^s_{pj} measures the change in the expected value of the signal y^s_p with changes in the level of agent j's effort, i.e., $\mu^s_{pj} = \dfrac{\partial \mathrm{E} y^s_p}{\partial a_j}$, where $s \in \{M, U\}$. In addition, the *signal-to-noise ratio* ϕ^s_{pj} of the signal with respect to agent j is defined as $\phi^s_{pj} = \mu^s_{pj} \cdot Var[y^s_p]^{-1}$.

Proof of Proposition 0:

Part (1)

With both organizational forms, the signal-to-noise ratio of performance measure y^s_p with respect to bottom-level agent j is identical, i.e., $\phi^M_{pj} = \phi^U_{pj},\ j, p \in \{1\text{A}, 1\text{B}, 2\text{A}, 2\text{B}\}$. Furthermore, agents' effort choices are mutually independent. This is true because each agent j chooses his effort level non-cooperatively according to $\max\limits_{a_j} \mathrm{E}[w^s_j] - \kappa_j(a_j)$ and signals are additively separable in agents' efforts. Taken together, the information available on which to base incentives for bottom-level agents is identical for both organizational forms. The same argument applies to the top level agent. $\blacksquare$

Part (2)

For the second part of the proof, we compare the M-form to the U-form based on the (single dimensional) sufficient statistics the organizational forms give rise to. An aggregate that constitutes a sufficient statistic contains the same information as the basic signals for all agencies.[23] Thus, the comparison of M-form and U-form based on sufficient statistics allows to derive general results regardless of a particular incentive scheme.

To calculate the sufficient statistics, we first need to establish the joint density function of

[23] See Holmström (1979) for a detailed analysis of statistical sufficiency and aggregation and Amershi/Hughes (1989) for the superiority of sufficient statistics compared to non-sufficient statistics.

performance measures. However, this requires inverting the variance-covariance matrix, which is singular with disaggregated information and therefore not invertible. Hence, we need to proceed stepwise instead. In a first step, we aggregate the signals with identical sensitivities into two statistics for each organizational form. In a second step, we aggregate these two statistics into a single sufficient statistic per agent on which we base our comparison of organizational forms.

Step 1:

The first step is similar to Maskin et al. (2000), who take advantage of the fact that two performance measures with identical sensitivities are merely weighted to minimize noise. With M-form, the sensitivities of performance measures y_{1r}^M and $y_{2r}^M, r \in \{\text{A,B}\}$ are identical, hence, within the statistic for division r the respective performance measures are weighted according to

$$\min_{\lambda_r} Var[\lambda_r(\theta_1+\delta_r)+(1-\lambda_r)(\theta_2+\delta_r)], \qquad r=\text{A,B}, \tag{A.1}$$

with λ_r as the weight assigned to performance measure y_{1r}^M.

Accordingly, with U-form, performance measures y_{iA}^U and $y_{iB}^U, i \in \{1,2\}$ have the same sensitivity and the weights assigned to the performance measures of department i are calculated according to

$$\min_{\lambda_i} Var[\lambda_i(\theta_i+\delta_A)+(1-\lambda_i)(\theta_i+\delta_B)], \qquad i=1,2. \tag{A.2}$$

Solving (A.1) and (A.2) for λ_r and λ_i, respectively, and applying these weights yields the following statistics for M-form and U-form

$$\mathbf{\Psi^M}=\begin{pmatrix} a_A+\delta_A+\dfrac{\theta_1\sigma_2^2+\theta_2\sigma_1^2}{\sigma_1^2+\sigma_2^2} \\ a_B+\delta_B+\dfrac{\theta_1\sigma_2^2+\theta_2\sigma_1^2}{\sigma_1^2+\sigma_2^2} \end{pmatrix} \qquad \mathbf{\Psi^U}=\begin{pmatrix} a_1+\theta_1+\dfrac{\delta_A\sigma_B^2+\delta_B\sigma_A^2}{\sigma_A^2+\sigma_B^2} \\ a_2+\theta_2+\dfrac{\delta_A\sigma_B^2+\delta_B\sigma_A^2}{\sigma_A^2+\sigma_B^2} \end{pmatrix} \tag{A.3}$$

These expressions constitute sufficient statistics for the basic signals if the following condition holds (see, e.g., Feltham/Xie 1994)

$$\mathbf{Y^s} = \mathbf{\Xi^s \Psi^s} + \epsilon^{\mathbf{s}}, \qquad s \in \{\text{M,U}\},$$

where $\mathbf{Y^s}$ is the vector of basic signals, $\mathbf{\Xi^s}$ is a constant matrix and $\epsilon^{\mathbf{s}}$ is the independent residual noise vector. With the following expression, the condition holds and $\mathbf{\Psi^s}$ constitute sufficient statistics.

$$\mathbf{Y^s} = \begin{pmatrix} y^s_{A1} \\ y^s_{A2} \\ y^s_{B1} \\ y^s_{B2} \end{pmatrix}, \quad \mathbf{\Xi^M} = \begin{pmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 1 \end{pmatrix}, \quad \mathbf{\Xi^U} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{pmatrix}.$$

Step 2:

In the second step, we calculate the single sufficient statistic for every agent. As the results differ between agents (and organizational forms), but the underlying calculations are identical, we limit the proof to the sufficient statistic ψ^M_{Ad} for division manager A with M-form, where d denotes the disaggregated accounting system.

Denote the first (second) element of $\mathbf{\Psi^M}$ as $\mathbb{A}$ ($\mathbb{B}$). It is well-known from standard statistics (e.g., DeGroot 1970) that the statistic ψ^M_{Ad} is sufficient for the underlying signals if the joint density can be factorized as follows

$$f(\mathbb{A}, \mathbb{B}|a_A) = g[\psi^M_A(\mathbb{A}, \mathbb{B}), a_A] \;\; h(\mathbb{A}, \mathbb{B}), \tag{A.4}$$

where $h(\bullet)$ is independent of a_A and $g(\bullet)$ depends on $\mathbb{A}$ and $\mathbb{B}$ only through the statistic ψ^M_A.

For $\mathbb{A}$ and $\mathbb{B}$ as defined by (A.3), the joint density function is given by

$$f(\mathbb{A},\mathbb{B},a_A) = K\ \ exp\Big\{\Big[(\sigma_1^2+\sigma_2^2)\sigma_A^2\sigma_B^2+(\sigma_A^2+\sigma_B^2)\sigma_1^2\sigma_2^2\Big]^{-1}$$
$$\Big[\big[a_A^2\sigma_B^2(\sigma_1^2+\sigma_2^2)+a_A^2\sigma_1^2\sigma_2^2-2a_A\Big(\mathbb{A}((\sigma_1^2+\sigma_2^2)\sigma_B^2+\sigma_1^2\sigma_2^2)-\mathbb{B}\sigma_1^2\sigma_2^2\Big)\big]$$
$$-\big[(\mathbb{A}-\mathbb{B})^2\sigma_1^2\sigma_2^2+(\sigma_1^2+\sigma_2^2)(\mathbb{A}^2\sigma_B^2+\mathbb{B}^2\sigma_A^2)\big]\Big]\Big\},$$

where K is a constant. It is obvious that the expression in the last row is equal to $h(\mathbb{A},\mathbb{B})$ and the expression in the second row equals $g[\psi_{Ad}^M(\mathbb{A},\mathbb{B}),a_A]$. Hence, the condition (A.4) is met and the sufficient statistic for division manager A is obtained by weighting $\mathbb{B}$ and $\mathbb{A}$ according to $-\dfrac{\sigma_1^2\sigma_2^2}{\sigma_1^2\sigma_2^2+\sigma_B^2(\sigma_1^2+\sigma_2^2)} = -\dfrac{Cov[\mathbb{A},\mathbb{B}]}{Var[\mathbb{B}]}$. In addition, by inspection of (A.3) we see that $\mathbb{A}$ is action-informative for division manager A whereas $\mathbb{B}$ is insurance-informative. Based on this finding we establish the general weights L and M assigned to an insurance-informative signal y_l relative to an action-informative signal y_m (see also Banker/Datar 1989 and Amershi et al. 1990).

$$\frac{L}{M} = -\frac{Cov[y_l,y_m]}{Var[y_l]}. \tag{A.5}$$

Applying the weights of (A.5) to $\mathbb{A}$ and $\mathbb{B}$ yields the sufficient statistic for division manager A. The results for the remaining agents are derived analogously and fully expressed by their respective signal-to-noise ratios.

$$\phi_{Ad}^M = 1\cdot\Big(\frac{(\sigma_1^2+\sigma_2^2)\sigma_A^2\sigma_B^2+\sigma_1^2\sigma_2^2(\sigma_A^2+\sigma_B^2)}{(\sigma_1^2+\sigma_2^2)\sigma_B^2+\sigma_1^2\sigma_2^2}\Big)^{-1} \qquad \phi_{1d}^U = 1\cdot\Big(\frac{(\sigma_A^2+\sigma_B^2)\sigma_1^2\sigma_2^2+\sigma_A^2\sigma_B^2(\sigma_1^2+\sigma_2^2)}{(\sigma_A^2+\sigma_B^2)\sigma_2^2+\sigma_A^2\sigma_B^2}\Big)^{-1}$$
$$\phi_{Bd}^M = 1\cdot\Big(\frac{(\sigma_1^2+\sigma_2^2)\sigma_A^2\sigma_B^2+\sigma_1^2\sigma_2^2(\sigma_A^2+\sigma_B^2)}{(\sigma_1^2+\sigma_2^2)\sigma_A^2+\sigma_1^2\sigma_2^2}\Big)^{-1} \qquad \phi_{2d}^U = 1\cdot\Big(\frac{(\sigma_A^2+\sigma_B^2)\sigma_1^2\sigma_2^2+\sigma_A^2\sigma_B^2(\sigma_1^2+\sigma_2^2)}{(\sigma_A^2+\sigma_B^2)\sigma_1^2+\sigma_A^2\sigma_B^2}\Big)^{-1}$$

It is straightforward to show that $Var[\psi_r^M] < Var[\psi_i^U]$, $r = A,B$, $i = 1,2$, if (and only if) $\sigma_r < \sigma_i$, and vice versa. With identical sensitivities and lower (conditional) variance, any effort level for agent r with M-form can be induced at less cost compared to agent i with U-form. Thus, the M-form dominates the U-form from an incentive perspective. ■

Proof of Proposition 1:

The proof follows directly from the fact that the signal-to-noise ratio of the signal y_f^s for a given agent j is identical with both organizational forms (i.e., $\phi_{jf}^M = \phi_{jf}^U$). ■

Proof of Proposition 2:

Part (1)

The calculation of sufficient statistics follows the same line as in Proposition 0, i.e., signals are weighted such that the conditional variance is minimized. We first prove the results for bottom-level and middle-level agents, because their respective actions only affect a single signal. Without loss of generality, we again limit the proof to division manager A with M-form, the remaining proofs are analogous. The weight of the insurance-informative signal y_B^M relative to the action-informative signal y_A^M is given by $-\frac{\sigma_1^2+\sigma_2^2}{4\sigma_B^2+\sigma_1^2+\sigma_2^2}$ (this follows directly from (A.5)). Applying these weights to performance measures y_A^M and y_B^M yields the following sufficient statistic for division manager A[24]

$$\psi_A^M = 2a_A + \theta_1 + \theta_2 + 2\delta_A - \frac{(\theta_1 + \theta_2 + 2\delta_B)(\sigma_1^2 + \sigma_2^2)}{\sigma_1^2 + \sigma_2^2 + 4\sigma_B^2}.$$

Thus, we have $\mu_A^M = 2$ and $Var[\psi_A^M] = 4\sigma_A^2 + \dfrac{\sigma_1^2 + \sigma_2^2}{\sigma_1^2 + \sigma_2^2 + 4\sigma_B^2}$, i.e., sensitivity and (conditional) variance are as depicted in Table 2.1, and accordingly for the remaining bottom-level and middle-level agents.

In contrast, both signals are action-informative for the CEO. As they also have identical sensitivities, we proceed analogously to the first step of Proposition 0, i.e., performance measures

[24]For notational simplicity, we drop the subscript p to denote the partially aggregated accounting system.

y_A^M and y_B^M with M-form are weighted according to (A.1)-(A.2), yielding $\lambda = \frac{\sigma_B^2}{\sigma_A^2+\sigma_B^2}$. Applying these weights gives the following sufficient statistic for the CEO with M-form

$$\psi_c^M = 2a_c + \theta_1 + \theta_2 + \frac{2(\delta_B\sigma_A^2 + \delta_A\sigma_B^2)}{\sigma_A^2 + \sigma_B^2}.$$

It follows that $\mu_c^M = 2$ and $Var[\psi_c^M] = \sigma_1^2 + \sigma_2^2 + \dfrac{4\sigma_A^2\sigma_B^2}{\sigma_A^2 + \sigma_B^2}$, which is identical to the result in Table 2.1. It is readily checked that performance measures y_1^U and y_2^U with U-form are weighted according to $\lambda = \frac{\sigma_1^2}{\sigma_1^2+\sigma_2^2}$, which yields ψ_c^U. ■

Part (2)

The proof follows directly from the results presented in Table 2.1. ■

Proof of Corollary 1:

The proof follows from a comparison of the signal-to-noise ratios of the sufficient statistics. The principal prefers M-form to set incentives for the CEO if $\phi_c^M > \phi_c^U$, i.e., if

$$\begin{aligned}
& \frac{2}{\sigma_1^2 + \sigma_2^2 + \dfrac{4\sigma_A^2\sigma_B^2}{\sigma_A^2+\sigma_B^2}} && > \frac{2}{\sigma_A^2 + \sigma_B^2 + \dfrac{4\sigma_1^2\sigma_2^2}{\sigma_1^2+\sigma_2^2}} \\
\Leftrightarrow \quad & \sigma_1^2 + \sigma_2^2 + \frac{4\sigma_A^2\sigma_B^2}{\sigma_A^2+\sigma_B^2} && < \sigma_A^2 + \sigma_B^2 + \frac{4\sigma_1^2\sigma_2^2}{\sigma_1^2+\sigma_2^2} \\
\Leftrightarrow \quad & \frac{(\sigma_1^2-\sigma_2^2)^2}{\sigma_1^2+\sigma_2^2} && < \frac{(\sigma_A^2-\sigma_B^2)^2}{\sigma_A^2+\sigma_B^2}.
\end{aligned}$$

Note that the left-hand side strictly decreases as $\min\{\sigma_1, \sigma_2\}$ increases. Thus, there exists a unique cut-off value $\sigma_{\underline{i}}^t$, where $\sigma_{\underline{i}} = \min\{\sigma_1, \sigma_2\}$, such that the principal prefers the M-form on the top level if $\sigma_{\underline{i}} > \sigma_{\underline{i}}^t$. Accordingly, she prefers the M-form if $\sigma_{\underline{r}} > \sigma_{\underline{r}}^t$, where $\sigma_{\underline{r}} = \min\{\sigma_A, \sigma_B\}$

■

Proof of Corollary 2:

First, note that the signal-to-noise ratio of the sufficient statistics for middle-level and bottom-level agents differs only with respect to a constant. Hence, it suffices to consider the sufficient statistics for one level of agents.

Step 1: Intra-Level Comparison

Comparing division managers A and B with M-form, we obtain

$$\phi_A^M - \phi_B^M = \frac{2(\sigma_B^2 - \sigma_A^2)}{(\sigma_1^2 + \sigma_2^2)(\sigma_A^2 + \sigma_B^2) + 4\sigma_A^2\sigma_B^2}.$$

With $\sigma_B > \sigma_A$, there are more efficient incentives when motivating agent A. Likewise, with U-form, there are more efficient incentives when motivating agent 1 compared to agent 2 if $\sigma_2 > \sigma_1$. Hence, to show that the principal prefers M-form over U-form, it suffices to show that

$$\begin{array}{llll}
\phi_B^M > \phi_1^U & \text{if} & \sigma_2 > \sigma_1 \quad \text{and} & \sigma_B > \sigma_A \\
\phi_A^M > \phi_1^U & \text{if} & \sigma_2 > \sigma_1 \quad \text{and} & \sigma_A > \sigma_B \\
\phi_B^M > \phi_2^U & \text{if} & \sigma_1 > \sigma_2 \quad \text{and} & \sigma_B > \sigma_A \\
\phi_A^M > \phi_2^U & \text{if} & \sigma_1 > \sigma_2 \quad \text{and} & \sigma_A > \sigma_B
\end{array}$$

Step 2: Inter-Level Comparison

Without loss of generality, we limit the proof to the first of the above cases, the remaining proofs are analogous due to the symmetry of the model. Let $\sigma_2 > \sigma_1$ and $\sigma_B > \sigma_A$; then, the principal strictly prefers M-form over U-form if $\phi_B^M > \phi_1^U$, i.e., if

$$\frac{2}{4\Big(\sigma_B^2 + \dfrac{(\sigma_1^2 + \sigma_2^2)\sigma_A^2}{\sigma_1^2 + \sigma_2^2 + 4\sigma_A^2}\Big)} > \frac{2}{4\Big(\sigma_1^2 + \dfrac{(\sigma_A^2 + \sigma_B^2)\sigma_2^2}{\sigma_A^2 + \sigma_B^2 + 4\sigma_2^2}\Big)}$$

$$\Leftrightarrow \qquad \sigma_B^2 + \frac{(\sigma_1^2 + \sigma_2^2)\sigma_A^2}{\sigma_1^2 + \sigma_2^2 + 4\sigma_A^2} < \sigma_1^2 + \frac{(\sigma_A^2 + \sigma_B^2)\sigma_2^2}{\sigma_A^2 + \sigma_B^2 + 4\sigma_2^2}$$

$$\Leftrightarrow \sigma_1^2 - \sigma_B^2 > \frac{(\sigma_1^2 + \sigma_2^2)\sigma_A^2}{\sigma_1^2 + \sigma_2^2 + 4\sigma_A^2} - \frac{(\sigma_A^2 + \sigma_B^2)\sigma_2^2}{\sigma_A^2 + \sigma_B^2 + 4\sigma_2^2}$$

$$\Leftrightarrow \sigma_1^2 - \sigma_B^2 > \Delta_{B1} \equiv \frac{4\sigma_2^2\sigma_A^2(\sigma_1^2 + \sigma_2^2 - (\sigma_A^2 + \sigma_B^2) - (\sigma_2^2 - \sigma_A^2)(\sigma_1^2 + \sigma_2^2)(\sigma_A^2 + \sigma_B^2)}{(\sigma_1^2 + \sigma_2^2 + 4\sigma_A^2)(\sigma_A^2 + \sigma_B^2 + 4\sigma_2^2)}.$$

The left-hand-side of the equation increases linearly with σ_1^2, whereas for the right-hand-side we have

$$\frac{\partial \Delta_{B1}}{\partial \sigma_1^2} = \frac{4\sigma_A^2}{(\sigma_1^2 + \sigma_2^2 + 4\sigma_A^2)^2}.$$

As Δ_{B1} is concave in σ_1^2 and the left-hand side of the inequality shown above is strictly smaller than the right-hand side for $\sigma_1 = 0$ (i.e., $\lim_{\sigma_1 \to 0} \Delta_{B1} > -\sigma_B^2$), there is a unique cut-off value σ_1^{bm} such that M-form becomes beneficial. In general, if $\sigma_{\underline{i}} = \min\{\sigma_1, \sigma_2\}$ is sufficiently large ($\sigma_{\underline{i}} > \sigma_{\underline{i}}^{bm}$), the principal prefers M-form over U-form to set incentives for bottom-level and middle-level agents. The proof for the advantage of U-form over M-form dependent on $\sigma_{\underline{r}}^{bm}$ is analogous. ■

Proof of Proposition 3:

We have shown in Corollary 1 that the principal prefers the M-form to set incentives for the CEO if $\sigma_{\underline{i}} > \sigma_{\underline{i}}^t$. Likewise, Corollary 2 establishes that the M-form dominates the U-form for bottom-level and middle-level agents if $\sigma_{\underline{i}} > \sigma_{\underline{i}}^{bm}$. As the likelihood that the M-form is preferred strictly increases with $\sigma_{\underline{i}} = \min\{\sigma_1, \sigma_2\}$ on all hierarchical levels, it follows that there is a unique cut-off value $\sigma_{\underline{i}}^{firm}$ such that the M-form is beneficial to set incentives for all agents, and accordingly for $\sigma_{\underline{r}}^{firm}$. ■

Proof of Corollary 3:

The proof follows from substituting $\sigma_A = \sigma_A \equiv \sigma_R$ and $\sigma_1 = \sigma_2 \equiv \sigma_F$ into the signal-to-noise ratios of sufficient statistics for agents on all hierarchial levels. For the top level agent, we obtain

$$\phi_c^M = \phi_c^U = \frac{1}{2(\sigma_F^2 + \sigma_R^2)},$$

hence, performance measures with M-form and U-form constitute equivalent incentive statistics for the top level agent.

For bottom-level and middle-level agents, we obtain

$$\begin{aligned} \phi_r^M &= \phi_{ir}^M = \frac{1}{4}\Big(\frac{1}{\sigma_R^2} + \frac{1}{\sigma_F^2 + \sigma_R^2}\Big), \\ \phi_i^U &= \phi_{ir}^U = \frac{1}{4}\Big(\frac{1}{\sigma_F^2} + \frac{1}{\sigma_F^2 + \sigma_R^2}\Big), \qquad i = 1,2 \qquad r = \text{A,B}. \end{aligned}$$

Comparison of ϕ_r^M and ϕ_i^U completes the proof. ■

Proof of Corollary 4:

The proof follows directly from the text. ■

Appendix B: LEN-model with Partially Aggregated Information

Given that agency problems are independent within the framework of our model regardless of the organizational form, we limit the presentation of solutions to the (representative) middle-level agents j=A,B with M-form. For simplicity, we define Π_h^s as profit on hierarchical level $h \in \{\text{bottom, middle, top}\}$ with organizational form $s \in \{M, U\}$. Consequently, firm profit equals the sum of profits across hierarchical level, $\Pi^s = \sum_h \Pi_h^s$.

Within the LEN-framework, the compensation paid to the agents is a linear function of the performance measures defined by (3a), i.e.,

$$w_j^M = f_j^M + v_{jA}^M \, y_A^M + v_{jB}^M \, y_B^M, \qquad j = \text{A,B},$$

with f_j^M as agent j's fixed wage and v_{jr}^M as his incentive rate for performance measure y_r^M, r=A,B. In addition, agents have a exponential utility function and noise terms are normally distributed, hence, agent j's effort choice maximizes the following certainty equivalent

$$\begin{aligned} CE_j^M =& f_j^M + v_{jA}^M \, y_A^M + v_{jB}^M \, y_B^M - \frac{a_j^2}{2} \\ & - \frac{\rho}{2}\Big(v_{jA}^2(4\sigma_A^2 + \sigma_1^2 + \sigma_2^2) + v_{jB}^2(4\sigma_B^2 + \sigma_1^2 + \sigma_2^2) + 4v_{jA}v_{jB}(\sigma_1^2 + \sigma_2^2)\Big). \end{aligned} \tag{A.6}$$

Setting the first derivate of (A.6) with respect to a_j equal to zero and solving yields the following second-best effort choices

$$\begin{aligned} a_A^{\dagger} &= 2v_{AA}, \\ a_B^{\dagger} &= 2v_{BB}. \end{aligned} \tag{A.7}$$

The principal chooses contract parameters such that she maximizes profit net of compensation

$$\begin{aligned} \Pi_{middle}^M &= \sum_{j=A,B} a_j - \sum_{j=A,B} w_j^M \\ &= a_A + a_B - f_A^M - f_B^M - (v_{AA}^M + v_{BA}^M) \, y_A^M - (v_{AB}^M + v_{BB}^M) \, y_B^M. \end{aligned} \tag{A.8}$$

The principal sets the fixed payment for agent j=A,B such that his reservation utility is met. Since the latter is scaled to equal zero without loss of generality, f_j^M solves $CE_j^M = 0$. Substituting the result back into (A.8) yields

$$\Pi^M_{middle} = a_A + a_B - \frac{a_A^2}{2} - \frac{a_B^2}{2} - \frac{\rho}{2}\Big((v_{AA}^2 + v_{BA}^2)(4\sigma_A^2 + \sigma_1^2 + \sigma_2^2) + (v_{AB}^2 + v_{BB}^2)(4\sigma_B^2 + \sigma_1^2 + \sigma_2^2) + 2(v_{AA}v_{AB} + v_{BA}v_{BB})(\sigma_1^2 + \sigma_2^2)\Big) \tag{A.9}$$

Substituting the effort choices defined by (A.7) into (A.9) gives the principal's unconstrained optimization problem. Setting the first derivatives with respect to v_{jA} and v_{jB} equal to zero and solving yields the optimal incentive rates depicted in Table 2.2. Finally, substituting these results back into (A.9) gives the expected profit on the middle-level with M-form.

Table 2.2: Incentive Rates and Profits with the LEN-model and Partially Aggregated Information

Unit Managers

$$v^M_{km\ m} = D^{-1}_{kn}\Big[\sigma_1^2 + \sigma_2^2 + 4\sigma_n^2\Big] \qquad v^U_{km\ k} = D^{-1}_{lm}\Big[4\sigma_l^2 + \sigma_A^2 + \sigma_B^2\Big]$$

$$v^M_{km\ n} = D^{-1}_{kn}\Big[-\sigma_1^2 - \sigma_2^2\Big] \qquad v^U_{km\ l} = D^{-1}_{lm}\Big[-2\sigma_A^2 - \sigma_B^2\Big]$$

$$\Pi^M_{bottom} = \sum_n D^{-1}_{kn}[\sigma_1^2 + \sigma_2^2 + 4\ \sigma_n^2] \qquad \Pi^U_{bottom} = \sum_l D^{-1}_{lm}[4\sigma_l^2 + \sigma_A^2 + \sigma_B^2]$$

Division Managers | **Department Managers**

$$v^M_{mm} = D^{-1}_n\Big[\sigma_1^2 + \sigma_2^2 + 4\sigma_n^2\Big] \qquad v^U_{kk} = D^{-1}_l\Big[4\sigma_l^2 + \sigma_A^2 + \sigma_B^2\Big]$$

$$v^M_{mn} = D^{-1}_n\Big[-\sigma_1^2 - \sigma_2^2\Big] \qquad v^U_{kl} = D^{-1}_l\Big[-\sigma_A^2 - \sigma_B^2\Big]$$

$$\Pi^M_{middle} = \sum_n D^{-1}_n[\sigma_1^2 + \sigma_2^2 + 4\ \sigma_n^2] \qquad \Pi^U_{middle} = \sum_l D^{-1}_l[4\sigma_l^2 + \sigma_A^2 + \sigma_B^2]$$

CEO

$$v^M_{c\ m} = D^{-1}_{cn}\Big[2\sigma_n^2\Big] \qquad v^U_{c\ k} = D^{-1}_{cl}\Big[2\sigma_l^2\Big]$$

$$\Pi^M_{top} = D^{-1}_{cn}[2(\sigma_A^2 + \sigma_B^2)] \qquad \Pi^U_{top} = D^{-1}_{cl}[2(\sigma_1^2 + \sigma_2^2)]$$

$$k, l \in \{1, 2\}, k \neq l$$

$$m, n \in \{A, B\}, m \neq n$$

with

$$D_{kn} = (1 + 4r(\sigma_A^2 + \sigma_B^2))(\sigma_1^2 + \sigma_2^2 + 4\sigma_n^2) - 16r\sigma_n^4 \qquad D_{lm} = (1 + 4r(\sigma_1^2 + \sigma_2^2))(\sigma_A^2 + \sigma_B^2 + 4\sigma_l^2) - 16r\sigma_l^4$$

$$D_n = 2((1 + r(\sigma_A^2 + \sigma_B^2))(\sigma_1^2 + \sigma_2^2 + 4\sigma_n^2) - 4r\sigma_n^4) \qquad D_l = 2((1 + r(\sigma_1^2 + \sigma_2^2))(4\sigma_l^2 + \sigma_A^2 + \sigma_B^2) - 4r\sigma_l^4)$$

$$D_{cn} = (\sigma_A^2 + \sigma_B^2)(4 + r(\sigma_1^2 + \sigma_2^2)) + 4r\sigma_A^2\sigma_B^2 \qquad D_{cl} = (\sigma_1^2 + \sigma_2^2)(4 + r(\sigma_A^2 + \sigma_B^2)) + 4r\sigma_1^2\sigma_2^2$$

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3 Essay II: Task Complementarity, Group-Size, and the Choice of Performance Measures

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3.1 Introduction

The choice of performance measurement systems is one of the main concerns in accounting and accounting research (Christensen et al. 2010). Prior research has mostly focused on performance measurement for CEOs and paid relatively little attention to agents below the executive level despite their importance for the value of the firm (Bushman/Smith 2001). As the system of performance measurement employed to motivate and evaluate executives is often not appropriate on lower hierarchical levels (Baiman et al. 1995), a gap exists between practical relevance and theoretical foundation. In the present paper, I aim to narrow this gap by analyzing how complementary effects and group-size affect the principal's choice between aggregate and individual performance measures for agents below the executive level.

Notwithstanding the predominance of research on the executive level, several empirical studies are concerned with performance measurement on lower levels. These studies, however, do not yield a consistent view regarding the use of aggregate and individual performance measures in incentive contracts. For example, Hwang et al. (2009) study performance measurement in U.S. manufacturing plants and find that individual measures, aggregate measures, and a mixture of both are employed to approximately equal parts. In addition, Shaw/Schneier (1995) show that many firms, such as Motorola and Hewlett Packard Medical Products Group, predominantly use individual performance measures to compensate their workers, whereas Hansen (1997), Weiss (1987) and Ehrenberg/Milkovich (1987) find that aggregate measures are frequently preferred over individual measures.

In this paper, I claim that complementary effects and group-size are important factors for the choice of performance measures and might help to explain the mixed evidence. In particular, complementary effects are ubiquitous in modern organizations (Brickley et al. 2009; Milgrom/Roberts 1992) and are seen as a driving force for organizational design within firms (Hughes et al. 2005). Organizational design, in turn, is an important determinant for the choice of performance measures (Ittner/Larcker 2001), with existing evidence from the U.S. apparel industry (Dunlop/Weil 1996) and empiricial studies (Luft/Shields 2003). Thus, organizational design establishes a strong link between complementary effects and performance measurement which has not yet been analyzed theoretically.

A similarly strong link has been shown for group-size, where Ittner/Larcker (2002) provide empirical evidence that the choice of performance measures in worker incentive plans is contingent on the number of agents covered by an incentive-plan (i.e., group-size). Moreover, emphasizing the impact of group-size naturally relates my study to lower hierarchical levels (such as workers in large firms) or to flat hierarchies (as given, e.g., in start-up companies) rather than to executives, where accounting research is still scarce. Finally, group-size forms a key component of organizational design which has attracted considerable interest in the recent past (e.g., Liang et al. 2008; Ziv 2000). Hence, it is perspicuous to focus on these two factors to analyze the impact of organizational design on performance measurement. In particular, modern organizations need to adapt their performance measurement system to their organizational design in order to capitalize on complementary effects, which implies that complementarities and size interact. The present paper elaborates on this interactions to provide insights which are helpful for further empirical studies.

I conduct my analysis within a LEN-model where I initially assume that an entrepreneur (the principal) hires a group of identical agents to perform two complementary tasks (*bundled* organization) in the sense that effort exerted on one task increases the marginal productivity of effort on the other task *performed by the same agent*. The total number of tasks, and thus the group-size, is taken as given. When setting up her company, the principal decides on the design of the performance measurement system; with aggregate performance measurement, only group output is tracked, whereas individual performance measurement captures the outcome of each task separately. The joint installation of both systems is assumed to be prevented by limited resources (capital, personnel, or time), likewise, the identification of individual outcomes is generally more difficult due to the larger demand of scarce resources compared to the identification of aggregate outcome.[1] Consistent with prior research (Liang et al. 2008; Ziv 1993) I assume that the costs associated with utilizing scarce resources are reflected by individual signals' precision and that these costs increase with the number of individual outcomes that need to be measured (i.e., group-size). As a consequence, individual signals are noisier than the aggregate signal. On the other hand, they give a possible advantage over aggregate measurement due to the ability to fine-tune incentives, that is, to induce effort levels for each task separately. Given that each agent performs several tasks, this allows the principal to avoid a *loss from noncongruity* (Feltham/Xie 1994) resulting from a deviation of the effort allocation induced by an incentive contract from the first-best allocation, where efforts are contractible. Consequently, the principal has to trade-off the costs associated with less precision (i.e., risk premium payments) against the benefits of the fine-tuning advantage when she decides on the use of individual versus aggregate performance measurement.

In an extension, I allow for the principal to employ an *undbundled* organization, where she hires

[1] For instance, it takes significantly more time to observe individual outcomes rather than an aggregate output, which can lead to the necessity to hire additional employees (e.g., monitors). Similarly, the information that can be processed by an information system is generally limited (Fellingham/Schroeder 2007; Marschak/Reichelstein 1998; Melumad et al. 1995), potentially requiring a more expensive information system. Holding resources constant then puts constraints on the quality of individual performance measures. These constraints are more severe in larger groups because the utilization of the scarce resource *for each observation* decreases.

one agent per task. The total number of tasks is held constant such that the principal doubles the group-size with unbundling compared to bundling. Whereas unbundling solves any congruity issues, it comes at the costs of the foregone complementarity because each agent performs only a single task (Fellingham/Schroeder 2007; Nikias et al. 2005; Zhang 2003). Hence, the impact of complementary effects on the trade-off between congruity and risk is critical for the principal's joint decision on organizational design (bundling vs. unbundling) and performance measurement (individual vs. aggregate).

An obvious result of the analysis is that aggregate performance measurement is preferred in larger groups. As the precision of individual measures decreases as group-size increases, the performance measurement becomes too coarse, which outweighs the fine-tuning advantage. Interestingly, in a bundled organization, this effect is amplified by the task complementarity, which strictly favors aggregate performance measurement. The reason is that the deviation between the first-best effort allocation and the allocation with an aggregate signal is decreased by the task complementarity. In other words, the aggregate signal becomes more congruent with stronger complementary effects. Hence, the fine-tuning advantage with individual signals is diminished. Even worse, congruity with individual signals decreases with the task complementarity. This is due to the fact that complementarities introduce an interdependence between tasks which prevents the principal from inducing the first-best effort allocation with individual signals. Moreover, I show that the likelihood that aggregate performance measurement is employed is greater if the principal's decision on task assignment is taken into account. As unbundling is strictly detrimental with individual signals but might well be beneficial with an aggregate signal, the likelihood that an aggregate signal is preferred over individual signals is increased if the principal can choose between bundling and unbundling complementary tasks.

Several implications with regard to optimal performance measurement systems can be derived from my results. First, group-size is an important determinant of performance measurement systems and, consequently, has a great bearing on incentives. Therefore, it should be controlled for in empirical compensation studies, e.g., by considering the number of agents that are compensated based on the same aggregate measure or whose performance is assessed by the same superior (span-of-control). This might help to gain a thorough understanding of firms' reliance on aggregate or individual performance measures. Moreover, complementary effects between tasks have an important impact on the interdependence of performance measurement and size. In particular, the alleged benefit of individual performance measures (i.e., the fine-tuning advantage) is dampened in the presence of a task complementary, thus, favoring the use of aggregate measures.

My study is related to Arya et al. (2004) who show that a benefit of aggregate performance measurement stems from an enrichment of the information available with respect to an upstream agent's effort in a sequential production setting. Similarly, Nikias et al. (2005) address performance measurement with sequential production and find that aggregation is beneficial because it allows the principal to take advantage of the agent's uncertainty with respect to the outcome of his first task. In addition, they find that the benefits of aggregate performance measurement are diminished by complementary effects. Contrary to these studies, I derive my results within a simultaneous production setting, which excludes the benefits from aggregation underlying their analyses. More precisely, simultaneous production does neither allow for an enrichment of information, nor for capitalizing on agents' uncertainty. I show that this substantially alters the impact of the task complementarity, which affects both of an agent's effort choices at the same time. Similar to my findings, Autrey (2005) and Adams (2006) show that the advantage of aggregate performance measures increases with complementary effects. Moreover, to the best of my knowledge, Adams (2006) is the only prior study to incorporate group-size and complementarity in the analysis. However, both studies assume that complementarities arise only between agents and not between a single agent's tasks. Moreover, they consider an aggregate signal which is able to capture the complementary effects. Consequently, neither study takes into account the impact of task complementarities on congruity, which is one of the major takeaways of my study.

The remainder of the paper is organized as follows. In Section 3.2 I lay out the basic model and derive the optimal linear contracts with aggregate and individual performance measurement. Section 3.3 analyzes the optimal performance measurement for a given task assignment and Section 3.4 considers the impact of task complementarities on congruity. Section 3.5 extends the analysis to the joint choice of organizational design and performance measurement and Section 3.6 concludes.

3.2 The Model

3.2.1 Task Complementarity, Payoff, Preferences, and Performance Measures

I consider a single-period setting in which a risk neutral entrepreneur (i.e., the principal) contracts with a group of identical agents to sell two products (indexed by $k = 1, 2$) on n independent markets, which are held constant throughout the analysis. The effort exerted on sales of product k on market j, $j = 1, \dots n$ is denoted by a_{jk} and is personally costly to the agents. When setting up the firm, the principal needs to decide on its organizational design, i.e., how to assign the given set of tasks to agents. Initially, I assume that she employs a *bundled* organization, where each agent is responsible for selling both products on his market, that is, agent j exerts effort a_{j1} and

a_{j2}.[2] Moreover, each agent's selling efforts are associated with a positive task complementarity in the sense that effort exerted on one task affects the marginal productivity of effort exerted on the other task. For example, if agent j puts a lot of effort into selling product 1 to the customers on his market by taking due care of their needs and establishing a good personal relationship, this increases the sales of product 2 on the same market. This assumption is relaxed at a later stage, when I consider the case of an *unbundled* organization, where agents are responsible for selling a single product on their respective market. In this case, the complementarities are lost because the products on a given market are sold by different agents (Fellingham/Schroeder 2007; Nikias et al. 2005; Zhang 2003).

Gross payoff accrues directly to the principal and is assumed to be non-contractible. It is given by

$$x = \sum_{j=1}^{n} \Big(b_1 a_{j1} + b_2 a_{j2} + \beta a_{j1} a_{j2} \Big),$$

where $b_k, k = 1, 2$ represents the payoff productivities of the agents' efforts and $0 \leq \beta \leq 1$ reflects the task complementarity. Note that productivities with respect to a given task are identical for all agents, thus focusing the analysis on the impact of performance measurement rather than on agents' characteristics.

The agents' preferences are characterized by a negative exponential utility function, $u_j = -\exp\{-\rho(w_j^\tau - \kappa_j)\}$, where ρ is an agent's absolute risk aversion, $\kappa_j = 1/2(a_{j1}^2 + a_{j2}^2)$ is agent j's cost of effort, and w_j^τ denotes his compensation.

As gross payoff is assumed to be non-contractible, the principal decides on the performance measurement system τ to provide signals of the agents' efforts on which incentives can be based;

[2]Limiting the agents' action space is common in the literature (e.g., Corts 2007; Hughes et al. 2005; Besanko et al. 2005; Nikias et al. 2005; Zhang 2003) and goes without loss of generality given that two tasks are generally sufficient to analyze multi-task issues (Feltham/Xie 1994). Hence, extending the agents' action space to more than two tasks would dampen the tractability of the analysis without providing additional insights.

given a performance measurement system, she designs incentive contracts to maximize gross payoff net of agents' compensation, i.e., she maximizes

$$\Pi^{\tau} = x - \sum_{j=1}^{n} \mathrm{E}[w_j^{\tau}]. \tag{1}$$

The principal decides whether to install an individual ($\tau = i$) or an aggregate ($\tau = a$) performance measurement system. The measurement systems are mutually exclusive, e.g., because of large set-up costs associated with their installation or due to a lack of resources (personnel, capital, or time).[3] With aggregate performance measurement only group performance is tracked, for example, overall revenue from sales (sales of both products across all markets). Hence, the information provided with respect to sales of a single product on a given market is rather coarse, which means that no distinct information is available for a single agent's performance. The aggregate signal is given by

$$y_a = \sum_{j=1}^{n} \Big(a_{j1} + a_{j2} \Big) + \epsilon_a,$$

where $\epsilon_a \sim (0, \sigma^2)$ is a normally distributed noise term reflecting random events beyond the agents' control. Consistent with previous literature (Hofmann/Rohlfing 2012; Hughes et al. 2005), I assume that the measurement system simplifies and condenses information such that the performance measure is not able to capture the task complementarity.

In contrast, an individual performance measurement system captures the outcome of every single task and therefore provides a finer representation of information.[4] However, tracking individual performance is usually more difficult than measuring aggregate output (Arya et al.

[3] Similar assumptions can be found in Autrey (2005) and Arya et al. (2004).

[4] Employing these extreme measurement systems is convenient as it allows to clearly exemplify the trade-off between aggregate and individual performance measurement. Additionally incorporating intermediate systems - such as measures for a single product across all markets - does not yield further significant insights as the basic trade-off is unchanged but the tension between aggregate and individual measurement is less demonstrative.

2004; Hansen 1997) due to identification problems and the attention that needs to be devoted to single outcomes. For instance, it might be hard to track revenue from sales for each product on every market separately if agents have discretion over the conditions they offer their customers, e.g., offering discounts when cross-selling products. Moreover, these difficulties increase with the number of observations as it is harder to track individual outcomes on an increasing number of markets (Liang et al. 2008; Ziv 2000; Ziv 1993). Particularly, there are often limits to the amount of information that can be processed (Fellingham/Schroeder 2007; Marschak/Reichelstein 1998; Melumad et al. 1995) or the principal might conduct the performance measurement herself. Then, the opportunity costs of observing individual outcomes become larger and the time spent on every single observation decreases as the number of observations increases. Most likely, spending less time on an observation yields a less precise measurement.[5]

I formalize this general assertion by the function $n^\gamma, \gamma > 1$, which captures that each individual measurement becomes noisier as the number of observations (measured by group-size) increases.[6] With individual performance measurement, signals are given by

$$y_{jk} = a_{jk} + \epsilon_{jk}, \qquad k = 1, 2 \quad \text{and} \quad j = 1, \ldots, n,$$

where ϵ_{jk} are mutually independent normally distributed parameters capturing random events beyond the agents' control, $\epsilon_{jk} \sim N(0, n^\gamma \sigma^2)$. The parameter γ reflects the severity of the measurement problem, where greater values of γ imply that the measurement of individual signals becomes increasingly noisy as group-size increases.

[5]Supporting this reasoning, empirical evidence shows that the value of aggregated information is greater with higher uncertainty (Gul/Chia 1994) and that the difficulty to obtain individual performance measures increases with firm-size (Cadman et al. 2010).

[6]Alternatively, the number of observations could be captured by the number of tasks which are separately observed, given that each agent performs exactly two tasks. This would, however, not change the results but require some additional notation.

3.2.2 Optimal Linear Contracts with Individual Performance Measurement

With an individual performance measurement system ($\tau = i$), the principal offers each agent j a linear incentive contract $z_j^i = (f_j^i, \mathbf{v_j^i})$, where f_j^i is agent j's fixed wage and $\mathbf{v_j^i} = (v_{j1} \;\; v_{j2})$ is the vector of incentive rates for performance measures $y_{jk}, k = 1, 2$. Given the incentive contract z_j^i and performance measures defined above, agent j's compensation is

$$w_j^i = f_j^i + \sum_{k=1,2} v_{jk}\, y_{jk}.$$

Note that performance measures $y_{lk}, l = 1, \ldots, n, l \neq j$, are not used to incentivize agent j because they are not (conditionally) controllable by this agent (that is, they cannot be used to induce effort or insure the agent against risk).

Agent j chooses his effort levels a_{jk} such that they maximize his certainty equivalent. With linear contracts, exponential utility, and normally-distributed noise-terms, his ex ante certainty equivalent is characterized by

$$CE_j^i = f_j^i + \sum_{k=1,2} \left(v_{jk}\mathrm{E}[y_{jk}] - {}^1\!/\!{}_2\big(a_{jk}^2 + \rho v_{jk}^2 n^\gamma \sigma^2\big)\right). \tag{2}$$

Differentiating (2) with respect to a_{jk} and solving yields agent j's second-best effort levels

$$a_{jk}^\dagger = v_{jk}, \qquad k = 1, 2. \tag{3}$$

Individual performance measures provide the principal with the means to induce effort for each of the agent's tasks separately, i.e., she can fine-tune incentives. Furthermore, since agents' effort choices are mutually independent, the principal faces n independent and identical agency problems.

When choosing the contract parameters, the principal has to take into account that the agents will accept the contract only if it provides them at least with their net reservation wage, which is assumed to equal zero without loss of generality ($CE^i_j \geq 0$). Since the fixed payments do not affect the agents' effort choices, the principal sets f^i_j such that $CE^i_j = 0$. Substituting $f^{i\dagger}_j$ and (3) into (1) gives the principal's unconstrained optimization problem. Setting the first derivatives with respect to v_{jk} equal to zero and solving gives the following optimal incentive rates. Substituting the optimal incentive rates back into (1) yields the expected net profit.

Lemma 1: With individual performance measurement, the optimal incentive rates and the principal's expected payoff are given by

$$v^\dagger_{jk} = \frac{b_k(1+\rho\, n^\gamma\, \sigma^2) + \beta\, b_m}{(1+\rho\, n^\gamma\, \sigma^2)^2 - \beta^2} \qquad k, m = 1, 2, k \neq m \qquad \text{(4a)}$$

$$\Pi^{i\dagger} = \frac{n((b_1^2 + b_2^2)(1+\rho\, n^\gamma\, \sigma^2) + 2\,\beta\, b_1\, b_2)}{2((1+\rho\, n^\gamma\, \sigma^2)^2 - \beta^2)} \qquad \text{(4b)}$$

All proofs are in the Appendix.

Whereas the incentive problems are independent between agents, the task complementarity introduces an interdependence between a given agent's tasks. In addition to the direct effect of effort devoted to task $k = 1, 2$ (through the productivity b_k) there is also an indirect effect (through the complementarity β). Hence, the principal increases $v^\dagger_{jk}$ as βb_m increases in order to capitalize on the task complementarity. In other words, she takes advantage of the means to fine-tune incentives. In particular, the increase of $v^\dagger_{jk}$ in β is greater if b_m is large (i.e., $\frac{\partial^2 v^\dagger_{jk}}{\partial\beta\partial b_m} > 0$).

In addition, incentives decrease with group-size n and the severity of the measurement problem γ. As the number of agents being observed increases, the precision of each observation decreases. Thus, a marginal increase of group-size yields a reduction of incentives for all agents.[7]

[7] Contrary to the study at hand, Liang et al. (2008) allow for an endogenous determination of optimal group-size and an analysis of the consequences for optimal incentives.

3.2.3 Optimal Linear Contracts with Aggregate Performance Measurement

If an aggregate performance measurement system is employed (τ=a), only a single incentive rate for each agent j is part of the linear incentive contract $z_j^a = (f_j^a, v_j)$.[8] Consequently, agent j's compensation is given by

$$w_j^a = f_j^a + v_j \, y_a,$$

yielding the following certainty equivalent

$$CE_j^a = f_j^a + v_j \, y_a - 1/2 \left(a_{j1}^2 + a_{j2}^2 + \rho v_j^2 \sigma^2 \right). \tag{5}$$

Comparing (5) to (2), it is obvious that the effort costs are identical because agents are assigned the same two tasks irrespective of the performance measurement system. Contrary to individual performance measurement, however, the risk premium is independent of group size. Furthermore, it contains only a single incentive rate, which is used to motivate the agent to exert effort on both tasks. This is reflected by the agent's effort choices, which are obtained by differentiating and solving (5) with respect to a_{jk}

$$a_{jk}^{\ddagger} = v_j, \qquad k = 1, 2. \tag{6}$$

Thus, changing the incentive rate v_j yields an identical change of effort levels because the aggregate signal is equally sensitive to effort on both tasks. Consequently, the principal cannot fine-tune incentives on individual tasks. Similar to the previous section, the principal chooses f_j^a such that $CE_j^a = 0$, takes into account the effort choices (6), differentiates and solves to obtain the optimal incentive rate. The resulting incentive rate for agent j and the principal's expected payoff are summarized in Lemma 2.

[8] To avoid notational clutter, the incentive rate does not have a superscript. Ambiguity is precluded by the fact that incentive rates with individual measurement have two subscripts rather than only one (i.e., v_{jk} versus v_j).

Lemma 2: With aggregate performance measurement, the optimal incentive rate and the principal's expected payoff are given by

$$v_j^{\ddagger} = \frac{b_1 + b_2}{2 + \rho\,\sigma^2 - 2\beta} \tag{7a}$$

$$\Pi^{a\ddagger} = \frac{n(b_1 + b_2)^2}{2(2 + \rho\,\sigma^2 - 2\beta)}. \tag{7b}$$

Unlike the case of individual performance measurement, the incentive rate $v_j^{\ddagger}$ does not reflect differences in the indirect productive effects between tasks (i.e., $\beta b_k, k = 1, 2$). Instead, the task complementarity has an increasing effect on the incentive rate independently of productivities, i.e., $\frac{\partial v_j^{\ddagger}}{\partial \beta} > 0$ and $\frac{\partial^2 v_j^{\ddagger}}{\partial \beta \partial b_k} = 0, k = 1, 2$. If the principal wants to capitalize on the task complementarity, the inability to fine-tune incentives forces her to induce equally more effort on both tasks.

3.3 Optimal Performance Measurement with given Organizational Design

To determine the optimal performance measurement system with a bundled organization, the principal's expected payoffs with individual performance measures (4b) and the payoff with an aggregate performance measure (7b) are compared. In order to emphasize the different factors influencing the choice of performance measures, I first analyze the basic trade-off between individual and aggregate signals for each factor separately before I turn to the combined analysis.

3.3.1 Basic Trade-off

From the previous analysis it is obvious that there are two key determinants for the choice of optimal performance measures. First, the principal takes into account the risk associated with aggregate and individual signals. As individual performance measures are generally noisier than the aggregate signal and because individual measurement requires to pay two risk premia per agent, risk considerations favor the use of an aggregate performance measure. Second, the principal considers the gains from the possibility to fine-tune incentives, which is only given with individual performance measures.

The inability to fine-tune incentives with an aggregate measure is meaningful because the agents perform several tasks. Feltham/Xie (1994) establish that the principal faces a *loss from noncongruity* if the allocation of an agent's efforts on several tasks differs from the first-best allocation where efforts are contractible, that is, whenever $a^*_{j1}/a^*_{j2} \neq a^\tau_{j1}/a^\tau_{j2}, \tau = \dagger, \ddagger$.[9] In particular, agents choose relative effort levels on the two tasks according to their impact on expected compensation, whereas the principal prefers an allocation of efforts relative to their impact on gross payoff. As individual performance measures provide her with the means to induce effort on each task separately, whereas she cannot change the effort allocation with an aggregate performance measure, the following result regarding the principal's choice is straightforward.

Lemma 3a: Assuming that a congruity problem exists and agents are risk neutral, the principal strictly prefers individual performance measurement.

Absent risk considerations, the benefits of aggregate performance measurement are foregone, whereas the benefit arising from the ability to cope with congruity issues by using individual measures is maintained.

On the other hand, if there is no congruity problem, the advantage of individual performance measures no longer holds and the choice of performance measures is made solely based on risk

[9]Note that the principal can avoid a loss from noncongruity with individual signals, given that she is always able to induce the first-best effort allocation. However, I refer to noncongruity if the allocation of efforts induced by the principal's choice of incentive rates deviates from the first-best effort allocation. This point is explored in greater detail in section 3.4.

considerations. Since individual performance measures are noisier than the aggregate measure, the following result is obtained.

Lemma 3b: Assuming that there is no congruity problem and agents are risk averse, the principal strictly prefers aggregate performance measurement.

If the effort allocation induced by the aggregate signal is equal to the first-best allocation, the principal employs an aggregate signal as this is the least costly way to incentivize agents. More precisely, the aggregate signal is associated with lower noise and therefore yields lower risk premium payments compared to individual signals.

3.3.2 Principal's Choice of Performance Measurement System

Whereas the isolated analysis undertaken above provides insights into the basic trade-off between risk and congruity, the effects are most likely to occur concurrently in many cases. For this reason, I analyze the choice of optimal performance measures based on both effects combined. It is intuitively clear that the aggregate performance measure is beneficial if the precision of individual signals is low. As the latter decreases with the number of agents being observed, the likelihood that the principal is better off with an aggregate measure increases with group-size. The following Proposition summarizes the principal's choice with regard to the performance measurement system.

Proposition 1: The principal strictly prefers aggregate to individual performance measurement, if (and only if) $n > n_1^*$, where

$$n_1^* = \left(\Big(2(\rho\sigma^2(b_1+b_2)^2)\Big)^{-1} \Big((b_1^2+b_2^2)(\rho\sigma^2-2\beta) - 4b_1b_2 \right. \tag{8}$$

$$\left. + \sqrt{(4\beta^2 + (2\beta-(2+\rho\sigma))^2)(b_1^2+b_2^2)^2 + 8\beta b_1 b_2((2+\rho\sigma^2)(b_1+b_2)^2 - 2\beta b_1 b_2)}\Big) \right)^{1/\gamma}.$$

The impact of group-size on the choice of performance measures is twofold. On the one hand, it impacts on risk as the individual signals' noise increases convexly with the size of the group, because $\mathrm{Var}[y_{jk}] = n^{\gamma}\sigma^2, \gamma > 1$. On the other hand, it affects the loss from noncongruity for each of the agents. The following Corollary 1 summarizes the respective comparative static results for the cut-off value n_1^*.

Corollary 1: The cut-off value n_1^*

(1) decreases in the severity of the measurement problem,

i.e., $\frac{\partial n_1^*}{\partial \gamma} < 0$,

(2) decreases in the task complementarity,

i.e., $\frac{\partial n_1^*}{\partial \beta} < 0$.

Consistent with the argument made above, the cut-off value decreases in the severity of the measurement problem because greater values of γ imply that group-size has a stronger impact on individual signals' precision, thereby increasing the risk-premium payments. In addition, n_1^* decreases in the task complementarity β. Consequently, aggregate performance measurement is expected to occur in firms where agent perform complementary tasks which are hard to track individually (e.g., investment counseling). With low complementary effects, in contrast, a firm of identical size and with a similar measurement system (in terms of precision) could be better off with individual measurement. Hence, task complementaritites are an important determinant for the choice of performance measures and should be controlled for in empirical studies in the field of performance measurement. For example, firms within the same industry (measured by SIC codes) are frequently assumed to exhibit similar production technologies (Davis/Thomas 1993). If such firms differ with respect to the assignment of tasks to agents, this might point towards differences with respect to the degree of complementary effects, which in turn implies differences in the performance measurement.

The following section provides further details on the impact of the task complementarity on the choice of performance measures. Particularly, it focuses on the impact of the task complementarity on congruity because the second influencing factor (i.e., risk) is independent of complementary effects.

3.4 Impact of Task Complementarity on Congruity

As established in the previous section, the principal faces a loss from noncongruity if the allocation of an agent's efforts on his tasks differs from the effort allocation preferred by the principal. Given that effort costs are identical for both tasks performed by an agent, coventional wisdom (e.g., Feltham/Xie 1994) suggests that the principal prefers an allocation of efforts according to their relative impact on gross payoff (i.e., $a_1^*/a_2^* = b_1/b_2$). However, this standard result does not hold in the presence of a task complementarity. Instead, the principal prefers the following first-best effort allocation.

$$\frac{a_{j1}^*}{a_{j2}^*} = \frac{b_1 + \beta b_2}{b_2 + \beta b_1}. \tag{9}$$

Complementary effects increase the marginal productivity of effort without changing effort costs. Consequently, optimal effort levels are increased by the impact of the task complementarity. Moreover, the increase is greater for the less productive task, that is, $\partial a_{j1}^*/\partial\beta > \partial a_{j2}^*/\partial\beta$ if $b_2 > b_1$, and vice versa. Effort levels thus converge as the complementarity increases and they are identical with perfect complementarity (i.e., $\lim\limits_{\beta\to 1} a_{j1} = \lim\limits_{\beta\to 1} a_{j2} = b_1 + b_2$). Intuitively, increasingly strong complementary effects imply that the marginal productivity of effort on the less productive task increases to a larger degree and therefore approaches that of the more productive tasks.

With aggregate performance measurement, in contrast, the principal is not able to induce effort levels according to their increased marginal productivities. Rather, compensating agents based on the aggregate signal yields identical effort levels on both tasks, regardless of complementary effects, i.e.,

$$\frac{a^{\ddagger}_{j1}}{a^{\ddagger}_{j2}} = 1. \tag{10}$$

With identical effort costs, agents choose effort levels according to their relative impact on expected compensation. As the aggregate measure is equally sensitive to both tasks performed by an agent (i.e., $\partial \mathrm{E}[y_a]/\partial a_{j1} = \partial \mathrm{E}[y_a]/\partial a_{j2}$), agents exert identical effort on both tasks. Moreover, the aggregate signal does not capture the task complementarity such that it does not have an impact on the effort allocation. Consequently, the difference between the first-best effort allocation and the allocation with aggregate performance measurement varies with β. To analyze this point in greater detail, δ_a is established as a measure of noncongruity based on the findings of Feltham/Xie (1994). Noncongruity arises whenever the first-best effort allocation deviates from the allocation with an aggregate measure, that is, whenever $a^*_{j1}/a^*_{j2} \neq a^{\ddagger}_{j1}/a^{\ddagger}_{j2}$. Taking into account the effort-levels defined by (9) and (10), rearranging terms and squaring the results to avoid a negative measure then yields

$$\delta_a = (1-\beta)^2(b_1 - b_2)^2.$$

Hence, the aggregate measure is said to be noncongruent unless $\delta_a = 0$, that is, unless task productivities are identical ($b_1 = b_2$) or the tasks are perfectly complementary ($\beta = 1$). Inspection of (9) reveals that, in both cases, $a^*_{j1}/a^*_{j1} = 1$, meaning that the first-best effort allocation is identical to the allocation with an aggregate signal. Moreover, δ_a decreases as β increases, which implies that the aggregate measure is more congruent when complementary effects are stronger. Hence, complementary effects favor the use of an aggregate measure because they diminish the disadvantage arising from the inability to fine-tune incentives even if the aggregate measure does not capture the task complementarity.

Contrary to aggregate performance measurement, individual signals provide the principal with the means to fine-tune incentives, that is, to motivate effort on each task separately. Hence, she can take advantage of individual signals by inducing effort levels according to their marginal productivity. As a consequence, the impact of the task complementarity is reflected in the effort allocation with individual performance measurement. Based on the effort choices (3) and incentive rates established by (4a) the following result is obtained

$$\frac{a_{j1}^{\dagger}}{a_{j2}^{\dagger}} = \frac{b_1 + \beta b_2 + b_1 \rho n^{\gamma} \sigma^2}{b_2 + \beta b_1 + b_2 \rho n^{\gamma} \sigma^2}. \tag{11}$$

Similar to First best, effort levels increase with complementary effects and the increase is larger for the less productive task. In this respect, the first two elements in the numerator and denominator of (11) are identical to (9), whereas the third element (i.e., $b_k \rho n^{\gamma} \sigma^2,\ k = 1, 2$) differs. It turns out that this difference has a significant impact on the measure of noncongruity with individual measures, which is again obtained by comparison of a_{j1}^{*}/a_{j2}^{*} and $a_{j1}^{\dagger}/a_{j2}^{\dagger}$, as defined by equations (11) and (9).

$$\delta_i = (\rho n^{\gamma} \sigma^2 \beta)^2 (b_1^2 - b_2^2)^2.$$

The effect with respect to the productivities is basically the same as with an aggregate measure because a larger difference between b_1 and b_2 yields an increased measure of noncongruity. In sharp contrast to aggregate measurement, however, δ_i strictly increases with the task complementarity. Even more, congruity with an aggregate signal is achieved with perfect complementarity ($\delta_a = 0$ if β=1), whereas it is achieved with individual signals if tasks are not complementary at all ($\delta_i = 0$ if β=0). This result is quite surprising, given that the principal can always induce the first-best effort allocation with individual performance measures. As a matter of fact, however, the complementarity prevents her from doing so. The following Proposition summarizes the impact of complementarity effects on congruity.

> **Proposition 2:** Increasingly strong complementary effects increase congruity with aggregate performance measurement and decrease congruity with individual performance measurement, i.e., $\frac{\partial \delta_a}{\partial \beta} < 0$ and $\frac{\partial \delta_i}{\partial \beta} > 0$, unless $b_1 = b_2$.

Whereas the impact of the task complementarity on congruity with an aggregate signal has been explained above, the rationale for individual signals needs to be explained by taking a closer look at the principal's decision problem with regard to optimal effort levels.

In First best, she trades off the agents' marginal costs of effort against the marginal productivities, where the latter are increased by the task complementarity. As the marginal costs are identical for both of an agent's tasks, First best foresees an allocation of efforts according to their marginal productivities. Considering Second best, marginal productivities remain identical whereas the marginal costs of inducing effort consist of the risk premium that the principal needs to pay the agents in addition to the effort costs. Hence, the difference between First best and individual performance measurement stems from the impact of the risk premium, which is reflected in the third term in (11).

Assume that (without loss of generality) $b_1 > b_2$. In this case, $a^{\dagger}_{j1}/a^{\dagger}_{j2} > a^*_{j1}/a^*_{j2} > 1$, that is, the principal induces more effort on task 1 than on task 2 and the effort on task 1 compared to task 2 is relatively lower in First best than with individual signals. As the marginal costs of (inducing) effort are lower in the first-best situation, the principal takes greater advantage of the indirect productive effect in First best compared to individual signals. Consequently, if the principal wants to avoid a loss from noncongruity, she needs to induce a higher effort level on task 2, which comes at the additional costs of a higher risk premium. Hence, the risk premium prevents the principal from fully exploiting the tasks' increased productivity.

In particular, the marginal benefit of increasing a_{j2} is $b_2 + \beta b_1$. Thus, effort on task 2 is already associated with the higher task productivity b_1 but to a lower degree than a_{j1} (because $1 \geq \beta \geq 0$). Since total effort levels are reduced by the risk premium relative to First best ($a^*_{jk} > a^\dagger_{jk}, k = 1, 2$), the principal reduces a_{j1} at a lower rate than a_{j2}. Thus, she deviates from the first-best effort allocation and induces a relatively higher effort level on task 1 than on task 2, thereby increasing the benefit from the direct productive effect (b_1) in return for some of the indirect productive effect (βb_1) that is associated with effort on task 2.

The result of Proposition 2 has important implications for accounting research because it puts the alleged benefits of individual performance measurement into perspective. Particularly, conventional wisdom suggests that the main benefit of individual signals stems from the ability to fine-tune incentives when agents perform multiple tasks (e.g., Corts 2007). When the impact of complementary effects is taken into account, however, this argument does not apply. Instead, the fine-tuning advantage diminishes with increasingly strong task complementarities whereas the benefit of aggregate performance measurement (i.e., less risk exposure) remains. Consequently, the principal does not necessarily need to trade off the costs and benefits of aggregate measurement, but rather prefers an aggregate signal based on both risk *and* congruity considerations. This rationale might help to explain the widespread use of aggregate performance measures despite the common practice of assigning several tasks to agents.

For illustration purposes, the following figure depicts the effort allocation in the first-best situation and with individual and aggregate performance measurement dependent on the task complementarity.

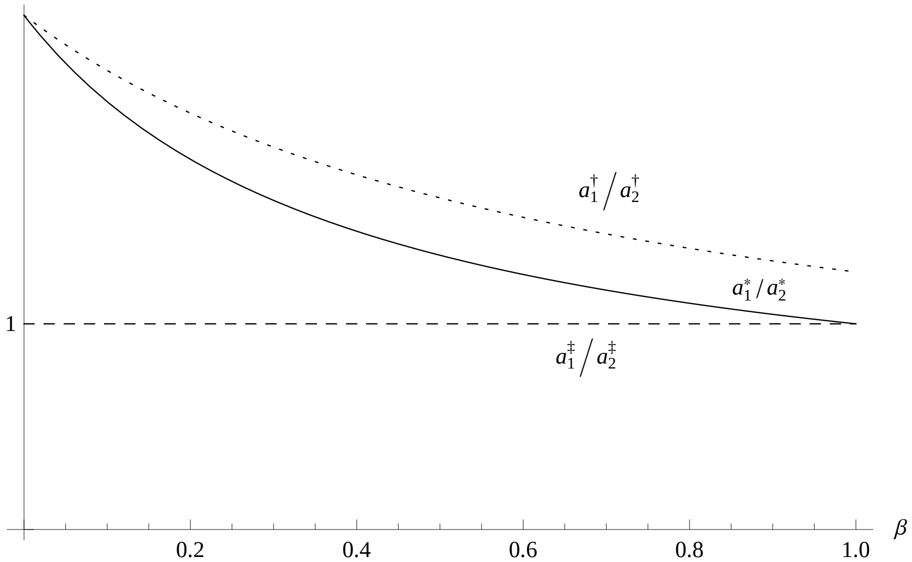

Figure 3.1: Impact of Task Complementarities on the Effort Allocation in First best and with Individual and Aggregate Performance Measurement

The dashed line shows the effort allocation with an aggregate signal ($a_{j1}^\ddagger / a_{j2}^\ddagger$), which is independent of complementary effects. The dotted line depicts the effort allocation with individual signals ($a_{j1}^\dagger / a_{j2}^\dagger$) whereas the solid line captures the first-best allocation (a_{j1}^* / a_{j2}^*). In the example, the first task is assumed to be more productive than the second ($b_1 > b_2$). As β increases, effort on task 2 is increased relative to effort on task 1. Consequently, the dotted and the solid curve are decreasing in β, but the latter decreases at a higher rate. This reflects that the principal takes greater advantage of the indirect productive effect in First best compared to individual signals. Hence, the gap between the dotted and the solid line increases with stronger complementary effects. Moreover, the first-best allocation approaches the allocation with an aggregate signal as β increases and both are identical for β=1. Obviously, for a sufficiently strong task complementarity, the principal achieves higher congruity with an aggregate compared to individual signals.

3.5 Organizational Design and Optimal Performance Measurement

In the previous analysis, I have analyzed the principal's means to overcome congruity issues through the choice of performance measures taking the organizational form as given. Subsequently, I relax this assumption and allow for an endogenous choice of organizational design.[10] More specifically, the principal can chose to *unbundle* tasks, as opposed to the bundled task assignment that was considered previously. With unbundling, the principal assigns each task to a single agent, thus, doubling the number of agents to perform the given set of tasks. Whereas unbundling solves any noncongruity issues because each agent performs only a single task, it also destroys the complementarity because the complementary tasks are covered by different agents. For example, if an agent establishes a good personal relationship to customers on his market, this enhances the sales of his own product, but does not affect sales of other products on the same market.[11] Based on this trade-off, I determine the principal's simultaneous choice of organizational design and performance measurement system.

[10] Corts (2007) and Hughes et al. (2005), among others, confine their analyses to the impact of organizational design on congruity.

[11] The assumption that complementarities arise only if tasks are performed by the same agent is commonplace in the literature, see, e.g., Fellingham/Schroeder (2007), Nikias et al. (2005), Zhang (2003). Further examples relate to bundling sales and service or bundling production and testing operations (Hughes et al. 2005).

3.5.1 Optimal Organizational Design for a given Performance Measurement System

If the principal unbundles tasks, she is able to induce effort for each task separately even with aggregate performance measurement. Thus, organizational design gives the principal the same fine-tuning advantage as the employment of individual performance measures, but at the additional costs of the foregone complementarity. Consequently, unbundling tasks cannot be beneficial for the principal with individual performance measurement.

With an aggregate signal, on the other hand, the principal faces a trade-off between the fine-tuning advantage and the forgone complementarity if she unbundles tasks. The following Lemma summarizes the result regarding the optimal organizational design with an aggregate signal.

> **Lemma 4:** With aggregate performance measurement, the principal strictly prefers bundling tasks, if (and only if) $\beta > \beta^*$, where
>
> $$\beta^* = \frac{(b_1 - b_2)^2 - 2b_1b_2\rho\sigma^2}{2(b_1^2 + b_2^2)}.$$

The benefit of the task complementarity with bundled tasks is twofold, because it increases the gross payoff and additionally reduces the loss from noncongruity with an aggregate signal. Hence, in accordance with the explanations regarding the measures of noncongruity, the cut-off value β^* increases in the difference between productivities. It is worth noting that unbundling can be beneficial despite the fact that it is associated with a lower productive efficiency arising from the foregone complementarity. More precisely, the task complementarity β has a strictly positive impact on gross payoff and can therefore be interpreted as enhancing productive efficiency (e.g., Nikias et al. 2005). Yet, for a low complementarity, unbundling is beneficial because it yields a lower expected compensation for the agents. Put differently, the principal faces a trade-off between the productive efficiency and control uses of accounting information (Christensen/Demski 2002; Christensen/Feltham 2003) if she decides on organizational design, where the former favors bundling whereas the latter favors unbundling tasks. To illustrate, I provide a numerical example, where I vary β for b_1=1, b_2=5, ρ=0.01 and σ=1. The expected gross payoff with bundling (unbundling) is denoted by $E[x_a^b]$ ($E[x_a^u]$) and the expected wage levels by $E[w_a^b]$ and $E[w_a^u]$.

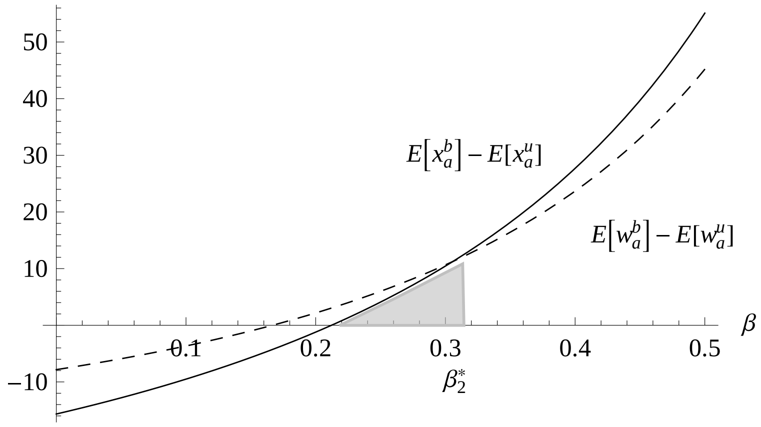

Figure 3.2: Productive Efficiency versus Control

For low values of β (solid curve below the abscissa), the loss from the foregone task complementarity is low and the principal prefers unbundling tasks. As β increases, the higher productive efficiency yields a greater gross payoff if tasks are bundled. However, as long as the control loss caused by the inability to fine-tune incentives is too large, the principal still prefers unbundling tasks (gray shaded area). Once the complementarity becomes sufficiently large to overcome the costs of reduced control, the principal prefers to bundle the complementary tasks. This reflects the trade-off between higher productive efficiency, which favors bundling tasks, and the control loss, which favors unbundling tasks.

3.5.2 Joint Choice of Organizational Design and Performance Measurement

As it is never in the principal's interest to unbundle tasks and employ an individual performance measurement system, she either bundles tasks with individual or aggregate performance measurement, or she employs an aggregate measurement system with unbundling. Intuitively, the likelihood that an aggregate signal is employed increases with the size of the group, because this increases the risk associated with the use of individual signals. Furthermore, a larger complementarity favors aggregate performance measurement with bundling, whereas it affects the fine-tuning advantage of unbundling adversely. The following Proposition 3 summarizes the optimal joint choice of organizational design and performance measurement system.

> **Proposition 3:** If the principal jointly decides on organizational design and the performance measurement system, she prefers
>
> (1) individual performance measurement and bundling tasks, if (and only if)
>
> $$n < \min(n_1^*, n_2^*), \text{ where}$$
>
> $$n_2^* = \left(\left(2\rho\sigma^2\right)^{-1} \left(\rho\sigma^2 - 1 + \sqrt{4\beta^2 + (1+\rho\sigma^2)^2 + \frac{8\beta b_1 b_2 (1+\rho\sigma^2)}{b_1^2 + b_2^2}}\right)\right)^{1/\gamma},$$
>
> (2) aggreate performance measurement if $n > \min(n_1^*, n_2^*)$, where bundling is preferred for $n_1^* < n_2^*$, and unbundling otherwise.

As established in Corollary 1, the cut-off value between aggregate and individual performance measurement with bundled task assignment decreases in the task complementarity (i.e., $\partial n_1^* / \partial \beta < 0$). High values of β imply that the fine-tuning advantage is diminished such that aggregate measurement is preferred with strong complementary effects. Comparing bundling with individual measurement to unbundling with aggregate measurement, however, yields the opposite result.

Whereas the principal still prefers aggregate measurement for a large group-size, the cut-off value n_2^* strictly increases with β. This is due to the fact that there is no congruity problem with unbundling that could be reduced by complementary effects. On the other hand, the foregone complementarity has a decreasing impact on the productive efficiency and therefore favors bundling, such that the principal can benefit from the complementary effect.

As a straightforward consequence of these comparative statics, $\beta > \beta^*$ implies that $n_1^* < n_2^*$, that is, the principal prefers aggregate bundling for a sufficiently large group-size and complementarity (i.e., for $n > n_2^* > n_1^*$). Intuitively, a large task complementarity means that bundling is beneficial whereas a large group-size indicates that aggregate measurement is preferred over individual measurement. The following figure illustrates these points and shows the optimal joint choice of performance measurement and task assignment dependent on $n \in [2, 8]$ and $\beta \in [0, 1]$. I depict the respective payoffs for b_1=1, b_2=5, ρ=0.01, σ=1, $\gamma = 1.5$

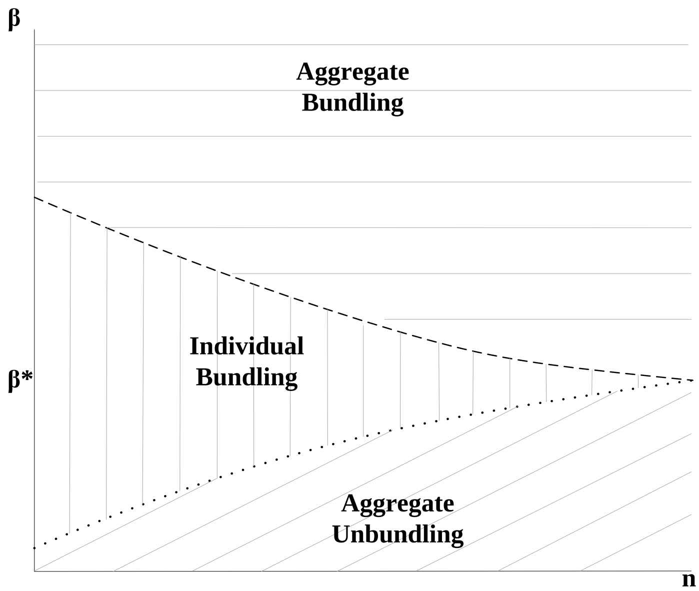

Figure 3.3: Optimal Organizational Design and Performance Measurement System

Moving up the ordinate, bundling is preferred over unbundling due to increasingly strong complementarities. In addition, moving along the abscissa, an aggregate signal is preferred over individual performance measurement due to the impact of group-size on individual signals' precision. The respective cut-off values as summarized in Proposition 3 are reflected by the dotted and the dashed curve. The dotted curve depicts n_2^*, which strictly increases with β. In contrast, n_1^* is reflected by the dashed curve and strictly decreases with β. Taken together, individual performance measurement and bundling is beneficial only if complementary effects and group-size are relatively small.

Importantly, the likelihood that an aggregate signal is employed increases if the principal's decision on organizational design is taken into account because aggregate unbundling displaces individual bundling for low β and increasing n. Consequently, aggregate performance measurement can be beneficial even in small groups as long as task complementarities are sufficiently small. Organizational design thus has a significant impact on performance measurement and can help to explain the widespread use of aggregate performance measures in practice. The results presented above imply that controlling for size effects alone is generally not sufficient and should be accompanied by consideration of further organizational design choices, such as task assignment.

3.6 Concluding Remarks

This study investigates the choice of optimal performance measurement systems dependent on task complementarities and group-size. Within a multi-agent LEN-model where each agent performs two complementary tasks, I distinguish between aggregate and individual performance measurement, where the former captures the joint output of all agents (i.e., group output), whereas the latter provides task-specific signals. I assume that the individual signals' precision decreases with group-size (e.g., due to difficulties in identifying separate outcomes), which results in the following basic trade-off. As each agent performs several tasks, individual signals enable the principal to motivate effort on each task separately. On the other hand, they are noisier than the aggregate signal, which increases the risk premium payments for the risk-averse agents. The main focus of the study is on the impact of complementary effects on this trade-off.

Consistent with empirical research (Ittner/Larcker 2002) I find that aggregate performance measures are preferred in larger groups. While it is intuitively clear that the noisiness of individual signals in large groups prevents the principal from employing individual performance measurement, the influence of complementary effects is less obvious. The results show that task complementarities strictly favor aggregate performance measurement due to their impact on congruity (measured according to Feltham/Xie 1994). More precisely, the complementarity increases the marginal task productivities, which yields a convergence of optimal effort levels. As the aggregate signal induces equal effort on an agent's tasks, the complementarity reduces the noncongruity with an aggregate signal. Interestingly, the reverse holds true for individual signals because the effort allocation with individual signals deviates from the first-best allocation if and only if tasks are complementary. This result is of particular interest for accounting research on optimal performance measurement, because it indicates that the alleged benefit of individual measures, namely the fine-tuning advantage with multi-task agents, is altered by the presence of a task complementarity. Given the ubiquity of complementarities in organizations, it is likely that relying on individual measures in order to alleviate multi-task problems results in an efficiency loss.

Building on these findings, I extend the analysis by incorporating organizational design as an endogenous variable to analyze the joint choice of performance measurement system and task assignment. Whereas the principal still chooses between aggregate and individual performance measurement, organizational design provides her with the means to bundle tasks (as in the previous analysis) or to unbundle tasks. With unbundling, the principal assigns each task to a single agent, which solves any multi-task issues but destroys the complementary effects. The analysis reveals that unbundling with individual signals is strictly detrimentral, whereas it is often beneficial with an aggregate signal. As a consequence, the likelihood that aggregate performance measurement is employed increases if the principal disposes over the task assignment in addition to the design of the performance measurement system. Hence, the results imply that task assignment and group-size have a great bearing on performance measurement and, consequently, on incentives and should generally be considered simultaneously.

Of course, the parsimonious structure of the model gives rise to some caveats with respect to the generalizability of the results. Especially, it is likely that further organizational design variables, such as monitoring technologies (Liang et al. 2008; Ziv 2000), are important determinants of performance measurement systems. In addition, the consideration of further elaborated measurement systems and more complex hierarchical structures shows great promise for further research. Still, I believe that the results of my analysis provide some important insights into the dependence of optimal performance measurement systems on task complementarities, group-size and task assignment. I believe that lower hiearchical levels are frequently subject to these factors and therefore consider my study a starting point for further research on performance measurement for non-executives.

Appendix A: Proofs

Proof of Lemma 1:

Given that agent j's net reservation wage is set equal to zero, the fixed payment follows from solving his certainty equivalent (2) for f_j^i. Substituting the resulting $f_j^{i\dagger}$ and agent j's effort choices (3) back into (1) and taking into account that the principal hires n identical agents yields the principal's unconstrained optimization problem

$$\Pi^i = {}^n\!/_2\Big(2(b_1 v_{j1} + b_2 v_{j2} + \beta v_{j1} v_{j2}) - (1 + \rho n^\gamma \sigma^2)(v_{j1}^2 + v_{j2}^2)\Big).$$

Differentiating the unconstrained decision problem with respect to v_{j1} and v_{j2} and solving yields the incentive rates given in (4a). Substituting the incentive rates back into the unconstrained decision problem yields the expected payoff given in (4b). ■

Proof of Lemma 2:

Analogously to Lemma 1, the principal solves agent j's certainty equivalent (5) for f_j^a, subtitutes the resulting $f_j^{a\ddagger}$ and effort choices (6) back into (1) to obtain

$$\Pi^a = {}^n\!/_2\, v_j\Big(2(b_1 + b_2) + v_j(2\beta - 2 - \rho\sigma^2)\Big). \tag{A.1}$$

Differentiating the unconstrained decision problem with respect to v_j and solving yields agent j's incentive rate for the aggregate performance measure given in (7a). Finally, substituting the incentive rate back into the unconstrained decision problem yields the expected payoff given in (7b). ■

Proof of Lemma 3a:

For the sake of tractability, I define the difference between payoffs with aggregate and individual performance measures as $\Delta \equiv \Pi^{a\ddagger} - \Pi^{i\dagger}$, which is given by

$$\Delta = \Big(2(2-2\beta+\rho\sigma^2)((1+\rho n^{\gamma}\sigma^2)^2-\beta^2)\Big)^{-1} \cdot \Big(2b_1b_2\rho\sigma^2(2n^{\gamma}-1)(1+\beta+\rho n^{\gamma}\sigma^2)$$
$$- \big((1-\beta)^2+\rho\sigma^2(1-\rho n^{\gamma}\sigma^2(n^{\gamma}-1)-2\beta n^{\gamma})\big)(b_1-b_2)^2\Big)$$

where the denominator is strictly positive because $1 \geq \beta \geq 0$. Consequently, the principal prefers aggregate (individual) performance measurement if the numerator of Δ is greater (smaller) than zero. Moreover, she is indifferent between the measurment systems if Δ=0.

If agents are risk neutral ($\rho = 0$), Δ simplifies to

$$\Delta = -\frac{(b_1-b_2)^2}{4+4\beta} < 0.$$

Thus, the payoff is greater with individual than with an aggregate signal except for the special case of identical productivities. ∎

Proof of Lemma 3b:

Absent a congruity problem ($b_1 = b_2 = b$), Δ is given by

$$\Delta = \frac{2b^2\rho\sigma^2(2n^{\gamma}-1)(1+\beta+\rho n^{\gamma}\sigma^2)}{2(2-2\beta+\rho\sigma^2)((1+\rho n^{\gamma}\sigma^2)^2-\beta^2)} > 0.$$

As $n^{\gamma} > 1$, the principal prefers individual performance measurement except for the special case of risk neutral agents. ∎

Proof of Proposition 1:

The cut-off value is obtained by setting Δ equal to zero and solving for n, which gives

$$n_1^* = \Bigg(\left(2(\rho\sigma^2(b_1+b_2)^2)\right)^{-1} \left((b_1^2+b_2^2)(\rho\sigma^2-2\beta)-4b_1b_2 \right.$$
$$\left. + \sqrt{(4\beta^2+(2\beta-(2+\rho\sigma))^2)(b_1^2+b_2^2)^2+8\beta b_1 b_2((2+\rho\sigma^2)(b_1+b_2)^2-2\beta b_1 b_2)} \right) \Bigg)^{1/\gamma}.$$

This constitutes the unique positive solution because Δ is strictly decreasing in n. As $\lim_{n\to 0} \Delta > 0$ and $\lim_{n\to\infty} \Delta < 0$, Δ cuts the abscissa only once for restricted parameter values. ■

Proof of Corollary 1:

Part (1)

The proof follows directly from inspection of (8). ■

Part (2)

Taking the first derivative of (8) with respect to β yields that complementarities have an unambiguously decreasing impact on the cut-off value n_1^*. ■

Proof of Proposition 2:

The proof follows directly from the text. ■

Proof of Lemma 4:

I first derive the expected payoff with aggregate performance measurement and unbundled tasks. Similarly to the proofs of Lemmas 1 and 2, the principal solves the agents' certainty equivalents for the optimal fixed payments, substitutes the results and the agents' optimal effort choices into her expected payoff (1) to obtain the uncontrained optimization problem. Compared to (A.1), the optimization problem is altered by the fact that each agent performs only a single task and by the absence of a task complementarity.

$$\Pi^{au} = {}^{n}\!/_{2} \sum_{k=1,2} \left(v^u_{jk}(2b_k - v^u_{jk}(1+\rho\sigma^2) \right).$$

Taking the first derivatives with respect to incentive rates and substituting gives the following expected payoff

$$\Pi^{au\ddagger} = \frac{n(b_1^2 + b_2^2)}{2(1+\rho\sigma^2)}.$$

Solving $\Pi^{a\ddagger} - \Pi^{au\ddagger}$ for β gives

$$\beta^* = \frac{(b_1 - b_2)^2 - 2b_1 b_2 \rho\sigma^2}{2(b_1^2 + b_2^2)}.$$

As $\Pi^{au\ddagger}$ is independent of the task complementarity whereas $\Pi^{a\ddagger}$ strictly increases in β, the cut-off value is unique and $\Pi^{a\ddagger} > \Pi^{au\ddagger}$ if $\beta > \beta^*$. ■

Proof of Proposition 3:

To derive the cut-off value n_2^*, the difference between the respective payoffs $\Pi^{au\ddagger} - \Pi^{i\dagger}$ is solved for n, which yields

$$\Pi^{au\ddagger} > \Pi^{i\dagger} \qquad \text{if (and only if)}$$

$$n > n_2^* = \left(\left(2\rho\sigma^2\right)^{-1} \left(\rho\sigma^2 - 1 + \sqrt{4\beta^2 + (1+\rho\sigma^2)^2 + \frac{8\beta b_1 b_2 (1+\rho\sigma^2)}{b_1^2 + b_2^2}}\right)\right)^{1/\gamma},$$

where the proof for uniqueness is similar to Proposition 1. It is straightforward to show that $\partial n_2^*/\partial\beta > 0$. In addition, it is known from Corollary 1 that $\partial n_1^*/\partial\beta < 0$, which implies that $n_1^* = n_2^*$ for $\beta = \beta^*$ and $n_1^* > n_2^*$ for $\beta < \beta^*$, and vice versa. Consequently, $\Pi^{i\dagger} > \max\{\Pi^{a\ddagger}, \Pi^{au\ddagger}\}$ if $n < \min\{n_1^*, n_2^*\}$. ■

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4 Essay III: Decentralized Task Assignment and Centralized Contracting: On the Optimal Allocation of Authority

The paper was written with Anna Rohlfing-Bastian (WHU Vallendar).
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4.1 Introduction

The design of optimal incentives relies on three components of organizational architecture which have been described as a three-legged-stool in literature: performance measurement, rewards, and the allocation of decision rights (Brickley et al. 2009). Especially, incentives and the allocation of decision rights are closely interlinked (Athey/Roberts 2001) and need to be considered simultaneously when designing optimal incentive systems (Holmström/Milgrom 1994). Whereas previous literature has predominantly assumed that the elements of the incentive system are decided on by a central planner (the principal), this paper considers the hierarchical disentanglement of decisions. In particular, it analyzes the design of optimal incentive contracts by the principal if the decision on task assignment is delegated to lower hierarchical levels (the agents) and determines the optimal allocation of the decision right on task assignment.

The emphasis put on decision rights naturally embeds the paper in the greater context of authority within organizations. Prior research has established a distinction between "formal" and "real" authority (Aghion/Tirole 1997; Baker et al. 1999), where the former refers to the right to decide whereas the latter captures the effective control over decisions. It is usually assumed that the principal fully retains formal authority, whereas the agents exercise greater real authority (Wulf 2007). This paper differs from these assumptions given that the right to decide on task assignment is delegated to an agent, who thus has formal authority. This agent's assignment of tasks to all agents, in turn, determines their real authority.

In practice, the delegation of formal authority to lower hierarchical levels is commonplace. Kräkel (2010) cites the example of *ABB*, which is organized in a matrix structure along markets and products. The duties of the respective profit centers within the matrix structure are defined by the headquarter. The allocation of authorities to fulfill these duties, however, is decided on within the profit centers. *ABB* employs this local empowerment in order to "think global but act local". Similarly, the electric utility *E.ON* is organized according to markets and businesses. Whereas the group management determines the general aim and purpose of the different units, the local management is granted the right to decide on the allocation of authority within their units. In both cases, incentive contracts are mostly specified by a centralized authority (headquarter or group management). The study at hand analyses this hierarchical disentanglement of incentive design and the decision right on task assignment in detail.

The impact of authority on incentives has also attracted interest in empirical research. Wulf (2007) stresses the difference between formal and real authority but only captures the latter. She analyzes the impact of division managers' authority on incentives and finds a significant positive relation between them. Most notably, she finds that the pay-to-performance sensitivity for global performance measures (firm sales growth) is four times higher for division managers with more authority (measured by officer status) compared to those with less authority. However, she does not find a significant relation with respect to local measures (division sales growth).

Relatedly, Nagar (2002) states that *"(...) compensation studies' failure to control for the extent of delegation can potentially explain some of their puzzling results."* Consequently, his empirical study on the compensation of branch managers in retail banks incorporates the extent of authority delegated to these managers. His results show that incentive compensation increases with the branch managers' authority. However, while stressing the general relevance of authority, he does not distinguish between different types of authority but uses a single proxy to capture authority as a whole.[1] The present study contributes to this literature by providing insights into the impact that different types of authority have on incentives.

Theoretical literature has considered cases in which the principal cannot retain full formal authority. Mookherjee/Reichelstein (1997) consider the delegation of formal authority with respect to contract design and task assignment to agents and derive conditions where the principal does not incur a loss from this delegation. Melumad et al. (1995) and Macho-Stadler/Pèrez-Castrillo (1998) analyze a situation in which formal contracting authority is transferred to the agent(s), whereas the principal retains formal authority with respect to the decision about task assignment. These papers focus on the comparison of decentralized and centralized mechanisms in order to identify conditions under which the decentralized mechanism can - at best - replicate the results of a centralized mechanism. The present paper deviates from the previous analyses in two ways. First, it analyzes a situation in which the principal retains formal authority with respect to contract design, but agents are assigned formal authority to decide on task assignment, whereas previous literature has focused on the opposite case. Second, the present paper identifies the optimal allocation of authority when conditions outside the principal's control impede the installation of a centralized mechanism.

This paper analyzes the impact that *both* types of authority, i.e., formal and real authority, have on the design of incentive contracts based on an agency model where a principal hires two agents (e.g., production and sales manager) to perform three tasks (e.g., production, sales, and product innovation). Two tasks naturally fit the agents and can thus be assigned centrally, however, both agents are similarly capable of performing the third task, which cannot be assigned

[1] Another stream of empirical literature emphasizes the impact of authority on the weighting of performance measures in managerial incentive contracts (e.g., Aggarwal/Samwick 2003; Abernethy et al. 2004). These studies do generally not distinguish different types of authority either.

to either agent by the principal (e.g., due to large geographical dispersion or the principal's lack of information with respect to the management of day-to-day operations within the firm). Instead, the decision right on the allocation of that task (i.e., formal authority) is delegated to the *senior agent* who then decides on the distribution of real authority, i.e., whether to perform the task himself or assign it to the *junior agent*. The principal's optimization problem thus covers the allocation of formal authority to either agent and the design of optimal incentives with regard to their impact on the decentralized decision on real authority.

The main results of the paper can be summarized as follows. First, agents' incentives are sensitive to the delegation of formal authority because their incentive weights with delegation differ from those of centralized task assignment. This result applies to *all* agents and holds regardless of the authority they exercise. Moreover, agents' incentives are linked and the senior agent's characteristics (productivities, sensitivities, effort costs) cut through in all incentives. Second, it is often beneficial to have an agent with high effort costs exercising real authority. This result might seem counter-intuitive at first sight, however, the reason is that high effort costs can facilitate the inducement of effort on relatively more productive tasks. Third, unifying responsibility is never beneficial because the senior agent's impact on incentives is too great if he additionally disposes of real authority. Finally, the principal's joint decision on incentives and the allocation of authority yields surprising comparative static results. Most notably, incentives can increase in effort costs as a result of organizational changes, which not only has an impact on the absolute level of incentives, but also on the relation of incentives and effort costs (i.e., turning a negative into a positive slope).

These results imply that authority has an important impact on incentives and should therefore be included in empirical compensation studies. Particularly, the link between agents' incentives needs to be considered when hypotheses regarding incentives are derived. Hence, the common results from single-agent frameworks are frequently unsuitable to analyze incentives in a multi-agent context.[2] Moreover, it is generally not sufficient to focus either on real or on formal authority, as it has been common practice in prior studies. Likewise, proxying both types of authority by a single variable potentially weakens empirical results if formal and real authority lie with different agents. Not accounting for this effect can then yield hypotheses which do not go into sufficient depth.

This study also contributes to the literature on optimal incentives when the principal does not have full control over the agents' decisions (beyond their effort choices). In this vein, it is closely related to the literature on collusion (e.g., Tirole 1986; Holmström/Milgrom 1990; Itoh 1993; Feltham/Hofmann 2007). Similar to these studies the present paper addresses the efficiency loss caused by the agents' discretion on certain decisions and analyzes the principal's response with respect to the design of optimal incentives. Contrary to these studies, however, the agents do not engage in side-contracting to re-allocate their effort levels or otherwise change the incentives set by the principal. Instead, critical to the results of the paper is the delegation of formal authority to lower hierarchical levels, which can easily be translated into a control variable and therefore be incorporated in empirical studies.

The remainder of the paper is organized as follows. Section 4.2 establishes the basic model and derives the centralized solution as a benchmark. In Section 4.3, the decentralized mechanism is introduced in combination with the question of who should be the senior agent. Section 4.4 analyzes the impact of decentralization on incentives, whereas Section 4.5 develops a solution for the optimal distribution of authority. Finally, Section 4.6 concludes the analysis.

[2]Examples for empirical studies in a multi-agent context deriving their hypotheses from single-agent settings include Abernethy et al. (2004), Nagar (2002), Keating (1997).

4.2 Benchmark Model

4.2.1 Output, Effort Costs, and Performance Measure

A single-period setting is considered in which, at date $t = 0$, a risk-neutral principal (denoted by the index P) contracts with two risk-neutral agents (denoted by the index i, $i = 1, 2$) to perform personally costly effort (a_1, a_2, a_3) on three tasks in $t = 1$. The number of tasks is assumed to be exogenously given (e.g., the three tasks comprise production, sales, and product innovation). Agent 1 is always responsible for task 1 (production), accordingly, agent 2 is always responsible for task 2 (sales). The third task (product innovation) can be either performed by agent 1 (production manager) or agent 2 (sales manager). Consequently, when designing the incentive contracts, the principal needs to take into account that one of the agents exerts effort on the allocatable task (product innovation) in addition to his constantly assigned task (production or sales). In the benchmark setting, it is assumed that the principal can centrally decide about the task allocation, i.e., about who will be in charge of product innovation. This assumption is relaxed at a later stage. At date $t = 2$, payoffs are realized and contract payments are transferred.

Output x follows a linear function dependent on effort choices and payoff productivity measures,

$$x = b_1 a_1 + b_2 a_2 + b_3 a_3,$$

where x is non-contractible, e.g., because it is realized after contract payments have been made.

Agents bear a private monetary cost of effort $\kappa_i, i = 1, 2$ which is dependent on the number of tasks they perform. The agents' effort costs have the following structure,

$$\kappa_i = \begin{cases} 1/2 \cdot a_i^2, i = 1, 2 & \text{if agent } i \text{ performs a single task} \\ 1/2 \cdot \left(a_i^2 + c_i a_3^2\right), i = 1, 2 & \text{if agent } i \text{ performs two tasks.} \end{cases} \tag{1}$$

Note that taking over a_3 does not affect the effort costs for the constantly assigned task of agent i, i.e., $1/2 \cdot a_i^2$. However, the effort costs for the allocatable task 3 might be different from the agents' constantly assigned tasks, where c_i represents a disproportionate effect on effort costs with respect to a_3.[3]

As output is assumed to be non-contractible, incentives must be based on an imperfect aggregate performance measure y of the agents' efforts,

$$y = m_1 a_1 + m_2 a_2 + m_3 a_3 + \varepsilon,$$

where m_1, m_2 and m_3 represent the sensitivity of the performance measure regarding the respective effort levels and ε is a random variable beyond the contracting parties' control.[4] The performance measure y is thus a random variable with distribution $H(y, a_1, a_2, a_3)$. Given a distribution of ε, $H(y, a_1, a_2, a_3)$ is the distribution induced on the performance measure via the relation $y = y(a_1, a_2, a_3, \epsilon)$ (Mirrlees 1976). The corresponding density function $h(y, a_1, a_2, a_3)$ is common knowledge and has well-defined first and second derivatives.

4.2.2 Incentive Contracts, Agents' and Principal's Preferences

The principal offers the agents linear incentive contracts $z_i = (f_i, v_i)$, $i = 1, 2$, where f_i is the fixed wage of agent i and v_i is an incentive rate specifying a variable bonus payment dependent on the contractible performance measure. Compensation w_i is restricted to be linear in the

[3]In line with Corts (2007) and Dewatripont et al. (2000) the present model refrains from considering effort substitution in the sense that changes of effort provided on one task affect the marginal costs of exerting effort on another task.

[4]The use of team-based or group measures is commonplace (e.g., Che/Yoo 2001).

performance measure[5], i.e.,

$$w_i = v_i \cdot y + f_i, \qquad i = 1, 2.$$

The agents' and the principal's preferences are described by the following linear utility functions,

$$u_i = w_i - \kappa_i,$$

$$u_P = x - \sum_i w_i, \qquad i = 1, 2. \tag{2}$$

The agents maximize their expected compensation less their effort costs, whereas the principal maximizes the difference between expected output and compensation paid to the agents.

Accordingly, the principal's optimization problem is characterized by

$$\max \quad E[u_P] = E[x] - \sum_i E[w_i], \tag{3a}$$

$$\text{s.t.} \quad E[u_i(\cdot)] \geq 0, \tag{3b}$$

$$a_i \in \underset{a_i'}{\operatorname{argmax}} \quad [E[u_i(\cdot)] \mid a_i' \in \mathbb{R}], \qquad i = 1, 2, \tag{3c}$$

$$a_3 \in \underset{a_3'}{\operatorname{argmax}} \quad [E[u_i(\cdot)] \mid a_3' \in \mathbb{R}], \tag{3d}$$

where it is assumed that a_3 is performed by agent i=1,2. The principal maximizes her expected utility subject to meeting the agents' incentive compatibility (3c), (3d) and individual rationality (3b) constraints, i.e., agents accept the contract only if it provides them at least with their net reservation wage, which is scaled to equal zero without loss of generality.

[5]Linear incentive schemes are dominant in practice (Bose et al. 2011; Bhattacharyya/Lafontaine 1995; Milgrom/Roberts 1992). Moreover, with risk-neutral agents and the mean-shifting effort assumption reflected in the performance measure, focusing the analysis on linear contracts is without loss of generality (Corts 2007; Schnedler 2011).

4.2.3 Optimal Linear Contracts with Centralized Decision

The solution to the case with centralized decision-making is provided as a benchmark. For the ease of presentation, the focus of the subsequent analyses is on agent 1 performing the allocatable task, unless stated otherwise. It is obvious from (3a)-(3d) that the results for agent 2 performing product innovation are derived analogously such that a separate presentation would not yield additional insights.

As agent 1 is assigned to perform the allocatable task in addition to his own task, the principal deals with a multi-task incentive problem for agent 1 and a single-task incentive problem for agent 2. The effort costs of the agents are represented by the respective function described in equation (1).

The agents' optimal effort choices are derived according to (3c) and (3d) and are given by

$$a_i^\dagger = m_i v_i, \qquad i = 1, 2, \tag{4a}$$

$$a_3^\dagger = \frac{m_3 v_1}{c_1}. \tag{4b}$$

The agents' fixed wages follow from setting (3b) equal to zero and solving for f_1 and f_2, respectively. Substituting the latter plus the optimal effort choices back into (3a) gives the principal's unconstrained decision problem. Setting the first derivatives with respect to v_1 and v_2 equal to zero and solving for v_1 and v_2, respectively, yields the optimal incentive rates,

$$v_1^\dagger = \frac{b_1 m_1 c_1 + b_3 m_3}{m_1^2 c_1 + m_3^2} \qquad \text{and} \tag{5}$$

$$v_2^\dagger = \frac{b_2}{m_2}. \tag{6}$$

Whereas the optimal incentive rate for agent 2 is the standard first-best result in agency theory for a single-task incentive problem, the optimal incentive rate for motivating agent 1 to exert effort on two tasks involves the payoff productivities and performance measure sensitivities of both tasks as well as his effort cost parameter c_1 for performing a_3.

Finally, the principal's payoff in this setting follows as

$$\Pi_1^\dagger = {}^1\!/_2 \cdot \left(b_2^2 + \frac{(b_1 m_1 c_1 + b_3 m_3)^2}{c_1(m_1^2 c_1 + m_3^2)} \right).$$

Although this setting assumes risk-neutral contracting parties, the principal cannot achieve a first-best result[6], unless the performance measure is perfectly congruent with respect to agent 1's tasks. Generally, the principal is interested in motivating agent 1 to distribute his effort among a_1 and a_3 according to the marginal impact on gross payoff, which is reflected by the payoff productivities b_1 and b_3, and the cost of effort for the respective tasks. Consequently, the principal prefers an effort allocation of $a_1^*/a_3^* = b_1 c_1/b_3$. However, agents act self-interestedly and are maximizing their personal utility, which is derived from the realization of the performance measure and their cost of effort. Hence, agent 1 prefers an allocation of efforts according to $a_1^\dagger/a_3^\dagger = m_1 c_1/m_3$. It is obvious that the effort allocation chosen by the agent does not comply with the one preferred by the principal if payoff productivities and performance measure sensitivities do not match, i.e., whenever $b_1/b_3 \neq m_1/m_3$, or put differently, whenever $\delta_1 \equiv (b_1 m_3 - b_3 m_1)^2 \neq 0$.[7] In this case the performance measure is said to be noncongruent, which leads to a *loss from noncongruity* (Feltham/Xie 1994) compared to the first-best solution.

Generally, the principal faces a similar problem when product innovation is performed by the sales manager, such that agent 2 performing multiple tasks potentially yields a loss from noncongruity. This naturally raises the question of the optimal centralized task assignment, that is, does the principal assign the allocatable task to agent 1 or to agent 2. The answer to

[6]In a first-best situation, efforts are contractible. The first-best result with agent 1 performing task 3 equals $\Pi^{FB} = {}^1\!/_2 \cdot \left(b_1^2 + b_2^2 + b_3^2 c_1^{-1}\right)$.

[7]Feltham/Xie (1994) established this as a measure for noncongruity in linear multi-task models.

this question forms the basis for the subsequent analysis of decentralized task assignment and it is based on equation (7), which defines the difference in payoffs for the two cases when either agent 1 or agent 2 assumes the multi-task responsibility,[8]

$$\Delta\Pi = \Pi_1^\dagger - \Pi_2^\dagger = 1/2 \cdot \left(\underbrace{b_3^2\left(\frac{1}{c_1} - \frac{1}{c_2}\right)}_{I} + \underbrace{\frac{(b_2 m_3 - b_3 m_2)^2}{m_3^2 + m_2^2 c_2} - \frac{(b_1 m_3 - b_3 m_1)^2}{m_3^2 + m_1^2 c_1}}_{II} \right). \tag{7}$$

Equation (7) shows the two forces driving the assignment choice, that is, the agents' effort costs to perform task 3 (part I) and also the loss from noncongruity (part II). Consequently, the principal assigns agent 1 the task if he has sufficiently low effort costs and/or higher congruity between the allocatable task 3 and his constantly assigned task 1, and vice versa.

Moreover, the effort cost parameter c_1 appears in the denominator of part II, which implies that higher effort costs of agent 1 might favor the assignment of task 3 to that agent. The reason is that the incentive rate $v_1^\dagger$ increases in c_1 for $\frac{b_1}{m_1} > \frac{b_3}{m_3}$, which is due to the fact that an increase of effort costs for the allocatable task 3 reduces the effort exerted on that task for a given incentive rate. If the relation of productivities to sensitivities is greater with respect to task 1 than to task 3, this is in the principal's interest and she sets stronger incentives in order to motivate more effort on task 1. Hence, the principal might actually take advantage of high effort costs on task 3 as this allows her to induce more effort on the relatively more productive task 1.

[8]Note that the payoff productivity and performance measure sensitivity of task 3 are task-sensitive and do not change with the agent performing the task.

4.3 Decentralized Task Assignment

4.3.1 Allocation of Authority

In the subsequent analysis it is assumed that a centralized decision about the task assignment is not feasible because the principal lacks information with regard to the management of day-to-day operations in the firm. For example, large geographical dispersion between her and the agents can make it impossible for the principal to observe which agent actually performs product innovation. In this case she assigns the right to decide on the task assignment either to agent 1 or to agent 2. The thusly installed *senior agent* has the formal authority to decide whether he performs a_3 himself or assigns it to the *junior agent*. The case in which the senior agent takes the allocatable task himself is referred to as *unified responsibility* because formal and real authority are unified at a single agent. In contrast, *split responsibility* relates to the case where the senior agent assigns the third task to the junior agent. Consequently, there are four possible scenarios regarding the allocation of authorities, which are summarized in the following figure.

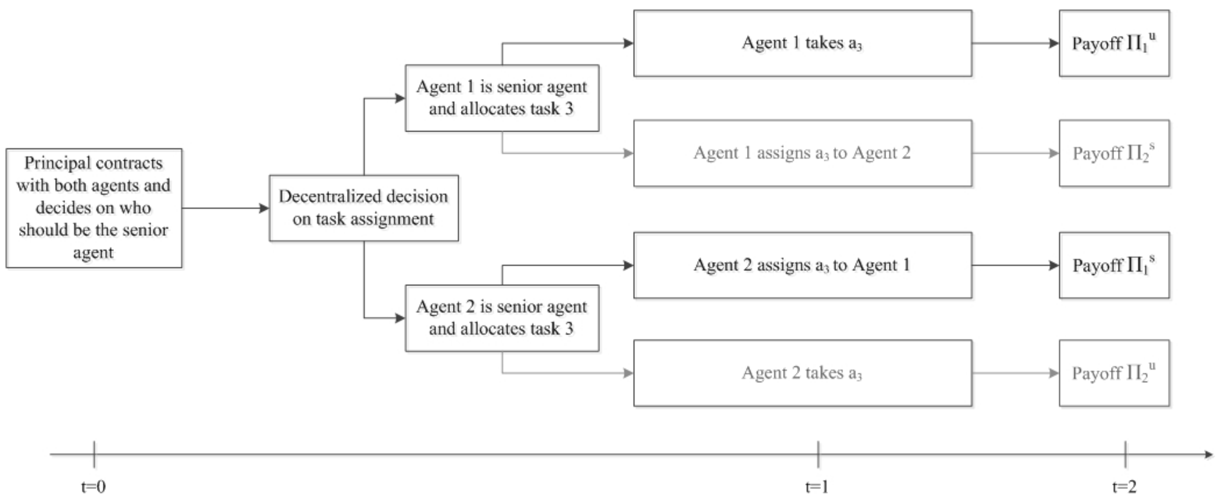

Figure 4.1: Timeline and Sequence of Events in the Decentralized Model

The figure shows that the four different scenarios yield four different payoffs $\Pi_i^\tau, i = 1, 2$, where $\tau = u, s$ stands for the allocation of responsibility (unified versus split). With unified responsibility, the principal achieves either Π_1^u or Π_2^u, dependent on whether agent 1 or agent 2 performs the third task. Accordingly, with split responsibility, either Π_1^s or Π_2^s is obtained. Again, the symmetry of the model is evident and it allows for focusing on agent 1 performing the allocatable task. The respective scenarios are highlighted with black font in the figure.

From this setup it follows that the principal makes a direct decision with respect to the allocation of decision rights, i.e., whether she prefers agent 1 or agent 2 to be the senior agent. In addition, her choice of incentive rates determines whom the allocatable task is assigned, i.e., the design of the incentive contract depends on her preference with respect to Π_1^τ or Π_2^τ, $\tau = u, s$. This aspect will be analyzed at a later stage, when the focusing on agent 1 performing product innovation is abandoned to analyze the joint decision on formal and real authority.

4.3.2 Optimal Linear Contracts with Unified Responsibility

Given that the production manager (agent 1) exerts effort on the third task, unified responsibility refers to the case in which agent 1 is also assigned the formal authority to decide on the task assignment. The agent makes his decision based on expected utilities, i.e., he will only take the task himself if this yields a higher expected utility than delegating the task to the sales manager (agent 2). Comparing the respective expected utilities yields

$$\begin{gathered} u_1(a_1, a_3) > u_1(a_1) \\ f_1 + {}^1\!/\!{}_2 v_1^2\big(m_1^2 + \frac{m_3^2}{c_1}\big) + m_2^2 v_1 v_2 > f_1 + {}^1\!/\!{}_2 v_1^2 m_1^2 + \big(m_2^2 + \frac{m_3^2}{c_2}\big) v_1 v_2. \end{gathered} \tag{8}$$

There are two key differences between $u_1(a_1, a_3)$ and $u_1(a_1)$. First, agent 1 has to bear higher effort costs if he performs product innovation himself. Whereas his costs for perfoming task 1 remain unchanged, he bears additional costs for exerting effort on the third task. If his respective effort costs are high (i.e., c_1 is large), he assigns the allocatable task to the other agent. Second, he benefits from the productive effort on the third task as this increases the expected value of the performance measure and therefore has a positive impact on his expected compensation. If he exerts less effort on the third task than agent 2 - either because he bears high effort costs or because he receives weak incentives - this favors the assignment of task 3 to agent 2. Consequently, agent 1 retains the task only if his effort costs are relatively low or his incentives are relatively strong compared to those of the agent 2. The following *decentralized assignment constraint* formalizes the argument, i.e., based on (8), agent 1 takes the task himself only if

$$
{}^1\!/_2 \cdot \frac{v_1}{c_1} \geq \frac{v_2}{c_2}, \tag{9}
$$

i.e., only if his incentives are sufficiently strong to overcome the disadvantage from the additional effort costs he has to bear, where the factor $^1\!/_2$ reflects that effort costs are quadratic.

The principal anticipates this behavior when designing the optimal incentive contracts for the agents. She faces the optimization problem stated in equations (3a) - (3d) and additionally has to take into account the decentralized assignment constraint (9), which is binding unless the standard incentive rates with a centralized solution (5) and (6) are already satisfying the condition. Hence, it must be the case that

$$
\begin{aligned}
& {}^1\!/_2 \cdot \frac{v_1^\dagger}{c_1} < \frac{v_2^\dagger}{c_2} \\
\Leftrightarrow A \equiv\ & \frac{(b_1 m_1 c_1 + b_3 m_3) c_2}{(m_1^2 c_1 + m_3^2) c_1} \cdot \frac{m_2}{b_2} < 2.
\end{aligned} \tag{10}
$$

The principal designs the incentive contracts in a way that leaves the agents with their reservation utility and considers the impact of the variable compensation on the agents' task assignment choice and effort choices. Standard optimization using backward induction then gives the following results with respect to the optimal incentive rates and the principal's expected payoff.

Lemma 1a: Given that $A<2$ holds, optimal incentives and the principal's payoff for unified responsibility (i.e., agent 1 has formal and real authority) are given by

$$v_1^{u\dagger} = \frac{2c_1(2b_1m_1c_1 + b_2m_2c_2 + 2b_3m_3)}{4c_1(m_1^2c_1 + m_3^2) + m_2^2c_2^2},$$

$$v_2^{u\dagger} = \frac{c_2(2b_1m_1c_1 + b_2m_2c_2 + 2b_3m_3)}{4c_1(m_1^2c_1 + m_3^2) + m_2^2c_2^2},$$

$$\Pi_1^{u\dagger} = \frac{(2b_1m_1c_1 + b_2m_2c_2 + 2b_3m_3)^2}{8c_1(m_1^2c_1 + m_3^2) + 2m_2^2c_2^2)}.$$

All Proofs are in the Appendix.

Before examining the incentive rates in more detail, the solution for the case in which the principal wants to split up authorities is presented.

4.3.3 Optimal Linear Contracts with Split Responsibility

If the principal wants to split up authorities, i.e., agent 2 is the senior agent, whereas agent 1 still performs the allocatable task 3, she needs to make sure that agent 2 decides to not perform the allocatable task, but to assign it to the junior agent 1. Again, the senior agent assigns the third task to the junior agent only if this yields a higher expected utility ($u_2(a_2) > u_2(a_2, a_3)$). This is the case whenever the following condition holds,

$$1/2 \cdot \frac{v_2}{c_2} \le \frac{v_1}{c_1}. \tag{11}$$

Analogously to the case of unified responsibility, this condition is binding only if the centralized incentive rates do not satisfy (11), i.e., only if

$$
\begin{aligned}
& {}^{1}\!/_{2} \cdot \frac{v_2^\dagger}{c_2} > \frac{v_1^\dagger}{c_1} \\
\Leftrightarrow A \equiv\; & \frac{(b_1 m_1 c_1 + b_3 m_3) c_2}{(m_1^2 c_1 + m_3^2) c_1} \cdot \frac{m_2}{b_2} < {}^{1}\!/_{2}. \qquad (12)
\end{aligned}
$$

It is obvious that (12) implies that (10) holds, so the following analyses are restricted to the case of $A < {}^{1}\!/_{2}$, which is henceforth taken as given.[9] The respective incentive rates for senior and junior agent as well as the principal's payoff in this case are summarized in Lemma 1b.

Lemma 1b: Given that $A < {}^{1}\!/_{2}$ holds, optimal incentives and the principal's payoff for split responsibility (i.e., agent 2 has formal authority, whereas agent 1 has real authority) are given by

$$
\begin{aligned}
v_1^{s\dagger} &= \frac{c_1(b_1 m_1 c_1 + 2 b_2 m_2 c_2 + b_3 m_3)}{4 m_2^2 c_2^2 + c_1(m_1^2 c_1 + m_3^2)}, \\
v_2^{s\dagger} &= \frac{2 c_2(b_1 m_1 c_1 + 2 b_2 m_2 c_2 + b_3 m_3)}{4 m_2^2 c_2^2 + c_1(m_1^2 c_1 + m_3^2)}, \\
\Pi_1^{s\dagger} &= \frac{(b_1 m_1 c_1 + 2 b_2 m_2 c_2 + b_3 m_3)^2}{2 c_1(m_1^2 c_1 + m_3^2) + 8 m_2^2 c_2^2}.
\end{aligned}
$$

It is obvious that agent 1's incentive rate with unified and with split responsibility does not only depend on his own characteristics (i.e., effort costs and productivity/sensitivity of his tasks), but also on agent 2's characteristics, and vice versa. This stands in sharp contrast to the results of centralized task assignment and reflects that originally independent incentive problems become interdependent once the agents engage in some kind of decentralized interaction.

[9]If agent 2 performs the allocatable task, the condition equals $B \equiv \frac{(b_2 m_2 c_2 + b_3 m_3) c_1}{(m_2^2 c_2 + m_3^2) c_2} \cdot \frac{m_1}{b_1} < {}^{1}\!/_{2}$. Hence, to be able to compare all four possible scenarios (split and unified responsibility with either agent 1 or agent 2 performing task 3) it must be the case that $\max\{A, B\} < {}^{1}\!/_{2}$. The existence of such solutions is proven in the Appendix.

Whereas similar results are known from the literature on collusion and delegated contracting (e.g., Feltham/Hofmann 2007; Macho-Stadler/Pèrez-Castrillo 1998), the result in the present paper is striking because agents do neither enter into decentralized contracts nor do they re-allocate their efforts for their constantly assigned tasks. In fact, their effort choices for a given incentive rate are identical to those with centralized assignment. Hence, it is the principal's choice of incentive rates which induces effort levels that differ from those of the second-best solution.

4.4 Impact of Decentralized Task Assignment on Incentives

Subsequently the impact of delegating formal authority on agents' incentives and the principal's payoff is analyzed. Especially, the focus is on the cause and effect of the efficiency loss the principal faces if she cannot retain formal authority rather than considering possible merits of delegation. This part of the analysis promises to be more fruitful given the commonplace that delegating decision rights is generally detrimental to the principal with regard to optimal incentives (e.g., McAfee/McMillan 1995; Gilbert/Riordan 1995).[10]

Naturally, this latter result also holds within the present model. If the principal delegates the decision right on task assignment, she is strictly worse off compared to centralized task assignment. The following Proposition formalizes this result.

> **Proposition 1:** Given that $A < 1/2$ holds, the principal strictly prefers retaining rather than delegating formal authority (that is, $\Pi_1^{\dagger} > \Pi_1^{\tau},\ \tau = s, u$).

The previous section has shown that the principal's optimization problems with centralization

[10] The literature on incentives and the benefits of delegation usually relies on the fact that the latter allows the principal to elicit (part of) the agents' decentralized information (e.g., Prendergast 2002; Mookherjee/Reichelstein 1997; Melumad et al. 1992; Christensen 1982). As all information beyond the agents' effort choices is common knowledge in the present model, this argument does not apply.

and decentralization are to a large extent identical but the latter additionally requires the consideration of the decentralized assignment constraint. It is intuitive that the principal cannot be better off if she faces an additional binding constraint in an otherwise identical optimization problem. However, the fact that the discrete choice on task assignment impacts incentives, whereas it does not directly affect the agents' effort choices, suggests to take a closer look on the adjustments undertaken by the principal as a response to delegation and the respective consequences. Especially, the following relation of incentive rates with decentralized compared to centralized task assignment is established.

Proposition 2: Given that $A < 1/2$ holds, the agents' incentive rates with centralized and decentralized task assignment are such that

$$(v_1^\dagger - v_1^\tau)(v_2^\dagger - v_2^\tau) < 0, \qquad \tau = u, s.$$

As shown above, agent 1's incentives are dependent on agent 2's characteristics, and vice versa. Hence, if agent 2's productivity is relatively low, the dependancy of his incentives on the higher productivity of agent 1 has an increasing effect compared to the centralized solution, in which incentives are independent. In addition, both agents' effort costs for the allocatable task 3 play an important role although agent 2 does not exert effort on that task. In particular, agent 2's incentive rate increases in c_2 if his incentives with decentralized task assignment are lower than with centralized task assignment, i.e., $\partial v_2^\tau / \partial c_2 > 0$ if $v_2^\dagger > v_2^\tau$, $\tau = u, s$, (and analogously for agent 1). As the weight placed on v_2^τ gets bigger as c_2 increases (by (9) and (11)), the principal takes advantage of greater effort costs for agent 2 by setting an incentive rate that is closer to optimal centralized incentives. By reducing the deviation of agent 2's incentives from the second-best solution, she also increases her expected payoff and thus reduces her loss from delegating formal authority.

Another conclusion drawn from Proposition 2 is that the principal faces a loss compared to centralized task assignment regardless of the performance measure's characteristics. Even with a congruent performance measure, the principal does not achieve the second-best result (let alone First best) although agents are risk-neutral. The decentralized assignment constraint requires an adjustment of incentives compared to the second-best solution, which inevitably yields a loss to the principal. To dampen the negative consequences from the necessity to delegate formal authority, the principal decides on the optimal distribution of responsibility within the firm.

4.5 Optimal Distribution of Responsibility

In this section, the principal's choice with respect to organizational design is analyzed, that is, the principal decides on the distribution of responsibility. This decision is twofold because it comprises the direct choice of formal and the indirect choice of real authority. Subsequently, these decisions are addressed separately before the joint choice of formal and real authority is analyzed.

4.5.1 Choice of Formal Authority

The first part of the principal's organizational design choices tackles the allocation of the decision right on task assignment. Starting with Simon (1951), the "right to decide" has frequently been related to a hierarchy between agents in the sense that a higher hierarchical position goes along with ampler decision rights (e.g., Aghion/Tirole 1997; Mookherjee/Reichelstein 1997; Melumad et al. 1995). Furthermore, it is well-known that an agent's hierarchical level is often linked to his compensation.[11] Thus, the allocation of authority is not only an integral part of organizational design (Roberts 2004), but it is also closely tied to optimal incentives. Those ties are emphasized in the subsequent analysis.

It should be clear that within the framework of the presented model, the principal decides on the allocation of formal authority based on a comparison of expected payoffs. More precisely, she compares Π_1^u to Π_1^s, i.e., whether or not to assign agent 1 formal authority given that this agent already has real authority and performs task 3.[12] The following Proposition summarizes the principal's choice.

> **Proposition 3:** Given that $A < 1/2$ holds and agent 1 has real authority, the principal strictly prefers split responsibility (i.e., $\Pi_1^s > \Pi_1^u$).

To understand the intuition behind this result it is necessary to take a closer look at the impact of formal authority on incentive rates with decentralized task assignment. In particular, for *both* agents' incentive rates, greater weight is placed on the senior agent's productivities. For instance, if agent 1 is assigned formal authority, the weight placed on b_1 and b_3 is greater in v_1^u and v_2^u than in v_1^s and v_2^s (see Lemmas 1a and 1b). However, placing greater weight on these characteristics is not in the principal's interest, which is evident from the condition $A < 1/2$ shown in equation (12). If $A < 1/2$, relatively little weight should be placed on agent 1's as opposed to agent 2's productivities. This is due to the fact that the left-hand side of A strictly increases in b_1 and b_3, such that $A < 1/2$ implies that agent 1 has a relatively low productivity. Emphasizing these low productivities in the incentive rates is unfavorable for the principal who thus refrains from

[11] See, e.g., Ederhof (2011), Ortin-Angel/Salas-Fumas (1998) and Gerhart/Milkovich (1990) for empirical evidence. While a manager's hierarchical position can be seen as a proxy for formal authority, these studies generally do not distinguish between formal and real authority. Incorporating the distinction between different types of authorities might strengthen their empirical results.

[12] Likewise, the opposite case of agent 2 performing product innovation would require a comparison of Π_2^u and Π_2^s. As described previously, these payoffs are derived analogously to Π_1^u and Π_1^s.

assigning formal authority to agent 1. In addition, A strictly decreases in c_1, such that high effort costs for agent 1 imply that condition (12) is met.

Furthermore, the relation of agents' effort costs for the third task plays an important role for incentives even though agent 2 does not exert any effort on the third task at all. Again, this is due to the decentralized assignment constraints (9) and (11), which necessitate an adjustment of incentives according to the agents' effort costs. If agent 1 is assigned formal authority, the effort cost parameter c_1 has a greater impact on his incentives than in the opposite case, in which agent 2 is the senior agent. If $A < 1/2$, agent 1's effort costs c_1 must be relatively large (because $\partial A/\partial c_1 < 0$), yielding a significant impact on the incentive rates. To diminish this impact and the appendant need to adjust incentives, the principal assigns formal authority to agent 2 rather than to agent 1 and thus splits responsibility.

The result presented above indicates that the senior agent is generally more important for setting incentives even if he is responsible for a smaller number of productive tasks. The principal's assignment of formal authority establishes a hierarchy between agents, which is reflected in both agents' incentive rates. Consequently, empirical studies analyzing compensation contracts should not only control for single agents' characteristics, but also include a proxy for the characteristics of the other agents, particularly those of the direct "boss". Moreover, the result implies that a distinction should be made between formal and real authority. Proxying both types by a single variable might dampen the strength of empirical results because different authorities frequently lie with different agents.

4.5.2 Choice of Real Authority

Extending the previous analysis, the focus on agent 1 performing the allocatable task is henceforth abandoned. Instead, the principal's decision with regard to real authority is considered, that is, which agent should exert effort on product innovation given that agent 1 is assigned formal authority. This relates to a situation in which a hierarchy between agents has been established and an additional task needs to be covered by one of the agents. This is a frequently observed issue in practice, for instance, when a member of a team leaves the company (e.g., parental leave) and his/her task(s) must be covered by the remaining agents within that team. Similarly, newly introduced tasks (e.g., controlling of a new product or market in the firm's portfolio) are often covered by agents already performing different tasks within the firm.

Importantly, in the present model, the principal does not directly assign task 3 to an agent but sets incentives such that the senior agent 1 assigns the task in the principal's interest.[13] Hence, formal authority determines the framework to set incentives (i.e., whether (9) or (11) applies), whereas real authority relates to incentive design within that framework. Thus, the principal's preference with regard to real authority and the incentives she sets are intrinsically tied.

Naturally, the choice of real authority is determined by comparing the respective payoffs Π_1^u and Π_2^s. The result is formalized in the following Proposition.

> **Proposition 4:** Given that $\max\{A, B\} < 1/2$ holds and agent 1 is assigned formal authority, there exists some $\hat{c}_1 \leq c_1$ such that the principal prefers unified responsibility if $\frac{b_3}{m_3} > \frac{b_1}{m_1}$ and prefers split responsibility if $\frac{b_3}{m_3} < \frac{b_1}{m_1}$ given that the allocatable task is sufficiently sensitive to effort.

[13] A large part of the literature concerned with task assignment and incentives assumes that the principal directly assigns tasks to agents (e.g., Hofmann/Rohlfing 2012; Corts 2007; Besanko et al. 2005; Hughes et al. 2005; Hemmer 1995; Holmström/Milgrom 1991).

It might seem surprising that the principal prefers the senior agent to take the task if he incurs high costs for exerting effort on that task. It is even more startling given the analysis of the previous section, where it was strictly detrimental to unify responsibility at a single agent. The reasoning behind this result, however, is quite intuitive. As explained earlier, the weight placed on the senior agent's task(s) within incentive rates is greater than that of the junior agent's task(s). If the former does also have real authority, b_1 and b_3 are emphasized whereas only b_1 is emphasized if agent 2 has real authority. Hence, less emphasis is put on b_3 relative to b_1 if agent 2 has real authority. As c_1 increases, the weight placed on b_1 relative to b_3 increases regardless of real authority (evident from Lemmas 1a and 1b) but the impact is obviously stronger with agent 2 performing the allocatable task. This increase is beneficial to the principal if she wants to induce relatively more effort on task 1 than on the allocatable task 3, which is the case if $\frac{b_1}{m_1} > \frac{b_3}{m_3}$, and vice versa (recall that $\frac{\partial v_1^\dagger}{\partial c_1} > 0$ if $\frac{b_1}{m_1} > \frac{b_3}{m_3}$). Consequently, the principal benefits from high effort costs if the respective task is not too productive, as this facilitates the inducement of effort on the relatively more productive task.

4.5.3 Joint Choice of Formal and Real Authority

Whereas the previous sections have tackled the principal's distinct choices on formal and real authority, respectively, the subsequent analysis considers the joint choice of both types of authority. Hence, it takes the ex-ante perspective, in which neither a hierarchy between agents (i.e., assignment of formal authority) nor real authority have been established. For example, she might open a new branch or location or, more generally, undertake major organizational changes within the firm. Note that this does not capture the agents' constantly assigned tasks due to the fact that they are specialized in these tasks regardless of the allocation of authorities.

To derive the principal's choice within this model, it is necessary to compare all four possible payoffs Π_1^u, Π_1^s, Π_2^u, and Π_2^s. It is known from Proposition 3 that unified responsibility cannot be the overall best solution. Hence, the principal prefers split responsibility with either agent 1 having formal and agent 2 having real authority, or vice versa. Consequently, the result of Proposition 4 does not apply in the greater context of a joint decision, because unified responsibility cannot be beneficial even if $c_1 \geq \hat{c}_1$ and $\frac{b_3}{m_3} > \frac{b_1}{m_1}$ holds. Consequently, when deciding on the allocation of real authority with *given* formal authority, the principal frequently takes a decision that is detrimental from an ex-ante perspective. Hence, she might be better off re-assigning formal authority (and thereby changing the hierarchy between agents) rather than just sticking to the hierarchy currently in place and allocating real authority accordingly. The following Proposition summarizes the principal's joint choice of formal and real authority.

Proposition 5: Given that $\max\{A, B\} < 1/2$ holds and the allocatable task is sufficiently sensitive to effort, the principal prefers split responsibility with

(1) agent 1 having formal and agent 2 having real authority if $c_1 \geq \tilde{c}_1$ and $\frac{b_3}{m_3} < \frac{b_1}{m_1}$

(2) agent 2 having formal and agent 1 having real authority if $c_1 \geq \tilde{c}_1$ and $\frac{b_3}{m_3} > \frac{b_1}{m_1}$.

Again, it can be in the principal's interest that agent 1 performs the third task even if he has high effort costs. The reasoning behind this result is similar to Proposition 4. If agent 1 is assigned formal authority (case (1)), only his constantly assigned first task is emphasized in the incentive rates. Moreover, high effort costs for agent 1 imply that it is not in the principal's interest to motivate that agent to exert high effort on the third task. If $\frac{b_3}{m_3} < \frac{b_1}{m_1}$ holds, the principal wants to induce more of agent 1's effort on his first task than on the third task. As a consequence, she does not have agent 1 exert any effort on task 3 at all but rather assigns it to agent 2.

This finding is of particular interest for empirical accounting research for several reasons. First, it indicates that organizational design (proxied by the allocation of responsibility) has a great bearing on incentives. Consequently, it should be controlled for in empirical studies, for instance, by incorporating agents' decision rights and scope of responsibilities. Second, increasingly strong effort costs do not necessarily mean that an agent should not perform a given task. To the contrary, it might in fact imply that the task should be performed by an agent precisely because he has high costs of exerting effort on that task. Naturally, this affects the strength of incentives, as illustrated by the following numerical example.

Numerical Example

Proposition 5 established that the principal strictly prefers split responsibility and decides whether to assign agent 1 or agent 2 formal authority. It is obvious from Lemma 1b that this decision has an impact on the *total* level of incentives. Moreover, the principal's choice depends on agent 1's effort costs, which have a different impact on incentives with agent 1 as the senior agent compared to the opposite case, in which agent 2 is assigned formal authority. For illustration purposes, the following figure depicts the incentive rates $v_2^{s\dagger}$ for agent 2 when he has real authority ($i = 2$, dashed line) and when agent 1 has real authority ($i = 1$, solid line). The underlying parameter values are $b_1 = b_2 = c_2 = 1$, $b_3 = 2$, $m_1 = m_2 = 1/2$, $m_3 = 10$ and c_1 is varied between 0 and 3.

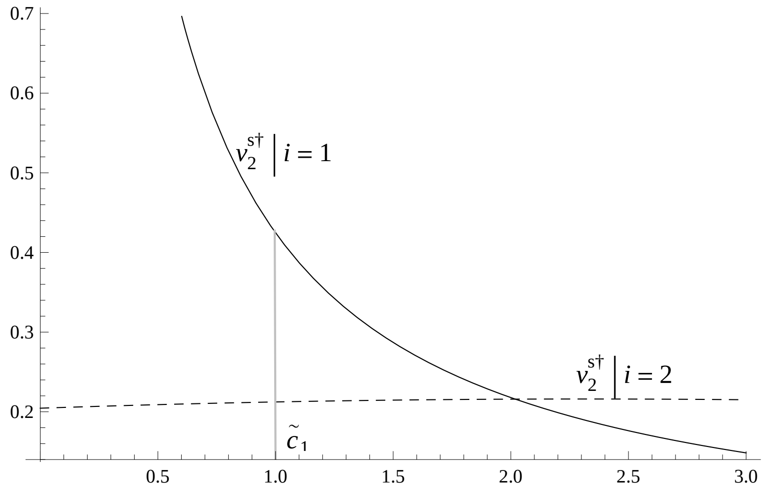

Figure 4.2: Impact of Responsibility on Incentives

In the example, $\frac{b_3}{m_3} < \frac{b_1}{m_1}$ such that the principal prefers split responsibility with agent 2 performing the third task if $c_1 > \tilde{c}_1$. In the figure, this decision is associated with a decrease of the total level of incentives, that is, incentives at $\tilde{c}_1$ drop from $v_2^{s\dagger}|i = 1$ to $v_2^{s\dagger}|i = 2$. In addition, comparative statics are changed, too, because the solid curve strictly decreases in c_1 whereas the dashed curve increases. The reason is that in the second case ($i = 2$), agent 1 has formal authority, which means that greater weight is placed on c_1 in the incentive rates, yielding an overall positive impact on incentives.

Hence, the example further emphasizes the importance of responsibility for empirical compensation studies, which not only affects the strength of incentives, but also the comparative static results. Consequently, the "standard" results from analytical accounting, which do not consider the impact of organizational design choices, might not be applicable to situations including a decision on organizational design. For example, agent 2's incentives are independent of agent 1's effort costs for the third task if organizational design is excluded from the analysis. In contrast, the example shows that agent 2's incentives increase in agent 1's effort costs for the third task, even if agent 1 is not responsible for performing that task.

4.6 Concluding Remarks

This paper studies the optimal design of incentive systems when formal decision authority with respect to parts of organizational architecture, namely the contract design and the allocation of tasks, is given to parties at different hierarchical levels. The analysis provides an investigation of the efficiency loss associated with this type of decentralization by taking an integrative perspective and accounting for the interdependencies between incentive systems and the organizational structure of a firm. Furthermore, it examines the optimal allocation of formal authority to lower hierarchical levels.

In line with previous literature, the analysis shows that under decentralized task assignment, the principal can never be better off than with a centralized decision, even though the agents' task assignment choice only affects a single allocatable task and does not relate to the agents' constantly assigned tasks. The paper then takes the decentralization of task assignment as an exogenous need (e.g., due to a lack of information or a large geographical dispersion) and further investigates the efficiency loss associated with decentralized task assignment. The results show that the delegation of the task assignment decision leads to an adjustment of incentives for all agents, despite the fact that the personal situation and job responsibility of at least one agent is not affected by decentralization. Moreover, the decentralization of formal authority links the agents' incentive problems, that is, agent 1's incentives are dependent on agent 2's characteristics, and vice versa. Agents' incentives are thus sensitive to the delegation of formal authority. Consequently, empirical compensation studies should take into account the impact of the principal's assignment choice on incentives, as this introduces an interdependence between agents' incentive problems. In particular, this aspect is frequently neglected when hypotheses are based on single-agent models, which normally preclude analyzing organizational design choices.[14]

Furthermore, the results show that an agent's hierarchical position is critical for the incentives of all agents. More precisely, the senior agent's characteristics (productivities and sensitivities) are emphasized in the incentive rates. This implies that a senior agent with a high productivity yields strong incentives for all agents despite the fact that agents' efforts are not interlinked (e.g., through synergies) and although the senior agent's productivity does not cascade down the hierarchy (see, e.g., Rosen 1982). Hence, even if the firm's production function is separable in agents' efforts, the superior agent's productivity is of importance for the agents' incentives down the hierarchy.

This argument forms the basis for the principal's preference with respect to responsibility. It turns out that it is often worthwile to unify responsibility at an agent whose assignment of formal authority is already given, that is, to additionally allot real authority to that agent. Even more, real authority can quite possibly be given to the agent who exhibits higher effort costs for performing the allocatable task. The analysis shows that this counter-intuitive result arises through the impact that effort costs have on the congruity effect of the performance measure because high effort costs facilitate the inducement of effort on the more productive task. Considering the organizational design and its interdependencies with the elements of the incentive system then alters the commonly known comparative static results with respect to the variable component of incentive contracts. This result also holds within the greater context of a joint decision on real and formal authority, in which unifying responsibility at a single agent turns out to be strictly detrimental.

[14]See, for example, Abernethy et al. (2004), Nagar (2002), Keating (1997) for empirical studies in a multi-agent context, which develop their hypotheses based on single-task models.

The analysis has several implications. It shows that the impact of formal and real authority (the right to decide and the effective control) needs to be taken into account when analyzing the provision of incentives. The results suggest that it is not sufficient to account only for the effective control or to proxy both types of authority by a single variable when analyzing the provision of incentives, as it has been done in previous empirical studies (e.g., Wulf 2007; Nagar 2002). Furthermore, the analysis provides insights into the impact that the choice of the "boss" has when a hierarchy between employees is established. The characteristics of the senior agent are relevant for all agents down the hierarchy independently of productive interdependencies (e.g., synergies, complementarities) and regardless of behavioral aspects of the superior-subordinate relationship. In this respect, the analysis is helpful to assess the impact that the promotion of a single employee has on incentives for all employees within a team. In particular, introducing an additional hierarchical level (by allocating formal authority) alters incentives even if agents' duties (real authority) remain unchanged. Importantly, the strict detriment of unified responsibility implies that an agent subject to promotion should dispose of little real authority to limit his impact on other agents' incentives.

Two words of caution are in order with respect to the generalizability of the presented results. First, risk-neutral contracting parties are assumed. Whereas the assumption of a risk-neutral principal can be justified by diversification arguments, agents are often assumed to show a risk-averse behavior. In consequence, possible reactions of agents to incentive contracts which are caused by underlying risk-aversion are not reflected in the model. Second, it is assumed that payoff productivities and performance measure sensitivities are task-sensitive and are not influenced by the specific agent that performs the respective task. Thus, potential synergies between tasks that are bundled in jobs for a single agent or split up among agents remain unconsidered. However, the parsimonious model of this paper provides some new insights into the interdependence between organizational design and the provision of incentives and offers venues for future research along the lines of authority in organizations.

Appendix A: Proofs

Throughout the Appendix, the results for agent 2 performing the allocatable task are not presented separately. Due to the symmetry of the model, these results are derived analogously to those of agent 1 performing task 3.

Proof of Lemma 1a:

First, the principal chooses a fixed payment f_i, $i = 1, 2$, such that the agents' individual rationality constraints described in equation (3b) are binding. Second, the principal anticipates that the agents maximize their expected utility when choosing their optimal effort levels according to equations (3c) and (3d). Substituting the optimal effort choices given in equation (4a) and (4b) and the result for the fixed payment into the principal's expected utility (2) yields the principal's optimization problem (expressed by the Lagrangian L) dependent on the decentralized assignment constraint (9).

$$\max_{v_1, v_2} L = b_1 m_1 v_1 + b_2 m_2 v_2 + \frac{b_3 m_3 v_1}{c_1} - 1/2 \cdot \left(m_1^2 v_1^2 + m_2^2 v_2^2 + \frac{m_3^2 v_1^2}{c_1} \right) - \lambda \left(\frac{v_1}{2c_1} - \frac{v_2}{c_2} \right).$$

The first-order conditions are given by

$$\frac{\partial L}{\partial v_1} : b_1 m_1 + \frac{b_3 m_3}{c_1} - v_1 \left(m_1^2 + \frac{m_3^2}{c_1} \right) - \frac{\lambda}{2c_1} = 0$$

$$\frac{\partial L}{\partial v_2} : b_2 m_2 - v_2 m_2^2 + \frac{\lambda}{c_2} = 0$$

$$\frac{\partial L}{\partial \lambda} : - \frac{v_1}{2c_1} + \frac{v_2}{c_2} = 0$$

The condition on λ has been explained in Section 4.3. As the decentralized assignment constraint (9) is an inequality, the associated multiplier λ is non-negative by the Kuhn-Tucker saddle point theorem because the optimization problem is concave and the constraints are linear. To avoid a trivial agency problem, it is evident that $\lambda > 0$, which is taken as given. It follows that $\frac{v_1}{2c_1} = \frac{v_2}{c_2}$

(by complementary slackness). Substituting this relation into the first-order conditions and solving for incentive rates yields $v_1^\dagger$ and $v_2^\dagger$ as given in Lemma 1a. Subtituting back into the principal's optimization problem yields her expected payoff. ■

Proof of Lemma 1b:

The proof of Lemma 1b is derived analogously to the proof of Lemma 1a. ■

Proof of Proposition 1:

Comparing the principal's payoff in the centralized case and the case with unified responsibility yields

$$\begin{aligned}\Pi_1^\dagger - \Pi_1^u &= 1/2 \cdot \left(b_2^2 + \frac{(b_1 c_1 m_1 + b_3 m_3)^2}{c_1(m_1^2 c_1 + m_3^2)} - \frac{(2b_1 c_1 m_1 + b_2 c_2 m_2 + 2b_3 m_3)^2}{4c_1(m_1^2 c_1 + m_3^2) + c_2^2 m_2^2} \right) \\ &= \frac{\Big((b_1 m_1 c_1 + b_3 m_3) m_2 c_2 - 2b_2 c_1 (m_1^2 c_1 + m_3^2) \Big)^2}{2c_1(m_1^2 c_1 + m_3^2)(4c_1(m_1^2 c_1 + m_3^2) + m_2^2 c_2^2)}.\end{aligned}$$

This difference is strictly non-negative. In addition, it equals zero if and only if

$$\frac{(b_1 m_1 c_1 + b_3 m_3) c_2}{(m_1^2 c_1 + m_3^2) c_1} \frac{m_2}{b_2} = 2.$$

This solution, however, is not feasible because it hurts the condition $A < 2$. The proof for the comparison of $\Pi_1^\dagger$ and Π_1^s is analogous. ■

Proof of Proposition 2:

The proof of Proposition 2 requires two steps. In a first step, the difference in incentive rates for the centralized case and the decentralized case with unified responsibility is calculated for the two agents, i.e.,

$$(v_1^\dagger - v_1^u)(v_2^\dagger - v_2^u) = -c_2 m_2^2 (2(m_1^2 c_1 + m_3^2)) < 0.$$

This equation is always smaller than zero when all parameters are assumed to be positive. In a second step, the described procedure is repeated for the decentralized case with split responsibility, i.e.,

$$(v_1^\dagger - v_1^s)(v_2^\dagger - v_2^s) = -2c_2 m_2^2(m_1^2 c_1 + m_3^2) < 0.$$

This equation is always smaller than zero when all parameters are assumed to be positive. ■

Proof of Proposition 3:

The proof follows straightforwardly from comparing the principal's payoffs with agent 1 and agent 2 having formal authority, respectively, given that agent 1 has real authority, i.e., by comparing Π_1^u to Π_1^s (as given in Lemmas 1a and 1b). For $A < 1/2$, split responsibility is strictly preferred, that is, $\Pi_1^u < \Pi_1^s$. ■

Proof of Proposition 4:

The proof of Proposition 4 is achieved by investigating the behavior of the differences in payoffs given in the following equation, i.e.

$$\Delta \equiv \Pi_1^u - \Pi_2^s = \frac{(2b_1 m_1 c_1 + b_2 m_2 c_2 + 2b_3 m_3)^2}{8c_1(m_1^2 c_1 + m_3^2) + 2c_2^2 m_2^2} - \frac{(2b_1 m_1 c_1 + b_2 m_2 c_2 + b_3 m_3)^2}{8c_1^2 m_1^2 + 2c_2(m_2^2 c_2 + m_3^2)},$$

depending on agent 1's effort cost parameter for performing task 3, i.e., c_1. It is straightforward to show that $\lim_{c_1 \to \infty} \Delta = 0$. Thus, $\Delta < 0$ if $\frac{\partial \Delta}{\partial c_1} > 0$ for large c_1, that is, the function aymptotes to zero from below. Inspecting the general expression of $\frac{\partial \Delta}{\partial c_1}$ reveals that the denominator is strictly positive, whereas the numerator depends on a sixth-order polynomial in c_1. The polynomial approaches $+\infty$ as $c_1 \to \infty$ if the coefficient on the highest order term is positive. This coefficient is given by $b_1 m_3 - b_3 m_1$, thus, Δ asymptotes to zero from below if $\frac{b_1}{m_1} > \frac{b_3}{m_3}$, and vice versa. Given the continuity of Δ for permitted parameter values, this ensures that there exists some $\hat{c}_1$ such that the principal prefers agent 2 (agent 1) to have real authority if $\frac{b_1}{m_1} > \frac{b_3}{m_3}$ $\left(\frac{b_1}{m_1} < \frac{b_3}{m_3}\right)$.

In addition, it must be the case that $A < 1/2 \wedge B < 1/2$ such that the decentralized assignment constraints are binding. It is straightforward to show that $\frac{\partial A}{\partial c_1} < 0$ and $\frac{\partial B}{\partial c_1} > 0$. Based on this result, $A = 1/2$ is solved for c_1 to establish $\underline{c}_1$ as the lowest possible value of c_1 to fulfill the condition $A < 1/2$. Likewise, solving $B = 1/2$ for c_1 yields the largest possible value $\bar{c}_1$ such that $B < 1/2$ is fulfilled. Finally, $\frac{\partial(\bar{c}_1 - \underline{c}_1)}{\partial m_3} > 0$ for large m_3 and $\lim_{m_3 \to \infty} \underline{c}_1 = 0$, $\lim_{m_3 \to \infty} \bar{c}_1 = \infty$, such that large values of m_3 imply that high effort costs c_1 do not hurt the conditions $A < 1/2 \ \wedge \ B < 1/2$. ■

Proof of Proposition 5:

It is obvious from the proof of Proposition 4 that a comparison of all four possible scenarios ($\Pi_1^u, \Pi_1^s, \Pi_2^u$, and Π_2^s) is possible because $A < 1/2$ and $B < 1/2$ can be fulfilled at the same time. Moreover, Proposition 3 has established that unified responsibility is strictly detrimental. Hence, it remains to compare the two alternatives with split responsibility, i.e., Π_1^s and Π_2^s.

The proof is similar to the proof of Proposition 4. Given that $\lim_{c_1 \to \infty} (\Pi_1^s - \Pi_2^s) = 0$, it suffices to check the sign of the highest coefficient on c_1 in the derivative of the respective delta function (i.e., the difference in payoffs). The coefficient is again positive if $\frac{b_1}{m_1} > \frac{b_3}{m_3}$, which implies that the delta function asymptotes to zero from below. The continuity of the delta function ensures the existence of a $\tilde{c}_i$ such that Π_2^s is preferred by the principal if $c_1 > \tilde{c}_1$ and $\frac{b_1}{m_1} > \frac{b_3}{m_3}$. ■

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5 Conclusion

The present dissertation analyzes the interdependencies between organizational design, performance measurement, and incentives within the framework of agency theory. The essays of this dissertation take different approaches to capture organizational design, which can all be traced back to the allocation of decision-making authority. In this respect, they address the key elements of organizational architecture, which are commonly referred to as a “three-legged stool” (Brickley et al. 2009).

Essay I considers the choice between organizational M-form and U-form, which is determined by the responsibilities of middle-level managers in a three-tier hierarchy. The key assumption is that the firm's accounting system provides information according to the internal structure of the firm, as required by accounting standards on segmental reporting (SFAS 131, IFRS 8). Hence, the paper establishes a link between organizational design and performance measurement (and thus incentives). Moreover, it differentiates between several levels of aggregation undertaken by the accounting system. The analysis reveals that the level of aggregation is critical for the interdependence of organizational design and incentives. In addition, it shows how organizational design affects relative performance evaluation (RPE) and how it impacts comparative static results with respect to optimal incentives. In particular, it is established that incentives frequently increase in the noisiness of performance measures due to changes in the firm's organizational design.

Several implications follow from this study. As organizational design has a great bearing on incentives, it should be included as a control variable in empirical compensation studies in order to avoid an omitted correlated variables bias. For instance, the distribution of responsibilities within the firm according to functions (U-form) or products/markets (M-form) can be used as a proxy. This might help to explain the puzzling empirical result of a positive relation between risk and incentives (Prendergast 2002) and to avoid a misspecification of peer-groups in studies on RPE (Albuquerque 2009). Moreover, aggregation turns out to have a significant impact on the interdependence of organizational design and incentives. As aggregation is commonplace in accounting (Demski 2008; Arya et al. 2004), the results of the study imply that accountants should take due care of incentive effects when designing accounting systems with respect to the extent of aggregation.

Essay II delineates the choice of task assignment and performance measurement and thus relates to a setting with more degrees of freedom (e.g., if there is no need to abide by certain accounting standards). In the study, the principal hires a group of identical agents and installs either an aggregate or an individual performance measurement system. The precision of individual measures decreases with group-size due to the difficulties associated with tracking individual performance. Initially, *bundled* task assignment is considered, where each agent performs two complementary tasks. In an extension, the principal can also decide to *undbundle* tasks, where she hires a group of single-task agents to perform the same number of tasks. The analysis reveals that aggregate measurement is generally preferred in larger groups and that the likelihood that aggregate measurement is employed increases if the principal can decide on the organizational design (bundling vs. unbundling). Moreover, it is shown how complementary effects affect the measure of noncongruity (Feltham/Xie 1994). Particularly, increasingly strong complementarities enhance congruity with an aggregate performance measure but have the opposite effect on individual measures.

These results provide insights that are important for analytical and empirical accounting research. Most importantly, the alleged benefit of individual measures (i.e., the fine-tuning advantage to overcome congruity issues) is dampened by the impact of complementary effects between tasks. Given the ubiquity of complementarities in organizations (Brickley et al. 2009; Milgrom/Roberts 1992), neglecting their impact potentially weakens the significance of empirical results. Likewise, group-size and task assignment are shown to be important factors influencing the design of performance measurement systems. Thus, taking their impact into account might help to gain a thorough understanding of the mixed empirical evidence regarding the use of aggregate versus individual performance measures (Hwang et al. 2009).

Essay III further emphasizes the impact of task assignment on incentives within a model where the decision right on task assignment is delegated to a lower hierarchical level. Contrary to the previous essays, the principal is unable to directly assign all tasks to the agents. Instead, she designates a *senior agent*, who then decides whether to perform an allocatable task himself, or assign it to the *junior agent*. As the study relates to the analysis of authority in organizations, the decision right on task assignment refers to *formal authority* (the right to decide) whereas the agent performing the allocatable task has *real authority* (the actual control over decisions, Aghion/Tirole 1995; Baker et al. 1999). The hierarchical disentanglement of decisions undertaken in this essay is novel in the literature, which is quite surprising given that its commonplace in practice (Milgrom 1988).

The main results of the study can be summarized as follows. First, the incentives of *all* agents are sensitive to the allocation of (formal and real) authority, regardless of the actual authority they exercise. Second, the characteristics of the senior agent have a significant impact on the junior agent's incentives despite the fact that their productive efforts are not linked (e.g., through synergies). Third, jointly analyzing formal and real authority reveals surprising comparative static results with respect to incentive weights and effort costs. Particularly, an increase of an agent's effort costs might not only alter his absolute strength of incentives, but also their dependence on effort costs (i.e., turning a negative into a positive slope). The results of the study imply that empirical studies should make a distinction between formal and real authority and include both types of authority to strengthen their results. Predominantly, empirical studies did not jointly incorporate formal *and* real authority (Wulf 2007) or proxied both types of authority by a single variable (Nagar 2002). Based on the findings of the study, these approaches potentially fail to reflect the respective impact of different types of authority on incentives for all agents across the hierarchy.

To summarize, the present dissertation provides several insights into the interdependencies of organizational design, performance measurement, and incentives. Particularly, it employs different facets of organizational design, thus, adding to different streams of literature (see Table 1.1). In this respect, it contributes to the growing accounting literature considering organizational design as yet another choice variable. This view has become popular for management consultants and in the business press over the last few years (Liang et al. 2008) and it has also attracted academic interest (Roberts 2004), but accounting research on this topic is still nascent. As the empirical and anecdotal evidence on the interdependence of organizational design and incentives is overwhelming, however, further accounting research is required. Particularly, given that research on the nature of organizations emerged almost eighty years ago (the seminal article is Coase 1937), there are plenty of promising venues for further research based on findings from organizational science. For example, connecting accounting research closer to organizational science might help to provide further insights into firms' decision to adopt a matrix or hierarchical structure or, more generally, into the grouping of activities in organizations. Thus far, relatively little is known about the determinants driving these decisions (Harris/Raviv 2002), and the gap between theory and practice constantly grows due to the technological progress providing firms with the means to employ novel (and more complex) organizational structures, e.g., in the form of increasing decentralization (Acemoglu et al. 2007).

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