Aggregate and specific performance measures and intra-firm interdependencies: Theory and evidence

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Abstract

We provide theory and empirical evidence on how three types of performance measures are used to evaluate business unit managers in response to intra-firm interdependencies. We analyze variation in the relative incentive weightings of aggregated "above-level" measures (e.g., firm-wide net income), "own-level" business unit measures (e.g., business unit profit), and "below-level" measures (e.g., specific product revenues) in response to interdependencies arising from either the focal manager's effect on the performance of other units in the firm or the other units' effect on the focal manager's performance. Our theory yields three predictions: (1) increasing the focal manager's effect on other units in the firm will increase the weighting of the below-level and above-level measures relative to the own-level measure, (2) increasing the other units' effect on the focal manager will increase the weighting of the above-level measures relative to the own-level measure, and (3) both types of interdependencies will interact. Empirical evidence based on a survey of 122 business unit managers is largely consistent with these predictions.

Keywords: Contracting, Business unit performance measurement, Organizational design, Interdependencies

JEL-code: D23, L22, M12, M4

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1. Introduction

One of the most fundamental problems in the management of firms with multiple business units is to ensure that these units cope well with the interdependencies that exist between them (Roberts 2004). A solid insight that derives from prior work in the area holds that performance measurement systems can be designed to achieve this aim. In particular, using aggregate measures that summarize the performance of multiple units have been shown to provide incentives to managers of each unit to "internalize" the effects of interdependencies (Bushman, Indjejikian and Smith 1995; Keating 1997; Abernethy, Bouwens and van Lent 2004). What has gone unrecognized so far, however, is that firms can also use specific measures that directly capture the effect managers have on others in the firm. Once we consider the full spectrum of available performance measures (from aggregate to specific), the question of how each of these measures should be used optimally in incentive contracts is far from trivial.[1]

We therefore examine how interdependencies between business units of a firm affect the incentive weightings of three types of performance measures used to evaluate business unit managers. Specifically, we consider: above-level measures, which aggregate the performance of two or more business units; below-level or specific measures, which capture the performance of spillover activities that affect other business units; and own-level measures, which summarize the overall performance of a single business unit. Each of these measures is differentially affected by the "level" and "direction" of intra-firm interdependencies. Here, "level" refers to the degree of spillover and "direction" refers to whether the interdependencies arise because other units in the

[1] While interdependencies create measurement challenges for responsibility accounting, these interdependencies can be addressed using cost allocation and transfer pricing (Zimmerman 2003). Under a well-designed transfer-pricing system, a business unit manager's own-level measure would reflect any externalities arising from intra-firm interdependencies, making above-level or below-level measures less useful in performance evaluation (Bushman, Indjejikian, and Smith 1995). We address in our paper those interdependencies that cannot be adequately accounted for by transfer-pricing schemes (Bushman et al. 1995) perhaps because of top management's lack of knowledge (Keating 1997) or exogenous restrictions such as tax laws (Bouwens and van Lent 2007).

firm affect the performance of the focal manager or because the focal manager affects the performance of other units in the firm. The direction of interdependencies follows from the way in which the work flow between units is organized. Not only is each performance measure differentially affected by these interdependencies, but in addition, due to the summing-up characteristic of accounting measures, the properties of above-level measures (such as firm-wide profits) are a function of the properties of the own-level measures (such as business unit profits) that add up to these aggregate measures. Together, interdependencies have both a direct and an indirect (summing-up) impact on performance measures. Understanding the incentives provided by each type of measure on the efforts of business unit managers requires a careful analysis of the totality of these effects.

Earlier work has demonstrated in theory and empirically that *above-level performance measures* can be used in response to increasing interdependencies (see, e.g., Bushman et al. 1995; Abernethy et al. 2004). Intuitively, it would seem that, unlike own-level measures, above-level measures at the firm level (more) fully reflect externalities arising from intra-firm transactions. However, this early work did not address any alternatives to above-level performance measures, such as *below-level* or *specific measures*, which capture the performance of a spillover task that affects the performance of other business units. Conceptually, appropriately weighted below-level measures can also enable a manager to internalize the externalities of his or her decisions, thereby supporting balanced managerial activities (Feltham and Xie 1994; Datar, Kulp and Lambert 2001). The idea that below-level measures can help business unit managers to cope with interdependencies is new to the literature (cf., Bouwens and van Lent 2007; Baiman and Baldenius 2009). No empirical evidence exists to date that evaluates the use of above-level versus below-level measures in the presence of varying degrees of interdependencies.

Moreover, Keating (1997) and Abernethy, Bouwens, and van Lent (2004) empirically document the importance of distinguishing the direction of the interdependencies: those that arise because other units in the firm affect the performance of a focal manager and those that arise because a focal manager affects the performance of other units in the firm. Both types of intra-firm interdependencies create noise in the affected performance measures. Additionally, when a manager affects the performance of other units in the firm, the performance of that manager's business unit is likely to become less congruent with firm profits. In the theoretical part of our study, we show that the direction of interdependencies has different implications for the optimal weighting of above-level, own-level, and below-level performance measures, and in the empirical part of our study, we document evidence that is largely consistent with our predictions.

Within a principal–two-agent LEN-contracting setting, we first consider a multi-task setting that contains both spillover and local actions and comprises specific measures that capture the performance of the spillover actions. We model the relations between the direction of interdependencies and the noise and congruity of performance measures and show how these relations influence the optimal incentive weightings of each type of measure.[2]

Our theoretical framework contributes to the empirical investigation of the association between interdependencies and the weighting of performance measures. Specifically, we empirically test for the relations between the direction of intra-firm interdependencies and the weightings of own-level, above-level, and below-level performance measures, while controlling for the degree of decentralization and various other factors known to influence the use of performance measures (Ittner, Larcker and Rajan 1997; Keating 1997; Abernethy et al. 2004). We gather survey data from a sample of 122 managers of business units across a range of industries. We use this survey data to obtain proxies for intra-firm interdependencies *at the business unit level* as well as information about how performance measures are used to evaluate business unit managers. We agree with Luft and Shields (2003) and others (Lanen 1995; Ittner

[2] Another paper related to ours is Keating (1997). While our assumptions regarding the effect of spillover *of* other business units on performance measure noise are identical, we differ regarding the consequences of spillover *to* other business units. Our setting distinguishes between the consequences of business unit spillover on performance measure noise and congruity, whereas Keating's (1997) setting collapses these consequences into the noise of the own-level and above-level performance measures. In particular, in our setting, spillover to the other business unit affects the sensitivity but not the noise of the focal unit's own-level performance measure.

and Larcker 2001) who emphasize the importance of maintaining consistency between the level of analysis in theory, variable measurement, and empirical work. In addition, we increase the scope to compare findings across studies by using proxies employed in earlier studies (Luft and Shields 2003). Because such data is not available from public data sources, we gather our data using surveys. We recognize that using surveys to gather data may be problematic. To address such potential problems, we implement several strategies, including the use of multiple proxies to conduct convergent validity tests for our main variables, statistical and procedural measures to mitigate concerns about common rater and other respondent biases, and simulations that explicitly account for estimation uncertainty in our regressions.

The results of this study contribute to the literature in two distinct ways. First, we extend the principal/agent literature on how intra-firm interdependencies affect optimal weightings of performance measures by considering a setting with (1) varying directions of intra-firm interdependencies and (2) own-level, above-level, and below-level performance measures. We provide comparative statics regarding the effect of intra-firm interdependencies on the weightings of performance measures relative to one another. Our results highlight how specific measures can be used to overcome spillover effects in the firm, a use that has gone unnoticed in the literature.[3]

Second, we document empirically that specific measures are indeed used in practice in response to interdependencies, much as theory suggests. What's more, our model predicts that the two directions of interdependencies can reinforce one another and thus affect the relative weightings of the performance measures. Note that business unit managers who have to deal with both incoming and outgoing interdependencies are facing great challenges in making decisions that are congruent with the firm's objective. We show empirically that when the two spillover effects reinforce each other the weight placed on both above-level and specific measures

[3] Bouwens and van Lent (2007) discuss the role of non-financial and cost and sales measures but these are not necessarily below-level or "specific" in our sense (e.g., *customer satisfaction* can be measured at the firm, business unit, and product levels). These authors do not distinguish between the two types of spillover and, in fact, collapse them empirically into one proxy.

decreases and more weight is put on own-level measures. Extant literature has focused on one-sided interdependencies where either a focal business unit delivers goods to another business unit or where a focal business unit receives goods from another business unit. We specifically study how performance measures are combined for evaluation purposes when a focal business unit both receives goods from other business units and delivers goods to other business units in the firm. We find that this reciprocal interdependence has a dramatic influence on performance measure choice. In particular, we find that own-level performance measures are used almost exclusively in firms with a high level of reciprocal interdependencies; in contrast, aggregate and specific measures, which can be tailored to deal with one-sided interdependencies, are only used when these reciprocal spillovers are present in modest degrees.

The next section considers the theoretical framework and derives predictions regarding the impact of intra-firm interdependencies on the relative weighting of own-level, above-level, and below-level performance measures.

2. Theoretical Framework

2.1 Model Description

In this section, we analyze a simple agency model where the performance of business unit managers of a multi-unit firm is assessed based on own-level, above-level, and below-level performance measures. By considering the consequences of intra-firm interdependencies on the characteristics of own-level, above-level, and below-level performance measures and the optimal incentive weights for these measures, we provide a framework for our empirical analysis.

Consider a risk-neutral principal (e.g., firm owners) who hires two risk-averse agents (i.e., business unit managers). Each agent i performs two tasks and the level of effort devoted to each task j is represented by $a_{ij} \in \mathbb{R}$, i,j=1,2. Agent i's cost of effort is $\kappa_i = ½ (a_{i1}^2 + a_{i2}^2)$. To capture the idea that intra-firm interdependencies typically relate only to a subset of a manager's responsibilities, we assume that agent i undertakes a local action, a_{ii}, and a spillover action, a_{ij},

$i \neq j$. For example, activities such as R&D or manufacturing operations are classified as a local action if they relate to goods or services that are sold to outside customers, whereas they are classified as a spillover action if the goods or services are delivered to another business unit.

Importantly, while the effort of the local action, a_{ii}, affects only the performance of the agent's own business unit, the effort of the spillover action, a_{ij}, affects also the performance of the other business unit. Specifically, the output of business unit i, y_i, is defined as

$$y_i = a_{ii} + (1 - \beta_i)\, a_{ij} + \beta_j\, a_{ji} + \varepsilon_i, \qquad i,j = 1,2 \text{ and } i \neq j,$$

where β_i (β_j) $\in$ [0,1] represents the fraction of the output from agent i's (the other agent j's) spillover action that is reflected in the other agent j's (agent i's) business unit metric and ε_i is a normally distributed independent random variable capturing events beyond the agents' control, $\varepsilon_i \sim N(0,\sigma_i^2)$ and $Cov[\varepsilon_1,\varepsilon_2] = 0$.[4] Generally, transfer-pricing or cost allocation schemes are supposed to reflect externalities arising from spillover actions in the performance of an agent's own business unit. We interpret β_i as indicating the extent to which agent i's spillover action is *not* adequately accounted for by transfer-pricing schemes.[5] When providing incentives, the output of business unit i, y_i, is used as the *own-level* performance measure for agent i.[6]

Aggregate firm output, x, is given by the sum of individual business unit outputs, i.e., $x = y_1 + y_2$. For example, when business unit output represents accounting profit, the aggregate measure reflects firm profits. Unlike the output of a business unit, the aggregate measure captures the total output for both, an agent's local action and his spillover action.[7] For both agents, aggregate firm output, x, can be used as an *above-level* performance measure.

[4] For both tasks we assume, in total, unit marginal productivity for a unit of agent i's effort. For simplicity, we opted to ignore differences in the marginal products of the local and the spillover action.

[5] With a "perfect" transfer-pricing scheme, β_i=0, the benefits and costs of agent i's spillover action are confined to the output of his business unit.

[6] As will become clear below, when setting incentives, it is without loss in generality, in our setting, to ignore the output of the other business unit as a performance measure.

[7] While transfer-pricing schemes typically allocate the output from the spillover action to the business units and, therefore, affect the sensitivity of an agent's own-level measure to his spillover action, the sensitivity of the aggregate metric to the spillover action is unaffected by the transfer-pricing scheme.

To motivate the spillover action, let the firm's accounting system provide the principal, for each agent i=1,2, with a specific measure, s_i, of the spillover effort. Specifically,

$$s_i = a_{ij} + \theta_i, \qquad i=1,2,$$

where θ_i is a normally distributed independent random variable that captures events beyond the agents' control, $\theta_i \sim N(0,\eta_i^2)$. For example, summary performance measures of activities such as R&D or manufacturing operations are specific measures of spillover effort if these activities relate to goods or services that are delivered to another business unit. The specific measure s_i can be used as a *below-level* performance measure for agent i.[8]

The principal offers agent i a contract that depends on three performance measures, i.e., the above-level measure, x, agent i's own-level measure, y_i, and agent i's below-level measure, s_i. We restrict the compensation w_i paid to agent i to be a linear function of the measures, i.e.,

$$w_i = f_i + v_{xi}\, x + v_{yi}\, y_i + v_{si}\, s_i, \qquad i=1,2,$$

where f_i is the fixed salary, v_{xi} is the incentive rate for the above-level measure, v_{yi} is the incentive rate for the own-level measure, and v_{si} is the incentive rate for the below-level measure.[9]

Agent i's preference is represented by a negative exponential utility function, with $u_i = -\exp[-r\,(w_i - \kappa_i)]$, and r is the coefficient of the agent's absolute risk aversion. Normally distributed noise terms and negative exponential utility yield a simple representation of the agent's certainty equivalent (Holmstrom and Milgrom 1987). In particular, agent i's certainty equivalent is characterized by

$$CE_i(f_i,v_{xi},v_{yi},v_{si},a_{i1},a_{i2}) = f_i + v_{xi}\,(a_{11} + a_{12} + a_{21} + a_{22})$$

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[8] An alternative to this setting is for the specific metric to measure the local activity (e.g., $s_i' = a_{ii} + \theta_i'$, i=1,2). As we will show below, including s_i into the agent's contract is beneficial to the principal because it improves the congruency of the agent's "total" performance measure with the principal's payoff. While appropriately weighting y_i and s_i' can also generate a total performance measure that is more congruent with the principal's payoff than y_i, the weight on s_i' can turn negative. This is the case, e.g., if the agent is sufficiently risk tolerant. Since negative weights are rather uncommon, we chose to consider specific metrics that measure the spillover activity.

[9] Restricting the contract to these 3 measures is without loss in generality: The above-level measure, x, and agent i's own-level measure, y_i, are an equivalent statistic for the other agent's own-level measure, y_j, $j\neq i$. Also, the other agent's specific measure, s_j, is neither controllable nor conditionally controllable by agent i.

$$+ v_{yi} [a_{ii} + (1 - \beta_i) a_{ij} + \beta_j a_{ji}] + v_{si} a_{ij} - ½ (a_{i1}^2 + a_{i2}^2)$$

$$- ½ r \{v_{xi}^2 (\sigma_1^2 + \sigma_2^2) + v_{yi}^2 \sigma_i^2 + 2 v_{xi} v_{yi} \sigma_i^2 + v_{si}^2 \eta_i^2\}, \quad i,j = 1,2 \text{ and } i \neq j, \tag{1}$$

representing the expected compensation net of effort cost and risk premium.

The principal selects incentive rates that maximize expected firm profit net of the agents' compensation, subject to the agents' individual rationality and incentive compatibility constraints. Specifically, the principal solves the following problem (Holmstrom and Milgrom 1990):

$$\max_{f_i, v_{xi}, v_{yi}, v_{si}, a_{i1}, a_{i2}} \mathrm{E}[x \mid a_{i1}, a_{i2}] - \mathrm{E}[w_1 + w_2 \mid a_{i1}, a_{i2}, f_i, v_{xi}, v_{yi}, v_{si}] \tag{2a}$$

subject to

$$CE_i(f_i, v_{xi}, v_{yi}, v_{si}, a_{i1}, a_{i2}) \geq 0, \tag{2b}$$

$$\text{and } (a_{i1}, a_{i2}) \text{ maximize } CE_i(f_i, v_{xi}, v_{yi}, v_{si}, a_{i1}, a_{i2}), \qquad i=1,2. \tag{2c}$$

Individual rationality constraints (2b) ensure contract acceptance by the agents. Without loss in generality, we scale each agent's reservation wage to equal zero. The incentive compatibility constraints (2c) reflect that agent i chooses actions a_{i1} and a_{i2} that maximize his certainty equivalent.[10]

2.2 Optimal contracts

The principal solves the problem expressed in (2a) through (2c). According to (2c), agent i's actions follow from the first-order conditions of (1) with respect to a_{ii} and a_{ij}:

$$a_{ii}^* = v_{xi} + v_{yi} \qquad \text{and} \tag{3a}$$

$$a_{ij}^* = v_{xi} + (1 - \beta_i) v_{yi} + v_{si}, \quad i,j = 1,2 \text{ and } i \neq j. \tag{3b}$$

For each action, the optimal effort is given by the sensitivity of a performance measure to the respective action times the measure's incentive rate, totalized over all measures. Expression (3b) indicates that contracting on the above-level or below-level measure can compensate for a reduced sensitivity of the own-level performance measure to the spillover action, where the

[10] We assume that the agents act non-cooperatively. Models with inter-agent negotiations include Holmström and Milgrom (1990); Itoh (1992); and Feltham and Hofmann (2007), among others. Our assumptions imply that there is a unique dominant strategy in the action-choice subgame played by the agents. In equilibrium, each agent's conjecture with respect to the other agent's actions is true.

reduced sensitivity follows from the transfer-pricing scheme not adequately accounting for the spillover action, $\beta_i \neq 0$. Following expression (3a), the above-level measure differs from the below-level measure as only the former provides incentives for the local action.

To obtain the optimal incentive contract, for each agent i, where $i = 1,2$, we set (1) equal to zero (based on (2b)) and solve for f_i^*. Substituting, for each agent i, f_i^*, a_{i1}^*, and a_{i2}^* into (2a), differentiating with respect to the incentive rates, and solving the first-order conditions for these variables yields the optimal incentive rates. Proposition 1 describes the ratio of the incentive rates for the above-level and own-level performance measures ($IR_{ai}^* = v_{xi}^* / v_{yi}^*$) and the ratio of the incentive rates for the below-level and own-level performance measures ($IR_{bi}^* = v_{si}^* / v_{yi}^*$).[11]

Proposition 1: Given the optimal contract offered to agent i, the relative incentive rates on x and y_i, and s_i and y_i, respectively, are given by

$$IR_i^a = \frac{v_{xi}^*}{v_{yi}^*} = \frac{\beta_i\,\eta_i^2\,(\beta_i + r\,\sigma_i^2)}{\sigma_j^2 - r\,\eta_i^2\,[\beta_i\left(\sigma_1^2 + \sigma_2^2\right) - 2\,\sigma_j^2]} \text{ and} \tag{4a}$$

$$IR_i^b = \frac{v_{si}^*}{v_{yi}^*} = \frac{\sigma_j^2\,(\beta_i + r\,\sigma_i^2)}{\sigma_j^2 - r\,\eta_i^2\,[\beta_i\left(\sigma_1^2 + \sigma_2^2\right) - 2\,\sigma_j^2]}, \quad i,j = 1,2 \text{ and } i \neq j. \tag{4b}$$

With two tasks and three performance measures, the incentive rates and ratios are the results of several tradeoffs faced by the principal.[12] To provide intuition for these tradeoffs, we characterize necessary conditions for the principal to contract on three performance measures.[13]

In our setting, the parameter β_i captures the non-congruity of own-level performance y_i relative to firm profit x.[14] For $\beta_i > 0$, the own-level measure does not capture the total output for both, the agent's local action and his spillover action. Then, contracting on x lets the agent, for

[11] All proofs are presented in Appendix 1.

[12] Incentive ratios have predominantly been considered for settings with two performance measures. Banker and Datar (1989) provide a general characterization for the ratio of optimal incentive rates. Datar, Kulp, and Lambert (2001) characterize incentive ratios for settings with multiple tasks.

[13] We discuss the comparative statics for the incentive ratios below after having introduced the consequences of intra-firm interdependencies on performance measure characteristics.

[14] Applying the definition provided by Feltham and Xie (1994), the measure of noncongruity for own-level performance y_i relative to firm profit x is given by $(\partial \mathrm{E}[x]/\partial a_{ii} \cdot \partial \mathrm{E}[y_i]/\partial a_{ij} - \partial \mathrm{E}[x]/\partial a_{ij} \cdot \partial \mathrm{E}[y_i]/\partial a_{ii})^2 = \beta_i^2$.

each task, internalize the total marginal product of a unit of his effort. However, given that the above-level measure is, in general, subject to random events from both business units, contracting on x entails a cost to the principal. Hence, the principal includes x in the agent's contract if the own-level measure is non-congruent, $\beta_i > 0$, and if there is no costless alternative to motivating the spillover action, i.e., if the below-level measure is noisy, $\eta_i \neq 0$.

First, suppose that the own-level measure is perfectly congruent with firm profit, $\beta_i = 0$; then, x is a noisy garbling of y_i, equally sensitive to the agent's spillover and local actions as the own-level measure. Consequently, the principal will not include x in the agent's contract, $v_{xi}^* = 0$. Second, suppose that the below-level performance measure perfectly captures agent i's spillover action, $\eta_i = 0$. Then, the principal can use the below-level measure to induce first-best spillover action and the above-level measure is not needed to motivate the spillover action. Also, to motivate the local action, the above-level measure is a noisy garbling of the own-level measure, implying that the principal does not include x in the contract, $v_{xi}^* = 0$.

Contracting on the below-level measure, s_i, is an alternative to using the above-level measure to let agent i fully internalize the total marginal product of his spillover effort. Since s_i is a noisy measure of agent i's spillover action, the principal includes s_i in the agent's contract if there is no costless alternative to motivating the spillover action. To the contrary, suppose that the above-level measure is not affected by random events from the other business unit, i.e., from the perspective of agent i, $\sigma_j = 0$, $j \neq i$. Then, $\text{Var}[y_i] = \text{Var}[x] = \text{Cov}[y_i, x] > 0$, implying that divergent signs for the incentive rates of own-level and above-level performance reduce the risk in agent i's performance evaluation. In fact, with $v_{xi} = -v_{yi}$, agent i is fully shielded from uncontrollable events affecting y_i (and x). Importantly, given the reduced sensitivity of y_i with respect to a_{ij}, i.e., given $\beta_i > 0$, even with full "insurance," agent i is left with incentives for spillover action, $a_{ij} = \beta_i\, v_{xi} > 0$. Consequently, the principal induces first-best spillover action, implying that the below-level performance measure is not needed for contracting, $v_{si}^* = 0$.

However, $v_{xi} = -v_{yi}$ does not provide agent *i* with incentives for local action; thus, in equilibrium, the principal selects – in absolute terms – stronger incentives for the above-level measure than for the own-level measure, $v_{xi}^* > -v_{yi}^*$.[15]

2.3 Intra-firm interdependencies and performance measure characteristics

In this subsection, we discuss specific relations between intra-firm interdependencies and performance measure characteristics. From the perspective of a focal agent, intra-firm spillover can take on two forms: *spillover to the other business unit*, i.e., the effect the focal agent's business unit has on the other unit, and *spillover from the other business unit*, i.e., the effect the other agent's business unit has on the focal agent's unit. We assume that noise and sensitivity of the above-level, own-level, and below-level performance measures vary differentially with intra-firm spillover.

For illustration, suppose that the two business units produce goods, sell them to outside customers, and ship a fraction of the goods to the other business unit, where they are processed before they are sold. In this setting, the units exchanged between business units are a measure of intra-firm spillover. Specifically, let δ_i represent the units delivered from business unit *i* to business unit *j*, $i,j = 1,2$ and $i \neq j$. From the perspective of focal agent *i*, with more units delivered to the other business unit (i.e., for higher values of δ_i) there is a larger *effect on the other business unit*; to the contrary, with more units received from the other business unit (i.e., for higher values of δ_j, $j \neq i$) there is a larger *effect on the focal agent's business unit*. Further, suppose that the principal uses projected demand, marginal cost, and sales prices to decide about the exchange of intermediate goods. Then, from the perspective of both agents, the extent of spillover is exogenously given.

[15] While selecting $v_{xi}^* > -v_{yi}^*$ imposes risk from ε_i on agent *i*, the principal continues to induce first-best spillover action. Neglecting s_i, note that incentive risk varies with $v_{xi} + v_{yi}$ and spillover action is given by $v_{xi} + (1 - \beta_j)\, v_{yi}$. Intuitively, for any positive incentive risk, by appropriately allocating total incentives $v_{xi} + v_{yi}$ to v_{xi} and v_{yi}, the principal can induce first-best spillover action at the same cost of risk.

Now, consider the consequences of varying the exchange of intermediate goods. Suppose that focal agent *i*'s business unit delivers more units to the other business unit. Most likely, the constraints faced by the principal when designing the transfer-pricing scheme are more severe for higher levels of internal deliveries. Then, for more units delivered to the other business unit, a larger fraction of the output from agent *i*'s spillover action is reflected in the other business unit's performance measure, $\partial\beta_i/\partial\delta_i > 0$. In turn, the focal agent's own-level metric is less sensitive to his spillover action.[16]

A second likely consequence of intra-firm spillover is that the number of exogenous, uncontrollable factors affecting a business unit's output increase. For example, consider a setting where the receiving business unit *i* refines the intermediate good before selling it to outside customers and the cost per unit is uncertain. Arguably, with more units received and refined by business unit *i*, the variance of the receiving business unit's output increases, $\partial\sigma_i/\partial\delta_j > 0$, $j \neq i$.[17] Alternatively, consider a setting characterized by reciprocal interdependencies (Thompson 1967); for example, the receiving business unit *i* refines the intermediate good before returning it to the delivering business unit *j*. Now, with more units received and refined by business unit *i* and returned to business unit *j*, the variance of the specific performance measure for the receiving business unit increases, $\partial\eta_i/\partial\delta_j > 0$.

2.4 Comparative statics

In this subsection, we consider the relation between intra-firm spillover and incentive ratios, given the relations between intra-firm spillover and performance measure characteristics

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[16] Our assumption that the sensitivity of the other agent's output to the focal agent's spillover action increases in the effect on the other business unit is consistent with Bushman et al. (1995). Different to our setting, however, they do not consider that varying the effect on other business units may have consequences for the sensitivity of the focal agent's output to his action. Consequently, while the marginal productivity of the spillover action is constant in our setting, in their setting, the marginal productivity increases in the focal agent's effect on other business units.

[17] This assumption is consistent with Keating (1997), who argues that the "greater a manager's impact on divisions other than his own, the greater the noise in division accounting metrics …". While Keating assumes that a larger effect lowers the noise in the above-level measure, in our setting, due to the aggregation of business unit output to firm output, the noise of the above-level measure increases in the effect on other divisions.

discussed in the previous subsection. Specifically, we investigate how the degree of spillover from a focal agent's business unit to another business unit and the degree of spillover from another business unit to a focal agent's business unit affect how own-level, above-level, and below-level measures are used in the focal agent's performance evaluation. Comparative statics of incentive ratios provide insights into changes in the weighting of one performance measure relative to the weighting of another and are supposed to structure our empirical analysis.

Intra-firm spillover has multiple direct and indirect consequences for own-level, above-level, and below-level performance measures that will affect the incentives provided for focal agent *i*. A direct consequence of increasing the effect on the other business unit is that the own-level measure, y_i, becomes less sensitive to the focal agent's spillover action. Increasing the effect on the other business unit also increases the noisiness of the other agent's own-level measure, y_j, thereby, indirectly, increasing the noisiness of the above-level measure.[18] To the contrary, increasing the effect on the focal agent's business unit increases the noise in the focal agent's own-level, above-level, and below-level measures. Often, these consequences interact.

To understand the trade-offs a principal faces when designing focal agent *i*'s contract, it is instructive to first consider the baseline results when spillover has purely a noise effect on the below-level measure, $\partial\eta_k/\partial\delta_l > 0$, purely a noise effect on the own-level measure, $\partial\sigma_k/\partial\delta_l > 0$, or purely a congruity effect on the own-level measure, $\partial\beta_k/\partial\delta_k > 0$, $k,l = 1,2$ and $k \neq l$. In subsequent analyses, we consider the effect of spillover when there are multiple effects.

Table 1 summarizes changes in agent *i*'s incentive ratios, IR_i^a and IR_i^b, given changes in the effect on the other business unit, δ_i, or changes in the effect on the focal agent's business unit, δ_j, $j \neq i$.[19] With pure effects, Panels A to C show the signs of the comparative statics when the

[18] Because the above-level measure is the aggregate of the two own-level measures, the effect on the noise in the other agent's performance measure translates into a noisier above-level measure.

[19] The purpose of analyzing the model is to gain insight into the relative usage of above-level, own-level, and below-level performance metrics that is supposed to structure and motivate our empirical analysis. Hence, in the text we emphasize the comparative statics for the incentive ratios. In Appendix 1, we also list the closed form solutions for the baseline settings and their combinations.

performance measure characteristics of the focal (other) agent vary as a consequence of an increased effect of (on) the other agent. Panel D shows the signs of the comparative statics when intra-firm spillover has multiple *linear* effects on the performance measure characteristics. Subsequently, we provide intuition for the results of Table 1.

---------------- Insert Table 1 about here. -----------------

Pure noise effect on below-level measure (*i.e.,* $\partial\eta_k/\partial\delta_l > 0, k,l = 1,2$ and $k\neq l$)

Given a setting wherein spillover increases the noise in the below-level measures, Table 1, Panel A indicates that varying the spillover to the other business unit has no consequence for the relative weightings of the performance measures of focal agent i. Intuitively, while increasing the effect on the other business unit increases the noise, η_j, of this unit's below-level measure, s_j, there is no impact on agent i's incentives because s_j is not included in agent i's contract.

As the effect on the focal agent increases, so too does the noise of focal agent i's below-level measure, $\partial\eta_i/\partial\delta_j > 0$, and the principal therefore increases the weighting of the above-level measure relative to the weighting of the own-level measure, $\partial IR_i^a/\partial\eta_j > 0$, and she increases the weighting of the below-level measure relative to the weighting of the own-level measure if the own-level measure is sufficiently non-congruent, $\partial IR_i^b/\partial\eta_i > 0$ if $\beta_i > 2\sigma_j^2/(\sigma_1^2+\sigma_2^2)$. Specifically, the principal reduces the weight on the noisier below-level measure, $\partial v_{si}^*/\partial\eta_i < 0$. To offset the weaker incentives for spillover effort, the principal increases the weight on the above-level measure, $\partial v_{xi}^*/\partial\eta_i > 0$, whereas she increases the weight on the own-level measure only if the non-congruity of the own-level measure is sufficiently small, $\partial v_{yi}^*/\partial\eta_i > 0$ if $\beta_i < \sigma_j^2/(1/r+\sigma_1^2+\sigma_2^2)$. Overall, the increase of v_{xi}^* dominates any increase of v_{yi}^*, implying that the principal increases IR_i^a for a noisier below-level measure. Interestingly, given a sufficiently non-congruent own-level measure, the decrease of v_{si}^* is dominated by the decrease of v_{yi}^*, implying that the principal increases IR_i^b for a noisier below-level measure.

In turn, assuming that spillover increases the noise in the below-level measures, for a larger effect on the focal agent the principal increases the weighting of the above-level measure relative to the weighting of the own-level measure, $\partial IR_i^a/\partial\delta_j > 0$, and she increases the weighting of the below-level measure relative to the weighting of the own-level measure if the own-level measure is sufficiently non-congruent, $\partial IR_i^b/\partial\delta_j > 0$ if $\beta_i > 2\sigma_j^2/(\sigma_1^2+\sigma_2^2)$.

Pure noise effect on own-level measure (*i.e.,* $\partial\sigma_k/\partial\delta_l > 0$, $k,l = 1,2$ and $k \neq l$)

When spillover increases the noise in own-level measures, Table 1, Panel B shows that varying the spillover either to or from the other business unit affects both relative weightings of focal agent *i*'s performance measures. As the effect on the other business unit increases, the other agent *j*'s own-level measure gets noisier, $\partial\sigma_j/\partial\delta_i > 0$, and so does the above-level measure. Consequently, the principal decreases the weighting of the above-level measure relative to the weighting of the own-level measure, $\partial IR_i^a/\partial\sigma_j < 0$, and she decreases the weighting of the below-level measure relative to the weighting of the own-level measure, $\partial IR_i^b/\partial\sigma_j < 0$. Specifically, the principal reduces the weight on the noisier above-level measure, $\partial v_{xi}^*/\partial\sigma_j < 0$. To offset the weaker incentives for local and spillover effort, the principal increases the weight on the own-level measure, $\partial v_{yi}^*/\partial\sigma_j > 0$, and she increases the weight on the below-level measure, $\partial v_{si}^*/\partial\sigma_j > 0$. Since local effort is only induced using the own-level measure, the increase of v_{yi}^* exceeds the increase of v_{si}^*, implying that the principal decreases the weighting of the below-level measure relative to the weighting of the own-level measure.

When the effect on focal agent *i*'s business unit increases, agent *i*'s own-level measure gets noisier, $\partial\sigma_i/\partial\delta_j > 0$, and the principal increases the weighting of the above-level measure relative to the weighting of the own-level measure, $\partial IR_i^a/\partial\sigma_i > 0$, and she increases the weighting of the below-level measure relative to the weighting of the own-level measure, $\partial IR_i^b/\partial\sigma_i > 0$. In particular, the principal reduces the weight on the noisier own-level measure, $\partial v_{yi}^*/\partial\sigma_i < 0$. To offset the weaker incentives for local and spillover effort, the principal increases the weight on the above-level measure, $\partial v_{xi}^{*}/\partial\sigma_i > 0$, and the weight on the below-level measure, $\partial v_{si}^{*}/\partial\sigma_i > 0$.

When spillover increases the noise in the own-level measures, varying the spillover to or from the other business unit has the same impact on the relative weightings of focal agent *i*'s performance measures as the comparative statics summarized in Table 1, Panel B.

Pure congruity effect (*i.e.,* $\partial\beta_k/\partial\delta_k > 0$, $k = 1,2$)

Given a setting wherein spillover reduces the congruity of the own-level measures, Table 1, Panel C indicates that it is only the spillover to the other business unit that affects the relative weightings of focal agent *i*'s performance measures. Intra-firm spillover to the other business unit yields a non-congruent own-level performance measure for agent *i*, and the degree of incongruity increases as the effect on the other agent increases, $\partial\beta_i/\partial\delta_i > 0$. Specifically, the incongruity of the own-level measure induces an inefficient effort allocation; the principal increases the weighting of the below-level measure relative to the weighting of the own-level measure, $\partial IR_i^b/\partial\beta_i > 0$, whereas she increases the weighting of the above-level measure relative to the weighting of the own-level measure only if the other agent's own-level measure is relatively noisy, $\partial IR_i^a/\partial\beta_i > 0$ if $(\sigma_1^2+\sigma_2^2)/\sigma_j^2 < B_1$. Varying the degree of incongruity has ambiguous effects on the three incentive rates, because the weight on the own-level measure turns negative for a relatively precise own-level measure of the other agent (i.e., for low values of σ_j^2). In turn, for a relatively noisy own-level measure of the other agent, contracting on the below-level and above-level measure, relative to the own-level measure, becomes useful because it enables the principal to shift the agent's effort allocation toward first-best.

Increasing the effect on focal agent *i* reduces the congruity of the other agent's own-level measure, $\partial\beta_j/\partial\delta_j > 0$. Intuitively, any variations of the other agent's actions as a consequence of a reduced congruity yield a mean effect in focal agent *i*'s decision problem; the principal, however, can adjust for any mean effect by choosing an appropriate fixed salary for the focal agent.

Multiple linear effects

When intra-firm spillover increases the noise in below- and own-level performance measures and reduces the congruity of own-level performance measures, the overall consequences for the agents' incentive ratios follow from combining the comparative statics in Panels A to C of Table 1. Overall, as the effect on focal agent *i* increases, the principal increases the weighting of the above-level measure relative to the weighting of the own-level measure (i.e., $\partial IR_i^a/\partial\delta_j > 0$, $j \neq i$). However, the overall consequence of variations in the effect on the other agent for the relative weighting of the above-level measure to the own-level measure, $\partial IR_i^a/\partial\delta_i$, depend on the relative magnitude of the effects of intra-firm spillover on performance measure noise and congruity. Likewise, the overall consequences of variations in intra-firm spillover on the relative weighting of the below-level measure to the own-level measure, $\partial IR_i^b/\partial\delta_i$ and $\partial IR_i^b/\partial\delta_j$, depend on the relative magnitude of the effects of intra-firm spillover for performance measure noise and congruity.

To sign the predictions of the relation between intra-firm spillover and the incentive ratios, subsequently, we assume a linear relation between spillover and performance measure noise and congruity. Specifically, $\eta_i^2 = (1+\delta_j)\ \eta^2$, $\sigma_i^2 = (1+\delta_j)\ \sigma^2$, and $\beta_i = \delta_i$, i,j=1,2 and $i{\neq}j$. Panel D of Table 1 summarizes the consequences of variations in intra-firm spillover for focal agent *i*'s incentive ratios.

With multiple linear effects, our model predicts a positive relation between the effect of the focal agent on the other agent and the two incentive ratios, namely, the incentive weighting of the below-level measure relative to that of the own-level measure and the incentive weighting of the above-level measure relative to that of the own-level measure. Likewise, as the effect on the focal agent increases, the weighting of the above-level measure relative to the weighting of the own-level measure increases. On the other hand, it is not possible to predict the sign of the relation between the effect on the focal agent and the weighting of the below-level measure relative to the weighting of the own-level measure.

Observe that for both incentive ratios, the cross-partials are, in general, non-zero (i.e., $\partial^2 IR_i^k/(\partial\delta_i\,\partial\delta_j) \neq 0$, $k = a, b$, $i, j = 1, 2$ and $j \neq i$), which suggests an interaction between the effect on the other agent and the effect of the other agent in terms of how the performance measures are weighted. In particular, the interaction can change the direction of the comparative statics (i.e., $\mathrm{sgn}[\partial IR_i^b/\partial\delta_j]$, $j \neq i$ depends on the magnitude of δ_i). Key to this observation is that the own-level and below-level measures' noise and congruency drive the weightings of these measures. These characteristics of the performance measures, however, depend on the extent to which the focal agent i affects the other business unit (i.e., δ_i) and the extent to which the agent of the other business unit affects the focal unit's performance measures (i.e., δ_j, $j \neq i$). Thus, the model does predict an interaction between the effect of other business units and the effect on other business units, which would affect the relative weightings of the performance measures.[20]

3. Sample, variable measurement, and model estimation

We use the client list of a major audit firm to obtain our sample of business unit managers from publicly listed firms. Using the names and addresses provided on the client list, we directly contacted a random selection of these business unit managers and invited them to participate in the survey. Although using only a single audit firm's client list may bias our sample, we feel that, in our setting, this effect is likely to be small and would not outweigh the advantages of making our first contact with our respondents through the audit firm and thereby securing their willingness to participate. To be included in the sample, firms must have more than one business unit. From our initial sample of 240 business units, 122 managers agreed to

[20] Generally, it is not possible to make an unconditional prediction regarding the interaction of the two types of intra-firm spillover because the marginal effect of each type of spillover depends on each performance measure's degree of noise and congruency.

participate, yielding a response rate of about 50%, which is in line with recent survey-based studies in accounting.

Surveys were administered by phone. Prior to the phone call, respondents received a package containing the questionnaire and a cover letter that explained the general aims of the research. Compared with mail surveys, phone interviews offer many of the same advantages as site visits while being less costly. The researcher can verify the respondent's understanding of the questions and ensure that all questions are answered. Phone interviews also ensure that the intended respondent, and not, for example, the respondent's assistant, answers the questions.

Common method/rater bias is a valid concern in survey-based research. We use both procedural and statistical remedies to mitigate the adverse effects of this bias (following Podsakoff, MacKenzie, Lee and Podsakoff 2003). We separate the measurement of dependent and independent variables by placing these questionnaire items as far apart as possible and by using different response formats. We protected respondent anonymity and reduced evaluation apprehension by assuring respondents that there are no right or wrong answers and that they should answer questions honestly. These procedures are designed "to make people less likely to edit their responses to be socially desirable, lenient, acquiescent, and consistent with how they think the researcher wants them to respond," thus reducing common method bias. We also heeded the warning that some scale items are more prone to common method bias than others. For this reason, we avoided as much as possible for our key dependent and independent variables the use of Likert scales with similar end points and formats as these similarities are likely to cause common method bias and to have anchoring effects. In addition, we conduct the single factor test in Harman (1967) to evaluate the extent to which common method bias is present in the data. If it is present, then either only a single factor will emerge or only one of several factors will account for the majority of covariance among the variables (see also, Abernethy et al. 2004). This test clearly rejects the hypothesis that common method bias is driving our results (chi-squared = 274.7; df = 77, p-value < 0.001) (Podsakoff et al. 2003).

Table 2, Panel A provides details about the characteristics of the firms in our sample. About 27% of the business units are in the service sector. Most business units have been part of their current parent company for a substantial period of time (mean = 17.50 years), although approximately 14% of the units were acquired within the past year (untabulated). The business units vary significantly in size; while the median number of employees is 290, the mean is much higher at 1,005. Approximately 10% of the business units have fewer than 25 employees (untabulated). On average, the units are responsible for 12.6% of total firm sales.

---------------- Insert Table 2 about here. -----------------

As Table 2, Panel B shows, the typical respondent is 44 years old and has been in their current job (business unit) for an average of 3.2 (5.9) years. The respondents are somewhat less experienced than their superiors, both in the industry (mean = –3.73 years) and in the firm (mean = –4.75 years).

3.2 Variable measurement

3.2.1. Dependent variables

Weighting of type of performance measure. Following earlier studies (Abernethy et al. 2004; Bouwens and van Lent 2007), we provide respondents with a list of performance measures and ask them to indicate, in percentage terms, their superior's weighting of each measure in evaluating their performance. These measures include stock-price related, firm-wide, group, own-level (i.e., business unit), and below-level (i.e., specific) performance measures. We also allowed respondents to fill in any other measures that they judged were not well represented by any of these categories (Fowler Jr. 1995).[21] Details are reported in Table 3, Panel A. We combined the separate weightings of stock-price related,[22] firm-wide, and group measures into a single

[21] These answers were reviewed separately by at least two of the authors and re-classified if possible to the remaining categories.

[22] Stock-price related measures are by definition associated with firm-wide performance and should therefore be treated as "above-level" measures. In addition, prior work has shown that stock-price related measures respond to interdependencies in very much the same way as other firm-wide measures (Keating 1997; Bouwens and van Lent 2007).

"weighting of above-level measures." We have two reasons for doing so. First, our theory focuses on the use of above-level measures versus the use of own-level and below-level measures and does not further distinguish between different types of above-level measures. Without more detailed theoretical guidance, any exploration of the use of individual above-level measures would merely be ad hoc. Second, depending on the firm's structure, business units are not necessarily part of a group, and thus we found that many respondents assigned zero weight to group measures. Analyzing group measures separately from firm-wide measures would confound issues of firm structure with those of performance measurement. In addition, as we describe below, "zero-inflation" could cause problems in our estimation procedures, and combining categories to reduce the number of zeros is a recommended way of dealing with such inflation (Fry, Fry and McLaren 1996). Below-level measures are defined as summary performance measures of specific activities within the respondent's unit. The idea is that specific activities such as R&D or manufacturing operations can affect internal deliveries to other business units, inasmuch as they influence the quality of the delivered goods or services. Below-level performance measures can therefore be informative about how the actions of one manager affect other managers in the firm.

The combined weighting of all three categories of performance measures (after reassigning the answers to the open-ended "remainder" category) in Table 3 Panel A must sum to 100 percent. One implication of this requirement is that the weightings of any two of the categories fully describe the distribution of weight among all three; that is, the weighting of any one of the categories of performance measures cannot be varied independently of the other two. In short, our data is "compositional." Statistical analysis of this kind of data requires that we explicitly incorporate the constant sum constraint into the model, which can be accomplished by using log-ratios of the proportions (Aitchison 1986; Abernethy, Bouwens and van Lent 2009). We therefore use *Log(above/own)*, the natural logarithm of the weighting of above-level measures divided by the weighting of own-level measures, and *Log(below/own)*, the natural logarithm of the weighting of below-level measures divided by the weighting of own-level measures, as the dependent variables in our tests. We rely on Aitchison's (1986) zero-replacement procedure to avoid the problem of dividing by zero and/or taking the logarithm of zero.

---------------- Insert Table 3 about here. -----------------

Our survey instrument has been tested in several earlier studies and is known to have good psychometric properties and construct validity (Abernethy et al. 2004; Bouwens and van Lent 2007). Some of its more salient benefits are that the weightings correlate strongly with the use of measures in formula-based bonus contracts, which reduces the possibility that we are merely capturing "softer" perceptions; the measures can have equal weightings and do not have to be rank-ordered; and Likert scales, which tend to elicit how respondents feel about an issue rather than what they actually do, can be avoided.

3.2.2. Test variables

Interdependencies. Researchers interested in exploring intra-firm dependencies face a dilemma when operationalizing this theoretical construct. Prior studies have relied either on somewhat coarse data taken from publicly available datasets (Bushman et al. 1995; Christie, Joye and Watts 2003) or on Keating (1997), who uses single-item survey instruments to obtain a measure of the focal unit's effect on other units and of the effect of the other units on the focal unit (see, e.g., Abernethy et al. 2004). Whereas archival-based measures can only serve as broad proxies for interdependencies aggregated at the firm-level (i.e., it is usually not possible to obtain reliable specific estimates for individual units within the firm), relying on single-item instruments clearly is not desirable either. Nevertheless, as Luft and Shields (2003) point out, using empirical proxies that closely approximate theoretical concepts significantly improves our ability to understand the role of accounting in organizations. We therefore use an instrument taken from Abernethy et al. (2004) and Bouwens and van Lent (2007) that relies on two survey items that ask directly about internal deliveries within the firm. Specifically, *Supply to others* asks the respondent to report the percentage of the focal unit's total production that is delivered to other units within the firm. *Supply from others* asks for the percentage of the focal unit's total production that uses inputs sourced from other units within the firm. Because the two items ask for actual deliveries between units, the instrument relies less on respondents' perceptions or feelings and in that sense yields "harder" data (Ittner and Larcker 2001). The mean *Supply to others* is approximately 16 percent, while the mean *Supply from others* is approximately 26.5 percent (see Table 3, Panel B). Median percentages are substantially lower at 5 and 10 percent, respectively. Importantly, because we are not sampling pairs of business units within one firm, there is no correspondence between these two interdependency proxies; that is, unit A's *Supply from others* is not unit B's *Supply to others*. Rather, these are separate measures of "incoming" and "outgoing" interdependencies for each business unit.

We use three other survey items to test the convergent validity of our test variables (following Abernethy et al. 2004). Details about the correlations underlying these validity tests are presented in Table 3, Panel C. To validate the test variables in our study, we emphasize the measures of interdependencies used in Keating (1997). We construct *Spillover to other managers* from a survey question that asks respondents to indicate the extent to which their units' actions affect work carried out in *other* organizational units of their firm. Similarly, *Spillover of other managers* is based on a question about the extent to which the actions of managers of other units within the firm affect work carried out in the respondent's unit. Respondents answer on a Likert-type scale that ranges from 1 (no effect at all) to 7 (a very significant effect). The Spearman correlation between *Supply to others* and *Spillover to other managers* is 0.34 (p-value < 0.01). Similarly, the Spearman correlation between *Supply from others* and *Spillover of other managers* is 0.48 (p-value < 0.01). Finally, we correlate both *Supply to others* and *Supply from others* with a survey item that asks about the extent to which the focal unit could operate as a stand-alone business (corr. with *Supply to others* is 0.36, p-value < 0.01; corr. with *Supply from others* is 0.35, p-value < 0.01) and with an item that asks about the amount of time (as a percentage of total working time) the respondent spends in meetings with managers from other units in the firm (corr. with *Supply to others* is 0.56, p-value < 0.01; corr. with *Supply from others* is 0.36, p-value < 0.01). Together, these tests suggest that our interdependency measures are valid.

Our theory predicts that the two types of interdependencies will interact. We therefore mean-center *Supply to others* and *Supply from others* before multiplying them to construct the interaction term *To* × *From*. In our regressions, the coefficient on *Supply to others* (*Supply from others*) represents the effect *Supply to others* (*Supply from others*) has on the dependent variable, holding *Supply from others* (*Supply to others)* constant at its sample mean (Wooldridge 2000; Jaccard and Turrisi 2003).

3.2.3. Control variables

To define our set of controls, we follow earlier studies on the determinants of the use of performance measures in business units (Bushman et al. 1995; Ittner et al. 1997; Keating 1997; Ittner and Larcker 2001; Abernethy et al. 2004; Bouwens and van Lent 2007). Table 4 presents summary statistics on these variables. *Varcomp* is the maximum percentage of total pay that is available as performance-dependent incentive pay (which can include cash bonuses, equity grants or stock options). *Decentralization* measures the difference in decision making authority between the respondent and his superior in five key areas: strategy, investments, marketing, internal operations, and human resources. The instrument is described in Abernethy et al. (2004) and Bouwens and van Lent (2007) and follows from an earlier proposal in Gordon and Narayanan (1984). A measure based on a composite of the above five items is correlated with five additional questions that in a yes/no format ask for detailed information about the respondent's decision making authority regarding investments.[23] Bouwens and van Lent (2007) suggest that these investment-decision questions can be used to check the validity of the *Decentralization* construct.

[23] These questions are as follows. If my business unit needs a new building, I can decide to purchase, rent, or build one without my boss's prior consent. If my unit needs to replace durable equipment, I can do so without asking my boss for permission. If I need to extend the production capacity in my unit, I can decide to do so without asking my boss for permission. I can decide on the level of R&D activities in my unit. When developing new products, I can make my own investment decisions.

Four out of five of the correlation coefficients between *Decentralization* and the five investment questions are positive and significant at the 5 percent level or better, and one coefficient has a *p*-value of 0.14, which can be interpreted as evidence of convergent validity. We use the four-item instrument in Khandwalla (1972) to capture the competitive environment of the business unit (here, labeled *Competition*). We use a two-item instrument taken from Abernethy et al. (2004) to capture the growth opportunities of the respondent's business unit and of the industry in which they compete (here, labeled *Growth opportunities*). *Size* is the natural logarithm of the number of full time employees of a given business unit. Finally, we include an indicator variable (here, labeled *Service*) that takes the value of unity when the business unit operates in a service industry.

---------------- Insert Table 4 about here. -----------------

3.3 Model estimation

Our estimation has two steps. First, we use factor analysis to construct a weighted composite measure for each theoretical construct (Hair, Anderson, Tatham and Black 1998; Chenhall 2005). We submit all indicator variables to the factor analysis simultaneously to ensure that we obtain a clean factor score; the (untabulated) results suggest that the constructs exhibit good reliability and construct validity.[24]

Second, we estimate seemingly unrelated regressions using the log-ratios (above/own) and (below/own) of the three performance measures as the dependent variables. As noted above, the compositional nature of our data (i.e., the fact that the weightings of the three categories of performance measures must sum to unity) means that any one performance measure cannot be varied independently of the other measures. We model this dependency explicitly by taking log-

[24] Our results, however, are not sensitive to this estimation choice. When we adopt a latent variable approach to deal explicitly with measurement error and provide evidence on construct validity as suggested by Ittner and Larcker (2001), neither the sign nor significance of our variables is affected. Specifically, we use Partial Least Squares to obtain estimates of the weightings used to create the latent variables scores and of the loadings that connect the latent variables with their associated manifest indicators (Chin and Newsted 1999).

ratios and by allowing the residuals from the two log-ratio regression equations to be correlated (Aitchison 1986).[25]

To correct departures from normality and improve the size of the test, we use bootstrapping to compute the standard errors (i.e., 1,000 replications with replacement where all samples have the same size as the original sample) (Moon and Perron 2008).

4. Empirical findings

We first discuss the summary statistics for our main variables as reported in Tables 3 and 4 as well as their Pearson correlations, which are reported in Table 5. Table 6 presents the estimation results of the seemingly unrelated regressions that examine the association between interdependencies and the use of above-level and below-level measures relative to own-level measures, and Table 7 presents analysis of the marginal effect of interdependencies for the purpose of exploring the nature of the interaction effect.

4.1 Summary statistics

We report descriptive statistics on the weightings of the above-, own-, and below-level performance measures in Table 3, Panel A. By far, the own-level measures receive the most weight on average (mean = 0.58). Above-level measures, on the other hand, are used frequently in our sample, and their average weighting in the performance evaluation of business unit managers is 0.30. In contrast, below-level, or specific, measures are not used in 54% of the companies and for that reason obtain an average weighting of 0.13. However, when we consider only those companies that do use below-level measures, the average weighting is much higher (mean = 0.28).

Panel B documents the summary statistics for our key interdependency variables *Supply from others* and *Supply to others*, as well as for the variables we use to establish convergent validity (*Spillover on other managers, Spillover of other managers, %Time-Meet,* and *Independent business*). The test variables span the full theoretical range of 0 to 100 percent and

[25] The estimated correlation between the residuals of the two equations is 0.47.

show on average substantial intra-firm interdependency (i.e., the mean is approximately 16 percent for *Supply to others* and 26 percent for *Supply from others*). We find similar variation in the two *Spillover* variables, which measure the degree to which the actions of managers have spillover effects on other units in the firm. Business unit managers spend between 0 and 40 percent of their time meeting with managers from other units in the firm (mean = 9.97). About 50% of the respondents report that their firm can operate as an independent business (outside of the current parent company) for a substantial part of their activities (median = 6).

As shown in Table 5, which presents the correlations among the variables in our study, the weightings of the three performance-measure categories (i.e., above-level, own-level, and below-level) are, as we would expect given their compositional nature, highly negatively inter-related. More importantly, we find that above-level measures are significantly positively associated with *Supply to others*, but not with *Supply from others*. Conversely, below-level measures are significantly positively correlated with *Supply from others*, but not with *Supply to others.* In line with these results, own-level measures are negatively associated with both types of interdependencies (albeit only weakly with *Supply from others*). Taken together, it appears that below-level and above-level measures are both used in response to increasing intra-firm dependencies, but that each type of measure is adapted to the different kinds of demands that arise from interdependencies that affect, on the one hand, the focal unit and, on the other, the other unit.

---------------- Insert Table 5 about here. -----------------

4.2 Main findings

The empirical specification of the model is based on our theoretical framework. Specifically, our model predicts that the relative weightings of the above-level versus the own-level measures and of the below-level versus the own-level measures depend on the effect the focal unit has on other business units as well as on the effect the other business units have on the focal unit. In addition, because both types of spillover can reinforce one another, our model motivates the inclusion of an interaction term.

Table 6 presents our seemingly unrelated regression results. First, we regress our set of control variables separately onto the log-ratios (above/own) and (below/own). We find that increasing the proportion of performance-dependent incentive pay in a manager's total compensation package reduces the weightings of both below-level and above-level performance measures relative to the weightings of the own-level measures. In addition, we find that the evaluation of managers in more decentralized business units tends to be based on own-level measures more than on above-level measures.

---------------- Insert Table 6 about here. -----------------

We compare the results for the regressions that include the test variables with our theoretical model's comparative statics, which are reported in Table 1, Panel D. *Supply to others* empirically captures the effect *on* the other agent. The comparative statics suggest that as *Supply to others* increases, the weighting of both the below-level and above-level measures will increase relative to the own-level measures. Indeed, we find that *Supply to others* is positively and significantly associated with both the log-ratio (above/own) (coeff. = 3.671, *z*-statistic = 1.81) and the log-ratio (below/own) (coeff. = 2.517, *z*-statistic = 1.72). Recall, however, that the simple effect on *Supply to others* represents the marginal effect when *Supply from others* is held constant at the sample average. The comparative statics suggest that the marginal effect of *Supply to others* will be positive irrespective of the value of *Supply from others*. We explore this issue more fully below.

We do not find that *Supply from others*, our empirical proxy for the effect *of* the other agent, is significantly associated with the use of either the above-level or below-level measures when *Supply to others* is held constant at the sample average. While the comparative statics suggest a positive association between the use of above-level measures and *Supply from others*, the association between the use of below-level measures and *Supply from others* is less straightforward. Indeed, we expect the sign of the association to depend on the interaction between the two types of interdependencies, and this expectation motivates us to include an interaction term in the regression specification.[26]

As expected, we indeed find evidence of an interaction between the two types of interdependencies (i.e., spillover). The sign on the interaction term *To* × *From* is negative and significant in both the log-ratio (above/own) equation (coeff. = –18.34, *z*-statistic = –2.14) and the log-ratio (below/own) equation (coeff. = –10.28, *z*-statistic = –1.91). Thus, when both *Supply to others* and *Supply from others* increase, the incentive weightings of the below-level and above-level measures decrease relative to the own-level measures.

Furthermore, Table 6 shows that as the proportion of performance-based incentive pay in a manager's total compensation package increases, the weighting of the below-level measures relative to own-level measures decreases. The adjusted R2 of our model is in line with that of earlier studies and varies from 19.0 percent (when the dependent variable is the log-ratio of (above/own)) to 20.6 percent (when the dependent variable is the log-ratio of (below/own)).

In Table 7, we report the marginal effects of each type of spillover when evaluating the other type of spillover at both its sample minimum and sample maximum. Doing so is important because the main effects presented in Table 6 *only* represent the marginal effect of *Supply to others* (*Supply from others*) when *Supply from others* (*Supply to others*) is held constant at its sample mean.[27]

---------------- Insert Table 7 about here. ----------------

[26] Note that we make some assumptions about the model parameters when deriving the comparative statics. Different assumptions can make the sign of the relation between the effect of the focal agent and the incentive ratios also a function of the interaction between the two types of spillover.

[27] Specifically, suppose we have the following equation: $Y = \beta_0 + \beta_1 X + \beta_2 Z + \beta_3 XZ + \Sigma\beta_j Controls_j + \epsilon$. The marginal effect of X on Y when Z is held at its sample minimum ($\underline{Z}$) is defined as $\partial Y/\partial X|_{Z=\underline{Z}}$, which equals $\beta_1 + \beta_3 \underline{Z}$. Clearly, owing to the interaction term, $\beta_1$only describes the marginal effect of X on Y when Z = 0, which equals the sample mean of Z due to our mean-centering procedure.

Because we expect the consequences of spillover to be more pronounced when either or both types of interdependencies are strong, evaluating the marginal effect at the sample average does not fully describe the relation between spillover and the use of performance measures. Indeed, the results presented in Table 7 suggest that a more intricate relation obtains than was first apparent. Note that the comparative statics in Table 1, Panel D suggest that *Supply to others* is unconditionally positively associated with the log-ratios (above/own) and (below/own). In addition, our model predicts that *Supply from others* will be unconditionally positively associated with the log-ratio (above/own). Thus, as we compute the marginal effect for different values of the interacting variable, we do not expect the sign of the relation to change. In contrast, our model predicts that the sign of the effect of *Supply from others* on the log-ratio (below/own) will change according to the relative noise in the own-level and below-level measure (σ^2/η^2).

Consistent with our model's predictions, we find that the marginal effect of *Supply to others* on the relative weightings of the above-level and below-level measures is always positive when *Supply from others* is held constant at the sample minimum. We also find that, as predicted, *Supply from others* has a positive effect on the log-ratio (above/own) when *Supply to others* is held constant at the sample minimum.

The comparative statics show that the effect of *Supply from others* on the log-ratio (below/own) depends on sgn[$\sigma^2/\eta^2 - B_2$], and thus on the noise of the own-level measures. In other words, depending on the noisiness of the own-level measures and the value of the cutoff B_2, either a positive or a negative effect can ensue. Thus, our empirical findings, which document a positive effect of *Supply from others* on the log-ratio (below/own) when evaluating at the sample minimum of *Supply to others* and a negative effect of *Supply from others* on the log-ratio (below/own) when evaluating the sample maximum of *Supply to others*, are consistent with our model's predictions.[28]

In contrast, we find that the effect of *Supply to others* on the log-ratio (above/own) when evaluating at the sample maximum of *Supply from others* and of *Supply from others* on the same log-ratio when evaluating at the sample maximum of *Supply to others* is both significant and negative, whereas the comparative statics predict a significant and positive relation. Thus, in situations in which both types of spillover are high, we find empirically that firms respond by increasing their weighting of own-level measures, which does not support our model's prediction of a higher weighting of the above-level measures. While we do not wish to speculate about the cause of this finding beyond what can be inferred from our data, it is possible that when firms are organized such that local managers face high levels of both incoming and outgoing interdependencies, own-level measures would provide sufficient incentives to do the right thing. Essentially, such high levels of reciprocal interdependencies might permit each local manager to "retaliate" against non-cooperative behavior of the other manager. Indeed, if the focal manager receives supplies of substandard quality, she can, in turn, reduce the quality of her deliveries. In equilibrium, with all parties aware of this potential for retaliation, managers will cooperate optimally without needing above-level or below-level performance measures to induce such cooperation.[29]

Figure 1 re-presents the marginal effects, this time taking the interaction between the two types of interdependencies into account. The plot displays the marginal effect of *Supply to others*

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[28] Technically, the cutoff B_2 depends on δ_1 and δ_2. Thus, from the perspective of focal agent *i*, varying the level of supply to others (i.e., δ_i) from the sample minimum to the sample maximum affects B_2 such that, in turn, the sign of $\sigma^2/\eta^2 - B_2$ can flip.

[29] An alternative scenario is that in the case of high reciprocal interdependencies, firms invest much more in transfer pricing systems that, in turn, alleviate many of the problems associated with spillover. As a result, own-level performance measures more fully capture the consequences of a manager's actions on others and vice versa, and there is less need for using above-level measures to achieve the same. We have little theoretical guidance on how transfer pricing and performance measurement systems interact in these circumstances, and absent data on the transfer pricing system of our sample firms (or even a validated instrument to measure transfer pricing systems empirically), we cannot explore these issues further.

(*Supply from others)* on the log-ratios (above/own) and (below/own). The marginal effect of *Supply to others* depends on specific values of *Supply from others* (and vice versa), and we graph the effect over the complete range of *Supply from others* in the figure. The dashed lines represent confidence intervals.

---------------- Insert Figure 1 about here. -----------------

At first glance, these results suggest that the interactions between the two types of spillover play a greater role than our comparative statics suggest. Note, however, that most of the sample is concentrated in the left tail of the distribution. Indeed, 90 (85) out of 122 observations have values of *Supply to others* (*Supply from others)* below the sample mean. Thus, very large values of the spillover proxies are obtained in only a few cases, and only in those cases does the sign of the relation between the spillover and the incentive ratio change significantly from positive to negative.

In sum, we find that both the above-level and below-level measures are weighted more heavily than the own-level measures when either the focal business unit has a substantial effect on other units in the firm *or* when other units in the firm have a substantial effect on the focal unit. In contrast, when both types of spillover are substantial, firms weight the own-level measures of the focal unit more heavily.

4.3 Simulation results

While our regressions are econometrically justified, three complications somewhat obfuscate the intuition behind them. First, we estimate a system of inter-related equations. Second, we model an interaction term that allows *Supply to others* and *Supply from others* to affect the relative use of each performance measure both directly and indirectly. Third, our dependent variable is a log-ratio, while our substantive interest is in what happens to the (relative) weighting of each performance measure as intra-firm interdependencies vary. In other words, using our regression results to answer questions of practical relevance—such as, what happens to the weighting of above-level measures when the firm increases deliveries between units—is not straightforward. Indeed, consider the implications of increasing *Supply to others* in the regression equations. Not only would this affect both log-ratios directly, but through the interaction term, it would also affect them indirectly. Then, given the compositional nature of the dependent variables, changes in one log-ratio (say, (below/own)) will have consequences for the other log-ratio (in this case, (above/own)). Taking all of these distinct effects into account, it is hard to foresee how increasing *Supply to others* would ultimately affect the weighting of the above-level measures.

As a result, we conduct simulations of first differences, that is, the difference in the expected value of the weighting of a performance measures (i.e., above-level, own-level, or below-level) when the value of *Supply to others* or *Supply from others* is changed from its sample minimum to its sample maximum.[30] All other explanatory variables are set at their mean. Simulations explicitly deal with the estimation uncertainty present in our model and provide an intuitive approach to statistical interpretation (King et al. 2000). Because our theory predicts that the two types of interdependency interact (i.e., the marginal effect of *Supply from others* on the use of performance measures depends on the amount of *Supply to others*) and interactions are difficult to interpret in a multi-equations context, we believe that these simulations increase our understanding of the underlying economic relation between the variables of interest (see also, Zelner 2009, for a recent discussion of the technique in the management literature). Figure 2 displays the results of our simulation in a ternary plot. Coordinates in the figure represent the expected weightings of each of the three performance measures for a single simulated case. The

[30] Specifically, the simulation involves taking M draws from the multivariate normal distribution with mean $\hat{\beta}$, the coefficient matrix from the seemingly unrelated regression model, and variance matrix $V(\hat{\beta})$, the estimated variance-covariance matrix for the coefficients in the model. We simulate first differences by setting the value for *Supply to others* (*Supply from others*) to its sample minimum and holding all other variables constant at their means. We then generate the expected value of the outcome variable (the log-ratio) conditional on these starting values for the explanatory variables by taking one draw from the normal distribution. Next, we set the value for *Supply to others* (*Supply from others*) to its sample maximum, holding all other variables at their means. We generate the expected value of the log-ratio conditional on these ending values for the explanatory variables. The first difference is simply the difference between these two expected values of the log-ratio. We then repeat this procedure 1,000 times to approximate the distribution of first differences (see, King, Tomz and Wittenberg 2000; Zelner 2009).

closer to one of the vertices a point lies, the larger the weighting of the performance measure associated with that vertex. A point near the middle indicates that the simulation predicts an equal weighting of the three performance measures. The “win-lines” in Figure 2 demarcate areas in the triangle where a given performance measure receives its highest weighting relative to the weightings of the other two measures.

---------------- Insert Figure 2 about here. -----------------

Figure 2, Panel A displays the simulation results for varying *Supply from others*. In other words, every point in the panel shows the weighting of each performance measure drawn randomly from a setting in which all firms have low (denoted by a solid dot) or high (denoted by an “x”) *Supply from others*. Most of the simulated expected values are concentrated close to the own-level vertex independent of whether *Supply from others* is high or low. When *Supply from others* is at the sample minimum (i.e., 0%), some weight is given to both the above-level and the below-level measures: the average expected value (computed over 1,000 simulations) for the weightings of performance measures is 0.23, 0.70, and 0.07 for above-level, own-level, and below-level measures, respectively. Increasing *Supply from others* to the sample maximum (i.e., 100%), however, substantially alters this picture and results in a much higher weighting of the own-level measures: the average expected values are now 0.04, 0.92, and 0.04; the change in the weightings of both the own-level and above-level measures is significant at the 1 percent level.

Panel B presents the simulation results for changing the value of *Supply to others*. A very similar picture emerges. Own-level measures always receive the highest weighting irrespective of the value of *Supply to others*. Nevertheless, when we change the value of *Supply to others* from the sample minimum (i.e., 0%) to the sample maximum (i.e., 100%) we again find that the weighting of the above-level measures decreases significantly and the weighting of the own-level measures increases. The average expected values for the weightings of the performance measures change from 0.27, 0.55, and 0.07 to 0.02, 0.95, and 0.04, respectively. Again, the change in the weightings of both the above-level and own-level measures is significant at the 1 percent level.

The "win-lines" in Panels A and B, at both the low and high levels of intra-firm interdependencies, suggest that own-level measures play a pivotal role in the evaluation of business unit managers. Above-level measures (and to a lesser extent, below-level measures) are used in situations where the business unit *either* affects other units *or* is affected by the other units. However, when a business unit faces both types of spillover, own-level measures are used almost exclusively. The changes in the weightings of above-level and below-level measures are relatively small, especially when we consider that the changes in the level of interdependencies range from 0 to 100%. We interpret this finding as evidence that the incentives that above-level and below-level measures provide are potentially quite strong. Small changes in the weightings of these measures are enough to make managers respond optimally to problems associated with spillover.

4.4 Additional analyses

Some recent studies suggest that information asymmetry is an important determinant of which performance measures are used to evaluate managers (Abernethy et al. 2004; Bouwens and van Lent 2007; Raith 2008; Hwang, Erkens and Evans 2009). Given that these earlier studies document a high correlation between decentralization and information asymmetry,[31] we include only *Decentralization* in our regressions. Nevertheless, when we include *Information Asymmetry*, which we measure using the instrument in Dunk (1993), in the regressions, the findings remain virtually unchanged and none of our test variables change in either sign or significance.[32]

5. Discussion and conclusions

Roberts (2004) cites how firms encourage cooperation between managers as one of the foremost issues in organizational design. He also points out that designing incentive systems that motivate managers to do the right thing is no trivial task. In firms with multiple business units,

[31] In their Table 5, Bouwens and van Lent (2007), for example, report that the correlation coefficient between decentralization and information asymmetry is 0.43.

[32] The instrument in Dunk (1993) asks respondents to compare their information about the work carried out in the business unit to that of their superior and consists of five questions, which are reproduced in Appendix 2.

doing the right thing requires local managers to cooperate with each other, and performance measures can play an important role in fostering such cooperation. We provide theory and empirical evidence on the existence of two types of spillover that may interfere with managers' efforts to cooperate. We show that each type of spillover can affect performance measures differently, and for that reason, we expect the weightings of these measures to depend on the degree to which each type of interdependency is present in the firm and, more importantly, on whether these interdependencies are present at the same time. Indeed, as expected, we find that the sign of the relation between each type of interdependency and the weighting of a performance measure depends critically on the magnitude of the effect of the other type of spillover. In addition, we predict and find that both above-level and below-level, or specific, measures receive more weight than own-level measures when the focal manager's actions affect other units in the firm. This role of specific measures has not been documented before (although some prior studies suggest that below-level measures can be effective in responding to knowledge asymmetry problems, see, e.g., Raith (2008) and Hwang, Erkens and Evans (2009)). We also observe that in the small fraction of our sample that experiences significant amounts of both types of spillover, own-level measures are used almost exclusively and the sign of the association between spillover and the weightings of above-level and below-level measures becomes negative.

The negative relation we document between the weighting of above-level measures and the simultaneous presence of both types of spillover is not consistent with our model's predictions. We therefore conclude that our model does not adequately capture the effects of very large levels of intra-firm spillover. In these cases, strategic interactions between the agents may become important. In our analysis, however, we ignore issues such as collusion or cooperation between the business unit managers.

We draw our empirical evidence from a survey of business unit managers, which supplies us with data appropriate to the level of analysis required to conduct research into intra-firm interdependencies. We use information gathered directly from business unit managers who are affected by these interdependencies and/or are encouraged to work with other managers to overcome the problems such interdependencies cause. These respondents also provide us with data about the performance measures their seniors use when evaluating their performance. As such, in our setting, the benefits of using survey data outweigh the potential validity-related costs. To offset these potential costs and further validate our findings, we employ several safeguards when selecting the sample, phrasing the survey questions, administering the survey, and analyzing the respondents' answers.

One ambitious follow-up to our study would involve synthesizing the theory and empirical evidence on the interplay between knowledge asymmetry and intra-firm interdependencies as well as their joint effect on which performance measures are selected to evaluate managers.

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APPENDIX 1

Proof of Proposition 1:

The certainty equivalent of agent i is

$$CE_i(f_i,v_{xi},v_{yi},v_{si},a_{i1},a_{i2}) = f_i + v_{xi}\,(a_{11} + a_{12} + a_{21} + a_{22})$$

$$+ v_{yi}\,[a_{ii} + (1 - \beta_i)\,a_{ij} + \beta_j\,a_{ji}] + v_{si}\,a_{ij} - ½\,(a_{i1}^{\,2} + a_{i2}^{\,2})$$

$$- ½\,r\,\{v_{xi}^{\,2}\,(\sigma_1^{\,2} + \sigma_2^{\,2}) + v_{yi}^{\,2}\,\sigma_i^2 + 2\,v_{xi}\,v_{yi}\,\sigma_i^2 + v_{si}^{\,2}\,\eta_i^2\}, \quad i,j = 1,2 \text{ and } i \neq j. \qquad \text{(A.1)}$$

The first order conditions on agent i's actions, a_{ii} and a_{ij}, are

$$v_{xi} + v_{yi} - a_{ii} = 0 \text{ and} \qquad \text{(A.2a)}$$

$$v_{xi} + (1 - \beta_i)\,v_{yi} + v_{si} - a_{ij} = 0. \qquad \text{(A.2b)}$$

Solving equations (A.2a) and (A.2b) for a_{ii} and a_{ij} gives (3).

Setting equation (A.1) equal to zero (based on (2b)) and solving for f_i gives the optimal fixed salary. Substituting, for each agent i, f_i^* plus $a_{i1}^{\,*}$ and $a_{i2}^{\,*}$ into the objective function (2a) yields an unconstrained problem for the principal. Taking first-order conditions with respect to v_{xi}, v_{yi}, and v_{si}, where $i = 1, 2$, and solving the equations simultaneously for these variables gives the optimal weightings of the performance measures, i.e.,

$$v_{xi}^{\,*} = D^{-1}\,\beta_i\,\eta_i^2\,(\beta_i + r\,\sigma_i^2), \qquad \text{(A.3a)}$$

$$v_{yi}^{\,*} = D^{-1}\,[\sigma_j^2 - r\,\eta_i^2\,[\beta_i(\sigma_1^{\,2}+\sigma_2^{\,2}) - 2\,\sigma_j^2], \text{ and} \qquad \text{(A.3b)}$$

$$v_{si}^{\,*} = D^{-1}\,\sigma_j^2\,(\beta_i + r\,\sigma_i^2), \qquad \text{(A.3c)}$$

where $D = \beta_i^2\,\eta_i^2\,[1 + r\,(\sigma_1^{\,2}+\sigma_2^{\,2})] + [1 + r\,\sigma_i^2 + r\,\eta_i^2\,(2 + r\,\sigma_i^2)]\,\sigma_j^2 - 2\,r\,\beta_i\eta_i^2\sigma_j^2$. The optimal incentive ratios (4a) and (4b) follow from substituting the solution in (A.3) into the definition for the incentive ratios.

Proof of Comparative Statics in Table 1:

Panel A: Pure noise effect on below-level measure (*i.e.,* $\partial\eta_k/\partial\delta_l > 0, k,l = 1,2$ and $k \neq l$)

When considering the variation of agent *i*'s incentive ratios with respect to a variation of the noise on the below-level performance measure of the other agent, η_j, the following comparative statics result:

$$\frac{\partial IR_i^a}{\partial \eta_j} = \frac{\partial IR_i^b}{\partial \eta_j} = 0.$$

Considering the variation of agent *i*'s incentive ratios with respect to a variation of the noise on his own below-level performance measure, η_i, yields the following comparative statics:

$$\frac{\partial IR_i^a}{\partial \eta_i} = \frac{2\,\beta_i\,\eta_i\,(\beta_i + r\,\sigma_i^2)\,\sigma_j^2}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\,(\sigma_1^2 + \sigma_2^2) - 2\,\sigma_j^2]\right)^2} > 0 \text{ and}$$

$$\frac{\partial IR_i^b}{\partial \eta_i} = \frac{2\,r\,\eta_i\,(\beta_i + r\,\sigma_i^2)\;\sigma_j^2\,\left(\beta_i\,(\sigma_1^2 + \sigma_2^2) - 2\,\sigma_j^2\right)}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\,(\sigma_1^2 + \sigma_2^2) - 2\,\sigma_j^2]\right)^2},$$

and the sign of the second derivative is given by the sign of $(\sigma_1^2+\sigma_2^2)/\sigma_j^2 - 2/\beta_i$.

Panel B: Pure noise effect on own-level measure (i.e., $\partial\sigma_k/\partial\delta_l > 0$, $k,l = 1,2$ and $k \neq l$)

Considering the variation of agent *i*'s incentive ratios with respect to a variation of the noise on the own-level performance measure of the other agent, σ_j, yields the following comparative statics:

$$\frac{\partial IR_i^a}{\partial \sigma_j} = -\frac{2\,\beta_i\;\eta_i^2\,[1+(2-\beta_i)r\,\eta_i^2]\,(\beta_i + r\,\sigma_i^2)\,\sigma_j}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\,(\sigma_1^2 + \sigma_2^2) - 2\,\sigma_j^2]\right)^2} < 0 \text{ for } \beta_i < 1 \text{ and}$$

$$\frac{\partial IR_i^b}{\partial \sigma_j} = -\frac{2\,r\,\beta_i\,\eta_i^2\,\sigma_i^2\,(\beta_i + r\,\sigma_i^2)\,\sigma_j}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\,(\sigma_1^2 + \sigma_2^2) - 2\,\sigma_j^2]\right)^2} < 0.$$

In contrast, variations of the noise on his own-level performance measure, σ_i, yield the following comparative statics:

$$\frac{\partial IR_i^a}{\partial \sigma_i} = \frac{2\,r\,\beta_i\;\eta_i^2\,[\sigma_j^2+\eta_i^2(\beta_i^2+(2-\beta_i)r\,\eta_i^2)]\,\sigma_i}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\,(\sigma_1^2 + \sigma_2^2) - 2\,\sigma_j^2]\right)^2} > 0 \text{ for } \beta_i < 1 \text{ and}$$

$$\frac{\partial IR_i^b}{\partial \sigma_i} = \frac{2\,r\,\sigma_j^2\,[\sigma_j^2+\eta_i^2(\beta_i^2+(2-\beta_i)r\,\eta_i^2)]\,\sigma_i}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\,(\sigma_1^2 + \sigma_2^2) - 2\,\sigma_j^2]\right)^2} > 0.$$

Panel C: Pure congruity effect (i.e., $\partial\beta_k/\partial\delta_k > 0$, $k = 1,2$)

When considering the variation of agent i's incentive ratios with respect to a variation of the congruency of his own-level performance measure, β_i, the following comparative statics result:

$$\frac{\partial IR_i^a}{\partial \beta_i} = \frac{\eta_i^2\left(\left(2\,\beta_i + r\,\sigma_i^2\right)\left(1+2\,r\,\eta_i^2\right)\sigma_j^2 - r\beta_i^2\eta_i^2\left(\sigma_1^2+\sigma_2^2\right)\right)}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\left(\sigma_1^2+\sigma_2^2\right) - 2\,\sigma_j^2]\right)^2}$$

and the sign of the derivative is positive if $B_1 - (\sigma_1^2+\sigma_2^2)/\sigma_j^2 > 0$, where $B_1 = (2\beta_i + r\sigma_i^2)(1+2r\eta_i^2)/(r\beta_i^2\eta_i^2)$;

$$\frac{\partial IR_i^b}{\partial \beta_i} = \frac{\sigma_j^2\left(\sigma_j^2 + r\,\eta_i^2\left(r\,\sigma_i^2\left(\sigma_1^2+\sigma_2^2\right)+2\sigma_j^2\right)\right)}{\left(\sigma_j^2 - r\,\eta_i^2\,[\beta_i\left(\sigma_1^2+\sigma_2^2\right) - 2\,\sigma_j^2]\right)^2} > 0.$$

In contrast, variations of the congruency of the other agent's own-level performance measure, β_j, yield the following comparative statics:

$$\frac{\partial IR_i^a}{\partial \beta_j} = \frac{\partial IR_i^b}{\partial \beta_j} = 0.$$

Panel D: Multiple linear effects

With multiple linear effects, $\eta_i^2 = (1+\delta_j)\,\eta^2$, $\sigma_i^2 = (1+\delta_j)\,\sigma^2$, and $\beta_i = \delta_i$, $i,j = 1,2$ and $i \neq j$, the incentive ratios are given by

$$IR_i^a = \frac{\delta_i + r\,(1+\delta_j)\sigma^2}{(1+\delta_i) - r\,(1+\delta_j)\eta^2\,[\delta_i\left(2+\delta_i+\delta_j\right) - 2(1+\delta_j)]}\,\frac{\delta_i\,(1+\delta_j)\,\eta^2}{\sigma^2} \text{ and} \tag{A.4a}$$

$$IR_i^b = \frac{\delta_i + r\,(1+\delta_j)\sigma^2}{(1+\delta_i) - r\,(1+\delta_j)\eta^2\,[\delta_i\left(2+\delta_i+\delta_j\right) - 2(1+\delta_j)]}\,(1+\delta_i), \quad i,j = 1,2 \text{ and } i \neq j. \tag{A.4b}$$

Taking the derivatives with respect to δ_i and δ_j, noting that $\delta_i < 1$ completes the proof.

A P P E N D I X 2

Appendix 2 reproduces the questionnaire items we used to construct our variables.

Weightings of above-level, own-level, and below-level measures

We are interested in the performance measures your superior uses to evaluate your annual performance. For each of the measures below, indicate your superior's weighting of each measure when he or she formally evaluates your annual performance. Your answers must sum to 100%.

1. Measures related to stock-price
2. Measures that summarize the performance of the whole company (e.g., firm-wide net income, firm-wide return-on-assets).
3. Measures that summarize the joint performance of the group in the firm of which your unit is part (e.g., group profit, divisional return-on-investment).
4. Measures that summarize the performance of your business unit (e.g., business unit profit, business unit return-on-investment).
5. Measures that summarize the performance of *specific* activities within your unit (e.g., sales of the marketing department, average costs of manufacturing, R&D expenses).
6. Other measures, please specify:

Above-level = (1) + (2) + (3)
Own-level = (4)
Below-level = (5)

Interdependencies

Supply from others
What percentage of your unit's total production (services) uses products (services) supplied by other units in the firm?

Supply to others
What percentage of your unit's manufactured products (services) is supplied to other units in the firm?

Effect on other managers
To what extent do your actions affect the performance of other units in the firm?

Effect of other managers
To what extent do the actions of other managers in the firm affect the performance of your unit?

Scale: 1 = not at all
4 = to some extent
7 = a great deal

%Time-Meet

What percentage of your total time available in the most recent month did you spend on meeting with managers from other units in the firm?

Independent business
To what extent could your unit operate as an independent company (i.e., detached from your current firm) in the marketplace?

Scale: 1 = not at all
4 = for about 50% of our activities
7 = for all of our activities

Decentralization

Please compare your influence in making decisions with the influence of your superior. If you or your subordinates in your unit make decisions without prior consent of your superior, you are considered to have complete influence.

1. strategic decisions
2. investment decisions
3. marketing decisions
4. decisions on internal processes
5. human resource decisions

Scale: 1 = I have complete influence
4 = my superior and I share influence almost equally
7 = my superior has complete influence

Scale is reverse coded

Competition

Please indicate the degree of competition your unit faces with regard to the following:
1. prices
2. marketing and distribution
3. quality of products
4. product mix

Scale: 1 = almost no competition
4 = moderate competition
7 = strong competition

Growth opportunities

Please indicate your expectations about the following:
1. The growth opportunities that exists within the industry in which you compete.
2. The growth opportunities your unit faces.

Scale: 1 = significant decline
4 = no growth
7= significant increase

Size

How many people work in your unit (in full time equivalents)?

Varcomp

Your total compensation may vary with your performance. Please indicate the maximum amount (as a percentage of your fixed salary) available as performance-dependent pay (either as cash bonus or as stocks or options).

Information asymmetry

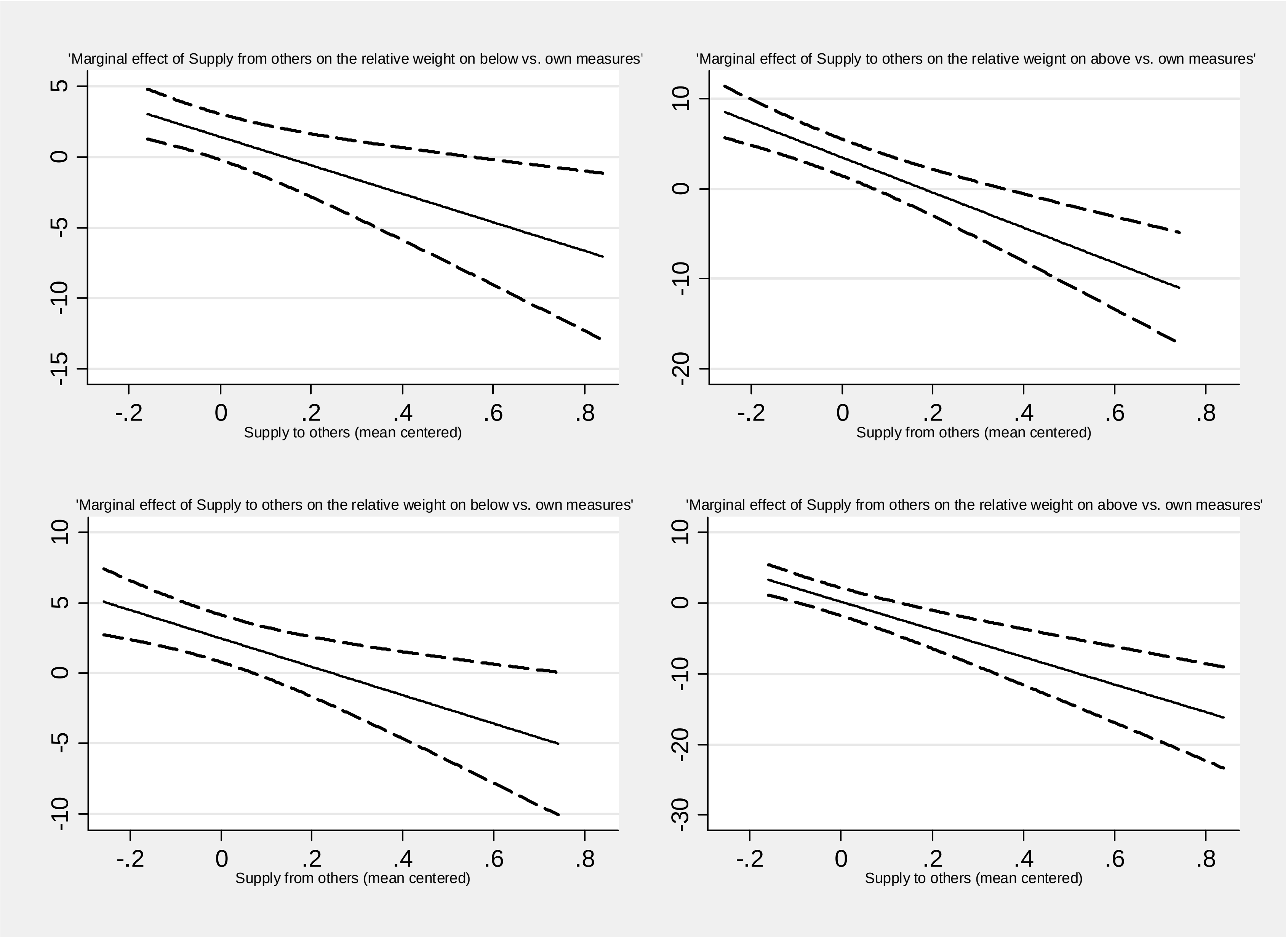
Please compare the amount of information you have relative to your superior.

1. Of you and your superior, who is in possession of better information regarding the activities undertaken in your unit?
2. Of you and your superior, who is more familiar technically with the work of your unit?
3. Of you and your superior, who is more certain of the performance potential of your unit?
4. Of you and your superior, who is better able to assess the potential effect factors external to your unit may have on your activities?
5. Of you and your superior, who has a better understanding of what can be achieved in your unit?

Scale: 1 = my superior does
4 = my superior and I do, almost equally
7 = I do

F I G U R E 1

Marginal Effects of Interdependencies on the log-ratio of Above-level, Own-level, and Below-level Performance measures

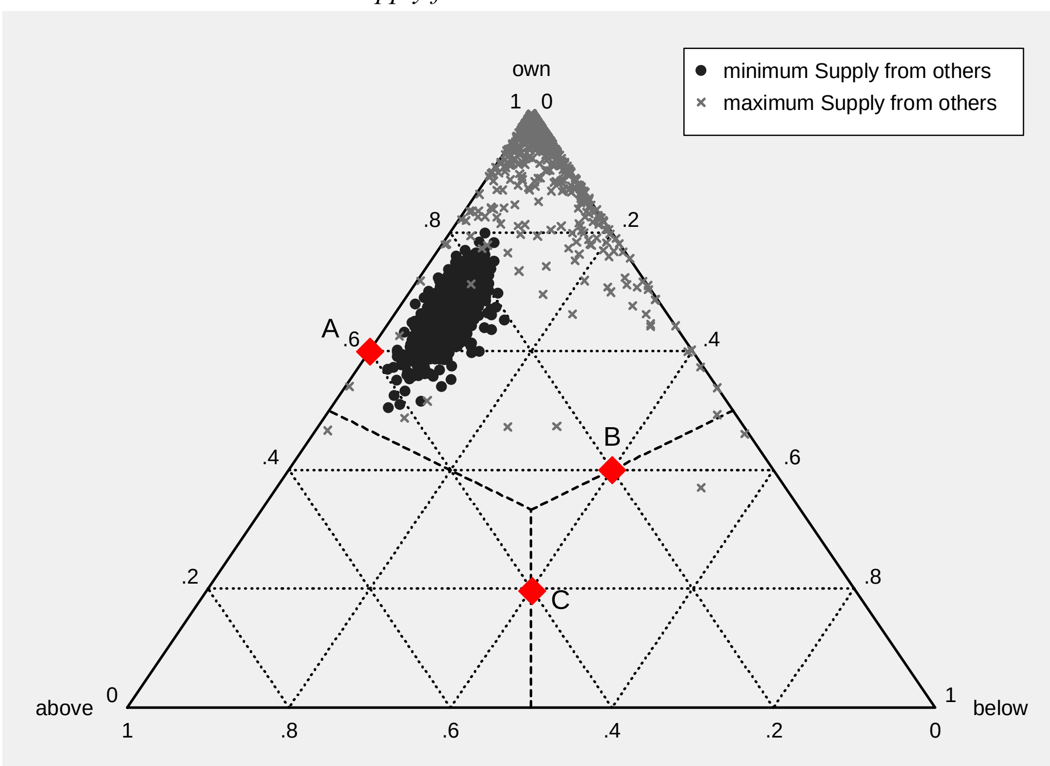


F I G U R E 2

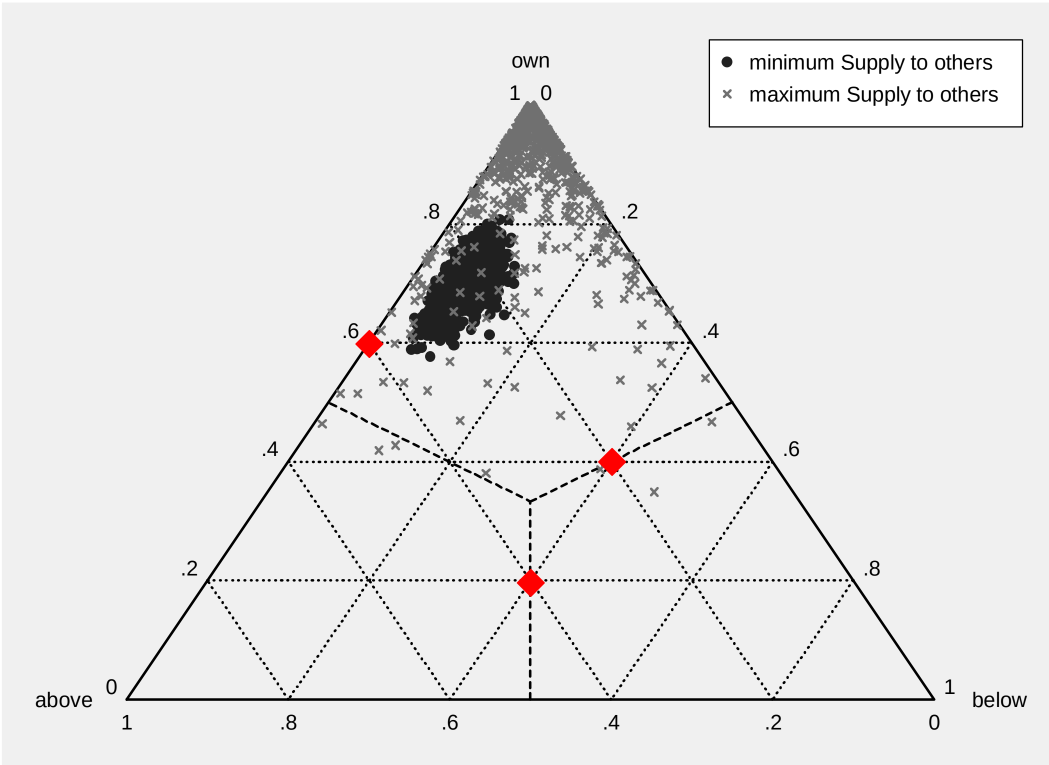
Ternary Plots of the Percentage Weight on Above-level, Own-level, and Below-level Performance Measures and First-Differences of Interdependencies

The plots below show the simulation results for the expected value of the weighting of a performance measure (at the above-level, own-level, and below-level) used to evaluate a business manager when the supply variables (i.e., in Panel A, *Supply from others* and in Panel B, *Supply to others*) are varied from their sample minimum values to their sample maximum values. The simulation takes into account that the supply variables work both through a direct effect and through an interaction term. All other explanatory variables are set to their mean. The axes of the triangle represent the weightings. The plots also incorporate long-dashed "win lines" that divide the diagram into areas that indicate which performance measure receives the most incentive weight. To facilitate interpretation, we have used diamonds to identify three coordinates. The weightings (at the above-level, own-level, and below-level) for these three coordinates are as follows. A (40%, 60%, 0%); B (20%, 40%, 40%); C (40%, 20%, 40%).

Panel A: First Differences of *Supply from others*



Panel B: First Differences of *Supply to others*



T A B L E 1

Comparative Statics of Optimal Incentive Ratios for Agent i =1, 2

Parameter k	above/own sgn[$\partial IR_i^a/\partial k$]	below/own sgn[$\partial IR_i^b/\partial k$]
Panel A: Pure noise effect on below-level measure (i.e., $\partial\eta_k/\partial\delta_l > 0$, k,l = 1,2 and $k \neq l$)		
Effect on other agent ($k = \eta_j$)	0	0
Effect on focal agent ($k = \eta_i$)	> 0	sgn[$(\sigma_1^2+\sigma_2^2)/\sigma_j^2 - 2/\beta_i$]
Panel B: Pure noise effect on own-level measure (i.e., $\partial\sigma_k/\partial\delta_l > 0$, k,l = 1,2 and $k \neq l$)		
Effect on other agent ($k = \sigma_j$)	< 0	< 0
Effect on focal agent ($k = \sigma_i$)	> 0	> 0
Panel C: Pure congruity effect (i.e., $\partial\beta_k/\partial\delta_k > 0$, k = 1,2)		
Effect on other agent ($k = \beta_i$)	sgn[$B_1 - (\sigma_1^2+\sigma_2^2)/\sigma_j^2$]	> 0
Effect on focal agent ($k = \beta_j$)	0	0
Panel D: Multiple linear effects[a]		
Effect on other agent ($k = \delta_i$)	> 0	> 0
Effect on focal agent ($k = \delta_j$)	> 0	sgn[$\sigma^2/\eta^2 - B_2$]

where

$B_1 = (1 + 2\,r\,\eta_i^2)(2\,\beta_i + r\,\sigma_i^2) / (r\,\beta_i^2\,\eta_i^2)$

$B_2 = \delta_i / (1+\delta_i)\,(2 - r\,\sigma^2\,(1+\delta_j)^2 - \delta_i\,(1 + \delta_i + 2\,\delta_j))$, $\quad i,j$ = 1,2 and $i \neq j$.

[a] With multiple linear effects, $\eta_i^2 = (1 + \delta_j)\,\eta^2$, $\sigma_i^2 = (1 + \delta_j)\,\sigma^2$, and $\beta_i = \delta_i$, i,j = 1,2 and $i \neq j$.

T A B L E 2

Summary Statistics on Business Units in the Sample and on Survey Respondents

The sample consists of 122 observations, and information is collected via a questionnaire. The survey respondents are business unit managers.

Panel A: Characteristics of the business unit

Variable	**Mean**	**Std. Dev.**	**Min.**	**Median**	**Max.**
Size of the business unit (measured in number of full-time employees	1,005.03	1,479.19	9.00	290.00	6,500.00
Service Industry (1 = service, 0 = manufacturing)	0.27	0.45	0.00	0.00	1.00
Longevity of business unit in firm (in years)	17.50	9.88	0.00	20.00	39.00
Relative size of business unit in firm (as a % of total sales)	12.62	17.55	0.00	5.00	100.00

Panel B: Respondent characteristics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Median**	**Max.**
Longevity in business unit	5.93	6.50	0.00	4.00	43.00
Tenure in current job	3.16	3.55	0.00	2.00	30.00
Experience in firm compared with that of superior(*)	–4.75	11.09	–27.00	–5.00	42.00
Experience in industry compared with that of superior(*)	–3.73	11.97	–30.00	–3.00	30.00
Age	43.85	8.13	25.00	44.00	63.00

(*) Negative numbers indicate that the respondent has less experience than his/her superior does.

TABLE 3

Summary Statistics on Weightings of Different Types of Performance Measures and Interdependency variables

Panel A: Summary statistics for weightings of above-level, own-level, and below-level performance measures. N = 122

Performance measure:	**Mean**	**Std. Dev.**	**Min.**	**Median**	**Max.**
Above-level	0.30	0.28	0.00	0.25	1.00
Own-level	0.58	0.30	0.00	0.50	1.00
Below-level	0.13	0.17	0.00	0.00	0.80
Weightings of performance measures for those companies using that measure (weight > 0)					
Above-level (N = 87)	0.41	0.24	0.06	0.35	1.00
Own-level (N = 113)	0.62	0.27	0.05	0.50	1.00
Below-level (N = 56)	0.28	0.15	0.04	0.30	0.80

Panel B: Summary statistics for *Supply to others*, *Supply from others* and corresponding convergent validity test variables. N = 122

Interdependency variables	**Mean**	**Std. Dev.**	**Min.**	**Median**	**Max.**
Supply to others (in %)	15.89	27.20	0.00	5.00	100.00
Supply from others (in %)	26.45	31.95	0.00	10.00	100.00
Spillover on other managers	4.02	1.52	1.00	4.00	7.00
Spillover of other managers	4.12	1.55	1.00	4.00	7.00
%Time-Meet	9.97	8.24	0.00	8.50	40.00
Independent Business	4.86	2.05	1.00	6.00	7.00

Panel C: Spearman correlations among the interdependency variables. N = 122

	(1)	(2)	(3)	(4)	(5)	(6)
(1) Supply to others (in %)	1.00					
(2) Supply from others (in %)	0.03	1.00				
(3) Spillover on other managers	0.34	0.09	1.00			
(4) Spillover of other managers	0.22	0.48	0.58	1.00		
(5) %Time-Meet	0.56	0.36	0.48	0.54	1.00	
(6) Independent Business	–0.36	–0.35	–0.47	–0.36	–0.41	1.00

TABLE 4

Summary Statistics for Questionnaire Items Used to Construct the Control Variables

Table 4 presents the distribution of each questionnaire item used to construct the control variables in this study. The sample consists of 122 observations, and information is collected via a questionnaire. The theoretical range for the manifest variables associated with *Information asymmetry, Growth opportunities,* and *Competition* is 1–7. Full details about the survey instruments are provided in Appendix 2.

Survey items	Mean	Std. Dev.	Min.	Median	Max.
Decentralization: Please compare your influence on decision-making with your superior's influence on decision-making. If you or your subordinates in your unit make decisions without your superior's prior consent, you are considered to have complete influence.					
Strategic decisions	4.64	1.34	1.00	5.00	7.00
Investment decisions	4.49	1.33	1.00	4.00	7.00
Marketing decisions	3.09	1.54	1.00	3.00	7.00
Internal processes decisions	2.60	1.36	1.00	2.00	6.00
Human resource decisions	3.29	1.39	1.00	3.00	7.00
Growth opportunities: Please indicate your expectations about the following:					
The growth opportunities that exist within the industry in which you compete.	5.40	1.02	1.00	5.00	7.00
The growth opportunities your unit faces.	5.84	0.88	1.00	6.00	7.00
Competition: Please indicate the degree of competition with regard to the following.					
Prices	5.44	1.32	2.00	6.00	7.00
Marketing and distribution	4.54	1.62	1.00	5.00	7.00
Quality of products	5.00	1.22	0.00	5.00	7.00
Product mix	4.50	1.51	0.00	5.00	7.00
Varcomp: Your total compensation may vary with your performance. Please indicate the maximum amount (as a percentage of your fixed salary) available as performance-dependent pay (either as cash bonus, stocks, or options).	37.91	25.09	0.00	30.00	100.00

TABLE 5

Pearson Correlations among All Variables Included in the Regression Model, and Cronbach's Alpha for All Latent Variables

Table 5 presents Pearson correlations among all variables used in this study. Variable definitions appear in Appendix 2. Also presented are Cronbach's alpha statistics for composite measures (Nunnally and Bernstein 1994). The sample consists of 122 observations. Correlations (in absolute value) larger than 0.15 are significant at the 10% level.

	Cronbach's alpha	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Above-level measures		1.00									
2. Own-level measures		–0.87	1.00								
3. Below-level measures		–0.12	–0.39	1.00							
4. Supply to others		0.22	–0.27	0.13	1.00						
5. Supply from others		0.05	–0.16	0.23	0.07	1.00					
6. Varcomp		–0.04	0.19	–0.31	–0.18	–0.11	1.00				
7. Decentralization	0.71	–0.17	0.07	0.19	0.07	0.00	–0.15	1.00			
8. Competition	0.54	–0.05	0.10	–0.10	–0.34	–0.13	0.15	–0.03	1.00		
9. Growth opportunities	0.85	0.09	–0.08	–0.01	–0.05	–0.13	0.17	0.00	–0.07	1.00	
10. Size		0.03	0.09	–0.23	–0.12	–0.31	0.36	–0.12	0.23	–0.22	1.00
11. Service		–0.02	0.02	–0.01	0.07	0.05	0.01	0.00	0.03	–0.07	–0.11

T A B L E 6

Seemingly Unrelated Regressions Examining the Association between the Weight on Above-, Own-, and Below-level Performance Measures and Interdependencies

Table 6 presents seemingly unrelated regressions based on 122 observations. Dependent variables are log-ratios of weightings of above-level performance measures versus own-level performance measures and the weightings of below-level performance measures versus own-level performance measures. We analyze log-ratios consistent with Aitchison (1986) to account for the compositional nature of our weightings of performance-measure variables. Log(above/own) measures the percentage weighting of above-level measures relative to the percentage weighting of own-level measures. Log(below/own) measures the percentage weighting of below-level measures relative to the percentage weighting of own-level measures. Independent variables are *Supply from others* and *Supply to others*, which have been mean-centered, and their interaction term *To×From*, which measures the interdependencies between business units within a firm. We control for *Varcomp*, *Decentralization*, *Competition*, *Growth opportunities*, *Size*, and *Service*. These variables are defined in Appendix 2. Standard errors are based on a bootstrapping procedure and are reported in parentheses. *, **, *** denotes significance at the 10%, 5%, and 1%-levels, respectively, and are one-tailed for test variables and two-tailed for the control variables.

	(1) *Log(above/own)*	(2) *Log(below/own)*	(3) *Log(above/own)*	(4) *Log(below/own)*
Intercept	0.0817	–0.392	–1.704	–3.225
	(6.062)	(4.078)	(5.367)	(4.140)
Test variables:				
Supply to others			3.671**	2.517**
			(2.024)	(1.464)
Supply from others			0.0545	1.403
			(1.771)	(1.332)
To×From			–18.34**	–10.28**
			(8.576)	(5.382)
Control variables:				
Varcomp	–0.0377*	–0.0503***	–0.0321	–0.0492***
	(0.0203)	(0.0159)	(0.0205)	(0.0162)
Decentralization	–0.831*	0.107	–0.924*	–0.0484
	(0.472)	(0.415)	(0.490)	(0.368)
Competition	–0.659	–0.419	–0.378	–0.0587
	(0.553)	(0.376)	(0.556)	(0.378)
Growth opportunities	0.718	0.142	0.707	0.261
	(0.583)	(0.471)	(0.541)	(0.496)
Size	0.267	–0.117	0.349	0.0158
	(0.313)	(0.244)	(0.297)	(0.244)
Service	0.673	–0.774	1.121	–0.427
	(0.791)	(0.733)	(0.799)	(0.751)
Chi-squared	9.57	18.63	26.2	29.2
p-value	0.14	0.00	0.01	0.00
adj. R^2	7.7%	13.9%	19.0%	20.6%

T A B L E 7

Marginal Effects of Interdependencies on Above-level, Own-level, and Below-level Performance Measures

Table 7 presents marginal effects (i.e., partial derivatives of the log-ratio (above/own) or (below/own) to *Supply to others* or *Supply from others*, respectively, holding the other variable constant at either its sample minimum or maximum value). Dependent variables are log-ratios of the weightings of above-level performance measures versus own-level performance measures and the weightings of below-level performance measures versus own-level performance measures. We analyze log-ratios consistent with Aitchison (1986) to account for the compositional nature of our weightings of performance measure variables. Log(above/own) measures the percentage weighting of above-level measures relative to the percentage weighting of own-level measures. Log(below/own) measures the percentage weighting of below-level measures relative to the percentage weighting of own-level measures. We compute the marginal effects based on the seemingly unrelated regressions reported in Table 6 with a variance-covariance matrix based on a bootstrapping procedure. The standard errors of the marginal effects (reported in parentheses) in the current table are based on the delta method. *, **, *** denotes significance at the 10%, 5%, and 1%-levels (one-tailed), respectively.

	Log(above/own)	*Log(below/own)*
Marginal effect of *Supply to others,* holding *Supply from others* constant at:		
▪ sample minimum	2.98** (1.82)	5.17*** (1.81)
▪ sample maximum	–9.93* (6.59)	–5.11 (4.41)
Marginal effect of *Supply from others,* holding *Supply to others* constant at:		
▪ sample minimum	2.98* (1.81)	3.04** (1.56)
▪ sample maximum	–15.36** (8.00)	–7.23* (4.76)