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**Interdivisional Information Sharing -
The Strategic Advantage of Knowing
Nothing**

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ABSTRACT

Interdivisional Information Sharing - The Strategic Advantage of Knowing Nothing

by Silke Neubauer

Divisional managers of multiproduct firms often only have precise information about market conditions of their own market. They may have expectations about the demand function of markets served by other divisions. When divisional profits are linked due to interrelated costs or demand parameters, it may be advantageous for a firm to provide each division with information about the other division's demand parameters. I study the incentives of owners to implement such an information structure and the value of intrafirm information sharing in a two firm - two market setting where there are interdivisional cost linkages. It is shown, that the value of bilateral information consists of a (positive) efficiency and a (negative) revenue effect, the weight of which depends on the incentive scheme used to evaluate managers. Regardless of managers' incentive scheme, owners of both firms always choose interdivisional information sharing, even if profits are lower than in a situation of non-information.

ZUSAMMENFASSUNG

Die Anreize zu interdivisionalem Informationsaustausch innerhalb von Mehrproduktunternehmen

Manager divisionaler Mehrproduktunternehmen sind oftmals in der Lage, Nachfragebedingungen innerhalb der von ihnen betreuten Märkte einzuschätzen. Marktparameter von Märkten außerhalb ihres Verantwortungsbereich sind ihnen i.d.R. nicht bekannt. Der Wert von und die Anreize zu interdivisionalem Informationsaustausch, wenn divisionale Profite über eine gemeinsame Kostenfunktion miteinander verbunden sind, wird im Rahmen eines zweistufigen Modells untersucht, in welchem zwei Zweiproduktunternehmen miteinander im Wettbewerb stehen. In einer ersten Stufe entscheiden sich die Eigner über die Einführung eines Managementinformationssystems, in der zweiten Stufe treten treffen divisionale Manager ihre Mengenentscheidungen. Der Wert der Information und das Ergebnis des Spiels hängen u.a. von dem Anreizsystem ab, nach welchem Manager beurteilt werden: Information ist nur dann vorteilhaft, wenn Manager divisionale Gewinne maximieren; sie hat negative Wirkungen bei Anreizsystemen, welche Manager zur Internalisierung divisionsexterner Effekte induzieren.

1. Introduction

When firms grow in size and serve several markets, the concept of a functional organizational structure may no longer be appropriate.¹ Big Multinationals have little by little moved to more decentralized organizational structures, where responsibility for operational performance in geographic or product markets is given to divisional managers who are nearer to the market and able to make better decisions based on their market specific knowledge.²

But the advantage of market specific information gained through decentralization may be offset by the fragmentation of information within the firm: each divisional manager knows his own market, but he is not informed about parameters of markets beyond his responsibility. This would not be a problem if divisions were completely independent of each other. Very often, though, divisional profits are interrelated. For example, divisions may use common central services or financial support. There might be congestion effects when central capacity is scarce, or synergies due to learning effects.³ The activity of one division then affects the utility of the other division. Or there may be demand linkages. When products are substitutes (complements), the demand in one market depends negatively (positively) on supply of the other division.⁴ Divisions may also build up reputation which radiates to the entire firm - and thus affects demand for other products.⁵ When divisional managers are not informed about the characteristics of the other markets, they are not able to optimally internalize the effects on corporate profits when taking their decisions. Consequently, whenever supply or production decisions have effects on multiple divisions, the firm-wide lack of information may be disadvantageous.

The importance of interdivisional profit linkages has made many firms think about optimal intrafirm information flows. In fact, the implementation of so called management information systems is - together with the issue of optimal managerial contracts - an issue often discussed in multidivisional firms.⁶

This paper questions the conception that more informative management information systems will always lead to better corporate performance. It is shown, that the value of intrafirm information flows in a duopolistic setting with stochastic demand and interdivisional cost linkages depends crucially on the incentive scheme used to evaluate divisional managers. Two possible and empirically relevant kinds contracts are discussed: contracts that tie managers'

¹ See Chandler (1962), who first introduced the thesis, that growing firms will move from functional to divisional organizational forms.

² See e. g. Bühner (1992), p. 164 - 174 for examples. Frese (1995), p.88 describes the growing importance of profit-center organization when firms grow in size.

³ See Gal-Or (1993), Hughes / Kao (1998) or Zimmermann (1979) for examples of congestion effects, and Westland (1992) for examples of positive externalities.

⁴ See Faulli-Oller / Giralt (1995) for the implications of demand linkages.

⁵ See for example Cabral (1998) for this argument.

⁶ See e. g. Brancheau /Wetherbe (1997) or Duffy (1991) for coordination issues of information systems.

revenue to corporate profits, such that division-external cost effects are internalized (for example, NEC makes its managers internalize interdivisional cost linkages)⁷, and contracts that use divisional profits as a basis for managers' evaluation (a compensation scheme, for example, applied by IBM)^{8,9}. The striking result is, that whenever managers of both firms consider corporate profits when taking their supply decisions, the value of information about other markets is negative, whereas in the case of divisional profit maximization it is positive. This result is due to the interplay of two effects of interdivisional information: a cost effect that makes firms better adapt their supply to changing demand- and cost conditions, leading to lower corporate costs, and a revenue effect that makes firm react to variations of demand in the other market, leading to lower expected revenue. The revenue effect can be explained with the strategic interaction of the two firms. Whenever the revenue effect is more important than the cost effect, the value of information is negative and firms should abstain from interdivisional information sharing.

To answer the question, which information structure competing multimarket firms would actually choose if they decided simultaneously about their information strategy before market competition takes place, the basic quantity game is embedded in an information game. It will be shown, that whenever intrafirm information sharing does not cause costs, firms will choose the more informative information strategy, even if they end up worse. If one considers fixed costs of information, i.e. for computer programs facilitating information exchange, the choice of firms depends on the importance of the information costs.

In order to evaluate the necessity for public intervention, the effects of information on consumer surplus and on welfare must be analyzed, and the socially optimal information structure within firms must be compared with the outcome of the information game. It will be claimed, that firms' information choice is socially optimal whenever there are no information costs. However, if information is costly, there might be situations in which firms choose a non-information strategy, but welfare would be higher with information.

The results of the analysis suggest, that the incentive scheme applied for managers plays a crucial role for the value of (bilateral) information. This raises the question, which compensation scheme firms should apply for their managers and which contract they would choose - given the strategy space of the other firm. Endogeneizing the choice of the compensation scheme in the above context with stochastic demand will emphasize general results derived in the literature dealing with strategic delegation:¹⁰ As products are strategic substitutes, owners want to commit to more aggressive behavior of their managers. Hence, they want managers to internalize positive, but to neglect negative external effects. In tendency,

⁷ See Porter (1986), p. 508.

⁸ FT November 27 1991, cited in Faulli-Oller / Giralt (1995), p. 79.

⁹ The first case coincides with a duopoly game without delegation - with the only difference that each manager is informed about his own market. As firms strictly prefer being informed about market parameters of the market in which decisions are to be taken, the question if firms are delegating at all or not must not be addressed in this context.

¹⁰ See especially Faulli-Oller / Giralt (1995).

I find, that divisional profit maximization is chosen in the presence of negative external effects, whereas owners would choose corporate profit maximization in the case of synergies in production.¹¹

There are three broad lines in the literature related to this paper. As mentioned above, there is a strand of literature analyzing the strategic effects of managers' incentive schemes and / or of divisionalization. Sklivas (1987) shows that by tying managers' incentives to a weighted average between profits and sales, firms are able to commit to more or less aggressive behavior. Fershtman / Judd (1987) have a similar approach, but they analyze additionally the impact of cost differences and uncertainty on the incentive scheme chosen by owners. Kedia (1998) tests empirically the influence of product market competition on pay-per-performance sensitivity of Top Management incentives. In Polo / Tedeschi (1992) it is shown that firms can obtain collusive outcomes if managers' profits depend negatively on the profits of competitors (relative performance evaluation). The study of Aggarwal / Samwick (1996) explores the incentives for relative performance evaluation in a Cournot- as well as a Bertrand context, pointing out that in a Bertrand context, owners rather put positive weight on other firms' profits. Baye / Crocker / Ju (1996) model the incentives of firms to divisionalize for strategic reasons when there is a common demand function and costs of divisionalization. They do not consider managers' incentive schemes. Gonzalez-Maestre (1997) combine these two approaches by modeling a two - stage game, where firms first decide about the number of divisions and then decide about managers' incentive schemes. All of these papers however only consider single-market firms. The implications of managers' incentives in divisionalized multimarket firms are analyzed by Gal-Or (1993), Faulli-Oller/ Giralt (1995) and Hughes / Kao (1998). Gal- Or and Hughes / Kao ask for the strategic effects of cost-sharing models when firms face a joint cost function. Faulli-Oller/ Giralt consider additionally demand linkages. Proposing a weighted average between divisional and corporate profits as the basis for managers evaluation, they underline the strategic effects combined with the internalization of effects on other divisions' profits.

The second line of research deals with the value of information and information structures. Marshak / Radner (1972) provide a framework to compare information structures for single person and team problems within a single organization. Ponsard (1976) mentions, that information may have a negative value for firms. Gal-Or (1988) shows, that duopolistic firms may have an advantage if they possess imprecise information about production costs.

Finally, in the literature about information sharing (for example Noveshek / Sonnenschein (1982), Clarke (1983), Vives (1984) Li (1985), Gal-Or (1985), Jin (1994) et. al.), the incentives and the value to share information between firms is explored.

The value of and incentives for intrafirm information sharing in multimarket firms has not been analyzed so far. This is somewhat striking, as big firms are becoming more and more aware of the dispersion of information within the company.

The organization of the paper is as follows. In the next section, the basic model is described.

¹¹ This also follows from the results derived by Faulli-Oller / Giralt (1995).

A two firm - two market setting is considered, where divisional profits are linked through a joint cost function and demand is stochastic. Owner hire managers who learn about the realization of demand in their own market, and choose, whether managers share their demand information. Managers may either be evaluated according to corporate or to divisional profits. In the second case, they share costs based on expected demand. The two-stage game will be solved by backwards induction for the two possible compensation schemes: First, equilibrium strategies of quantity setting managers are determined for different information structures in both firms. In a second step, the information game is solved. The effects of information and the information game on consumer surplus and welfare are then analyzed. In section 6 the impact of fixed information costs is explored, and in section 7 some remarks will be made with respect to the incentive scheme of managers as part of the organizational choice of firms. After a short summary of the results, I will conclude.

2. The General Setting

Cost-and demand-conditions

I consider two firms ($i = 1, 2$) which are active in two markets ($k = A, B$). Demand is stochastic, independent and linear and can be expressed by the inverse demand function:

$$\begin{aligned}\tilde{p}^A(x_1, x_2) &= \tilde{a}^A - x_1 - x_2 && (\text{market } A) \\ \tilde{p}^B(y_1, y_2) &= \tilde{a}^B - y_1 - y_2 && (\text{market } B),\end{aligned}$$

with

$$\tilde{a}^A \in \{a^l, a^h\}, \tilde{a}^B \in \{a^l, a^h\}, E[a^A] = E[a^B] = E[a^k]$$

The probabilities for low and high demand are

$$\begin{aligned}\Pr(\tilde{a}^A = a^l) &= \Pr(\tilde{a}^B = a^l) = \alpha \\ \Pr(\tilde{a}^A = a^h) &= \Pr(\tilde{a}^B = a^h) = (1 - \alpha).\end{aligned}$$

Costs are interrelated. The following cost function is assumed,¹²

$$C_i(x_i, y_i) = c^A x_i + g x_i y_i + c^B y_i \quad \text{for } i = 1, 2,$$

where g might be positive or negative. Costs of one division are hence increasing (decreasing) in the output of the other firm. Negative g indicates the presence of economies of scope. For example, there might be positive spillovers because of learning effects, if activities are similar and the learning rate depends on cumulative joint production,¹³ or network externalities when using a common resource.¹⁴ For positive g , the firm faces diseconomies of

¹² Bulow/Geanakoplos/Klemperer (1985) use a similar approach to model (dis-)economies of scope, but consider quadratic unit-costs of each single product.

¹³ See Porter (1985), p. 418.

¹⁴ See Westland (1992). For other examples involving economies of scope see for example Teece (1982), p. 53.

scope by serving both divisions. These may be due to congestion or switching costs when there are joint capacities,¹⁵ increased maintenance costs of flexible techniques, increasing marginal opportunity cost of capital (imperfect capital markets) or forgone learning effects when activities are dissimilar. In order to simplify the analysis, I will normalize c^k to zero.¹⁶ The effect of the joint cost- (benefit-)¹⁷ term can thus be highlighted.

Costs and hence optimal supply and resulting prices in each market depend on g and the level of demand in each market. To avoid boundary solutions (overproduction if economies of scope are getting too important, zero production if the negative spillover effect gets too high), I restrict g to be in the interval $[g^*, g^{**}]$.¹⁸

Given the demand and cost structure, corporate profits are

$$\Pi_i = x_i(\tilde{a}^A - x_1 - x_2) + y_i(\tilde{a}^B - y_1 - y_2) - C_i(x_i, y_i), \quad i = 1, 2.$$

If production decisions were made by the firms' owners (principals) without market specific information, production decisions would reflect their expectations about the level of demand in each market, or

$$x_i = y_i = \frac{E[a^k]}{3 + g}.$$

Profits would be

$$E[\Pi_i] = \frac{(2 + g)(\alpha a^l + (1 - \alpha) a^h)^2}{(3 + g)^2}$$

and are lower than expected profits when owners are informed about each market's demand parameter.

Owners (principals)

Owners (principals) hire managers to make production decisions in each market. In accordance with the M-form paradigm, the power to choose the incentive schemes and to use the "internal control apparatus to manage spillover effects"¹⁹ remains in the central department (Williamson (1975)). As divisional managers can concentrate on their market and are "nearer" to demand, they are able to obtain additional information about market conditions in their own market. Specifically, it is assumed, that managers learn the realization of their markets' demand before deciding about supply. However, they only know the distribution of the demand parameter of the other market, leaving some uncertainty about final costs.

In the first stage of the two-stage game, the principal of each firm is able to induce intrafirm

¹⁵ For example, the effectiveness of providing common services such as a personnel department, a computer department or managerial supervision utilized by multiple departments may decline as the extent of utilization of other departments increases. See Gal-Or (1993), p. 388, for this argument. See also Zimmermann (1979), p. 510, who talks about opportunity costs when common services (e.g. WATS telephone line) are used by several users (degradation, delay etc.), Teece (1982), p. 53, alluding to congestion effects of knowhow as a common input factor, or Westend (1992) for congestion effects in information systems.

¹⁶ This does not alter the qualitative results obtained. The resulting cost function is also used by Dixon (1992) when he considers two multiproduct firms and by Hughes/ Kao (1998).

¹⁷ In the following, I will only talk about joint cost, implying also the possibility of negative g (positive spillovers).

¹⁸ See appendix for the derivation of the boundaries.

¹⁹ Williamson (1975), p. 153.

information sharing by implementing an information system (IS), which informs each manager about the realization of demand in the other market. This is modeled via an uncooperative information game, where principals decide simultaneously whether to implement an IS (I) or not (N): Each principals strategy space is hence defined as $\eta_i = \{N, I\}$, which leads to the potential information situations figured in fig. 2.1.

$1 \setminus 2$	I	N
I	(I, I)	(I, N)
N	(N, I)	(N, N)

Fig. 2.1: Information Game

If both principals choose I , the outcome of the information game is symmetric information (I, I): both firms' managers will exchange information about their markets' demand. Both principals choosing N implies symmetric non-information (N, N). Finally, if in one firm information is exchanged, and in the other not the result is asymmetric information (N, I) or (I, N resp.).

The information strategies induce different quantity reactions of managers in the second stage, the basic Cournot game, as they determine whether managers consider expected or realized values for other divisions' demand. Therefore, principals must foresee the Cournot outcome of the second stage for the different information situations. Using the concept of subgame perfect equilibrium, their strategies must then be best responses to each other, given the quantity reactions of managers and the resulting Cournot profits in the Cournot game.

Managers

Managers' utility is linear in monetary rewards and does not depend on non-pecuniary variables. Their salary is a function of divisional managers' action variables and the realization of demand in each market. Assuming that their compensation includes a bonus on profits, they select the level of divisional output in order to maximize those profits. As there are interdivisional cost linkages, compensation could be based both on corporate and on divisional profits.²⁰ Tying compensation to corporate profits is equivalent to allocating total joint costs to each division. In the case of evaluation according to divisional profits, the principal has to apply a sharing rule to allocate joint costs, which defines the fraction of total costs each division has to bear. Because of the motivational disadvantages of unequal cost allocation²¹ and to concentrate on the strategic effects of information sharing, asymmetric cost allocation schemes will be neglected.²² So in essence the following two compensation schemes are studied:

²⁰ See Faulli-Oller (1995) for this argument.

²¹ Fairness / equity of a cost allocation is one of the properties often required in the literature dealing with allocation of joint costs. See for example Jensen (1977), p. 844 or Ewert/ Wagenhofer (1993), p. 540 - 546. See also Hughes / Scheiner (1980), p. 86 - 87 who underline the existence of a tradeoff between behavioural benefits and efficiency criteria.

²² The strategic effects of asymmetric cost allocation are analyzed in Hughes / Kao (1998) who points out that asymmetric cost allocation schemes may result in the specialization of firms in one market. A similar model was parallelly developed by Neubauer (1998).

(1) Compensation on the basis of corporate profits :

$$S_i^{kC}(\tilde{a}^A, \tilde{a}^B) = S_0^C + \beta^C(x_i(a^A - x_1 - x_2) + y_i(a^B - y_1 - y_2) - C_i(x_i, y_i)), \quad 23$$

with

$$C_i(x_i, y_i) = gx_i y_i$$

This compensation scheme can be justified with the existence of the external effect the supply of one division has on the costs of the second division. It implies allocation of total costs, such that divisions take into account the entire effect of their action on corporate costs.²⁷

(2) Compensation on the basis of divisional profits, where joint costs are allocated based on expected (standard) divisional demand:

$$\begin{aligned} S_i^{AD} &= S_0^D + \beta^D(x_i(a^A - x_1 - x_2) - C_i^A(x_i, y_i)) \\ S_i^{BD} &= S_0^D + \beta^D(y_i(a^B - y_1 - y_2) - C_i^B(x_i, y_i)) \end{aligned}$$

with

$$C_i^A(x_i, y_i) = C_i^B(x_i, y_i) = E\left[\frac{a^A}{a^A + a^B}\right] gx_i y_i = \frac{1}{2} gx_i y_i$$

This mechanism is in accordance with the standard cost approach and implies equal cost sharing.²⁸

Obviously, the compensation scheme influences managers' behavior in each market and hereby the strategic position of the firm towards its competitor.²⁹ If managers maximize divisional profits, they internalize only part of the negative (positive) effect, the production of their product has on the costs of the other product and behave more (less) aggressively in each market. For the time being I will abstract from the possibility of choosing the incentive scheme and analyze the impact of intrafirm information sharing for each incentive scheme separately.³⁰

3. The Cournot Game

As managers are only interested in monetary rewards, they maximize their expected salary over x_i (divisions in market A) and y_i (divisions in market B) in accordance with their informational situation and the realization of demand in each market. When managers' compensation is tied to corporate profits, their objective function is $S_i^{kC}(\tilde{a}^A, \tilde{a}^B)$, the variable part of which coincides with the objective function of the principal: managers internalize the complete external effect that their production has on the costs of the other division. In the other case, managers maximize $S_i^{kD}(\tilde{a}^A, \tilde{a}^B)$ and neglect the externality of their action.

²⁷ A potential disadvantage of this approach is that more than total costs / benefits are allocated, such that the budget is not equalized and divisional profits used as a basis for manager's evaluation can not at the same time serve as a basis for the evaluation of a division's contribution to corporate success.

²⁸ See also Zimmermann (1979) for a justification of this approach: Zimmermann argues, that joint costs should be allocated on the basis of expected utilization of a common resource to approximate opportunity costs which are difficult to measure.

²⁹ See Gal-Or (1993) and Hughes / Kao (1998) for the strategic implications of cost allocation schemes.

³⁰ It will be assumed that both firms' owners apply the same incentive scheme.

Expected corporate profits are derived by inserting the equilibrium quantities chosen by managers in accordance with their informational situation ($\eta_i = I, N$) and the incentive scheme applied ($\Phi = C, D$) for each demand combination and considering probabilities for these demand combinations:

$$\begin{aligned} E[\Pi_i^{\Phi\eta_i\eta_j}] &= E[x_i(a^A - x_1 - x_2) + y_i(a^B - y_1 - y_2) - C_i(x_i, y_i)] \\ &= \alpha^2 \Pi_i(a^l, a^l) + 2\alpha(1 - \alpha) \Pi_i(a^l, a^h) + (1 - \alpha)^2 \Pi_i(a^h, a^h) \end{aligned} \quad (3.1)$$

No information about other markets' demand (N,N)

If neither firms' manager share information about market conditions, managers consider the expected value of the other markets demand in their maximization problem. First order conditions are:

$$\begin{aligned} \frac{\partial E^A[S_i^{AC}]}{\partial x_i} &= \tilde{a}^A - 2x_i - x_j - g E[y_i] = 0 \\ \frac{\partial E^B[S_i^{BC}]}{\partial y_i} &= \tilde{a}^B - 2y_i - y_j - g E[x_i] = 0 \end{aligned}$$

in the case of corporate profit maximization, and

$$\begin{aligned} \frac{\partial E^A[S_i^{AD}]}{\partial x_i} &= \tilde{a}^A - 2x_i - x_j - \frac{1}{2}g E[y_i] = 0 \\ \frac{\partial E^B[S_i^{BD}]}{\partial y_i} &= a^B - 2y_i - y_j - \frac{1}{2}g E[x_i] = 0 \end{aligned}$$

for divisional profit maximization.

The only linear strategy equilibrium is:³¹

$$x_i^{*C}(\tilde{a}^A) = \frac{\tilde{a}^A}{3} - \frac{g E[\tilde{a}^k]}{3(3+g)}, \quad y_i^{*C}(\tilde{a}^B) = \frac{\tilde{a}^B}{3} - \frac{g E[\tilde{a}^k]}{3(3+g)}$$

(corporate profit maximization)

$$x_i^{*D}(\tilde{a}^A) = \frac{\tilde{a}^A}{3} - \frac{gE[a^B]}{3(6+g)}, \quad y_i^{*D}(\tilde{a}^B) = \frac{\tilde{a}^B}{3} - \frac{gE[a^A]}{3(6+g)}$$

(divisional profit maximization).

Inserting the equilibrium quantities into 3. 1 leads to $E[\Pi_i^{CNN}]$ for divisional profit maximization and $E[\Pi_i^{DNN}]$ for corporate profit maximization.

Full Information Situation (I,I)

If managers of both firms are informed about the demand in the other market, first order conditions are

$$\frac{S^{AC}}{\partial x_i} = a^A - 2x_i - x_j - g y_i = 0$$

³¹ Proof see Appendix B.

$$\frac{S_i^{BC}}{\partial y_i} = a^B - 2y_i - y_j - g x_i = 0$$

(corporate profit maximization)

$$\begin{aligned}\frac{\partial S_i^{AD}}{\partial x_i} &= a^A - 2x_i - x_j - \frac{1}{2}g y_i = 0 \\ \frac{\partial S^{BD}}{\partial y_i} &= a^B - 2y_i - y_j - \frac{1}{2}g x_i = 0\end{aligned}$$

(divisional profit maximization).

Equilibrium quantities will be

$$\begin{aligned}x_i^{*C}(\tilde{a}^A, \tilde{a}^B) &= \frac{3\tilde{a}^A - g\tilde{a}^B}{9 - g^2} = \frac{\tilde{a}^A}{3} - \frac{g(3\tilde{a}^B - g\tilde{a}^A)}{3(9 - g^2)} \\ y_i^{*C}(\tilde{a}^A, \tilde{a}^B) &= \frac{3\tilde{a}^B - g\tilde{a}^A}{9 - g^2} = \frac{\tilde{a}^B}{3} - \frac{g(3\tilde{a}^A - g\tilde{a}^B)}{3(9 - g^2)}\end{aligned}$$

and

$$\begin{aligned}x_i^*(\tilde{a}^A, \tilde{a}^B) &= \frac{6(2\tilde{a}^A - g\tilde{a}^B)}{36 - g^2} = \frac{\tilde{a}^A}{3} - \frac{g(g\tilde{a}^A - 18\tilde{a}^B)}{3(36 - g^2)} \\ y_i^*(\tilde{a}^A, \tilde{a}^B) &= \frac{6(2\tilde{a}^B - g\tilde{a}^A)}{36 - g^2} = \frac{\tilde{a}^B}{3} - \frac{g(g\tilde{a}^B - 18\tilde{a}^A)}{3(36 - g^2)}.\end{aligned}$$

Instead of considering the expected value of the other market's demand, managers react to demand variations. They supply more than uninformed managers

- when $g > 0$ and other market's demand is low
- when $g < 0$ and other market's demand is high

whereas they supply less

- when $g > 0$ and other market's demand is high
- when $g < 0$ and other market's demand is low.

Knowing the supply strategy for each demand realization, expected corporate profits can again be calculated according to 3.1, leading to $E[\Pi_i^{CII}]$ and $E[\Pi_i^{DII}]$.

Asymmetric Information ((I, N) or (N, I))

As firms and markets are symmetric, it suffices to analyze the situation, where one firm (say firm 1) chooses I, whereas the other firm (firm 2) chooses N. First order conditions of the informed managers are the same than in the full information situation. FOC of the uninformed firm change to change to:

$$\begin{aligned}\frac{\partial E[S_2^{AC}]}{\partial x_2} &= \tilde{a}^A - E[x_1] - 2x_2 - g E[y_2] = 0 \\ \frac{\partial E[S_2^{BC}]}{\partial y_2} &= \tilde{a}^B - E[y_1] - 2y_2 - g E[x_2] = 0\end{aligned}$$

or

$$\begin{aligned}\frac{\partial E[S_2^{AD}]}{\partial x_2} &= \tilde{a}^A - E[x_1] - 2x_2 - \frac{1}{2}g E[y_2] = 0 \\ \frac{\partial E[S_2^{BD}]}{\partial y_2} &= \tilde{a}^B - E[y_1] - 2y_2 - \frac{1}{2}g E[x_2] = 0.\end{aligned}$$

Firm 2's managers cannot be certain any more about the equilibrium reaction functions of their competitors in the same market, as the divisional managers of firm 1 change their strategies according to realized demand in the other market. In market A (B) the respective manager of firm 2 therefore not only has to take into account an average value for y_2 (x_2) but also for x_1 (y_1). The asymmetric information of divisional managers leads to different equilibrium quantities of firms 1 and 2.³²

Inserting the equilibrium quantities into (3. 1) results in $E[\Pi_i^{CIN}]$ and $E[\Pi_i^{DIN}]$.

4. The Information Game

To solve the information game, corporate profits for the different information situations must be compared. The equilibrium implies that each firms' informational strategy is the best answer to the informational strategy of the competitor.

Comparing expected corporate profits for the full-information situation with profits in case of no information sharing in any firm, it can be seen, that the value of information depends on the incentive scheme applied for managers:

$$\begin{aligned}E[\Pi_i^{CII}] - E[\Pi_i^{CNN}] &= -\frac{2\alpha(1-\alpha)(a^h - a^l)^2 g^4}{9(9-g^2)^2} < 0 \\ E[\Pi_i^{DII}] - E[\Pi_i^{DNN}] &= \frac{2\alpha(1-\alpha)(a^h - a^l)^2 g^2 (108 - g^2)}{9(36 - g^2)^2} \geq 0.\end{aligned}$$

This leads to

Proposition 1 : *In the model described above, a situation of bilateral information is preferred to a situation of bilateral non-information, when managers maximize divisional profits and share costs. It leads to lower profits, if managers objective function coincides with the objective function of the corporate firm.*

This result is due to the interplay of a positive cost effect and a negative revenue effect of information, which have different weights for both incentive schemes.

If managers are informed, they consider realized values of demand in the other market, whereas uninformed managers must decide on the basis of their expectations about other markets' demand. Informed managers are thus responsive (more or less aggressive depending on the sign of the cost interaction term and the state of demand in the other market) to demand variations in the other market. More aggressive behavior of both firms implies higher supply and lower prices, less aggressive behavior has the reverse effect.

³² For value and proof of equilibrium quantities see Appendix C.

With respect to revenue (R), information has a negative effect. This is due to the concavity of the revenue-function in x and y respectively. When managers take into account expected values of demand in the other market, the ex-post variance of their own supply is lower than if they were informed about the state of demand. The less variance there is, the higher are expected profits as

$$\begin{aligned} R_i^A(E[y_i(a^B)]) &\geq E[R_i^A(y_i(a^B))] \\ R_i^B(E[x_i(a^A)]) &\geq E[R_i^B(x_i(a^A))] \end{aligned}$$

The effect of information on costs is reversed. Being informed about demand in the other market, managers are able to adjust their supply optimally to different cost conditions. This has a positive effect on profits. When there are congestion effects, information leads to a lower spread in joint supply. Because of the convexity of the cost function in joint supply, this leads to lower costs. In the case of positive externalities, information increases the spread in joint supply and therefore the benefits resulting from joint production.

Whereas in the case of corporate profit maximization, the negative effect of information outweighs its positive effect, the reverse is true for divisional profit maximization. This is due to the different incorporation of the externality produced by each division:

When managers maximize divisional profits, congestion costs (synergies) are evaluated less. As they only internalize half of the effect of their supply decision on the profits of the other division, they do not care so much about demand in the other market. This makes them react less to information about a^h or a^l , such that the spread in supply is not as high. The **negative** effect of information on revenue is then lower as in the case of corporate profit maximization because the variance of supply is lower. With respect to costs, one can see, that the **positive** effect of information is also higher in the case of cost-sharing when $g > 0$, and only slightly lower when $g < 0$. For any g , the positive information effect outweighs the negative effect on revenue in the case of cost sharing.

Analyzing the effects of asymmetric information on firms profits, one gets, that - independent of the incentive scheme applied - there is a advantage for firms being asymmetrically informed when competitors are not informed:³³

$$E[\Pi_1^{\Phi IN}] \geq E[\Pi_1^{\Phi NN}], \quad \Phi = C, D.$$

At the same time, corporate profits of a firm whose managers are not informed while other firms' managers are informed (asymmetric non-information) are lower than in the full-information situation:

$$E[\Pi_2^{\Phi IN}] \leq E[\Pi_2^{\Phi II}], \quad \Phi = C, D.$$

Hence, regardless of the strategy of the other firm, information is always a dominant strategy, such that we can derive

³³ See Appendix D.

Proposition 2 : *In the model described above, regardless of the incentive scheme for managers, the equilibrium of the information game is (I,I).*

Note, that firms are in a prisoner's dilemma, when compensation of managers is tied to corporate profits: Firms would prefer a situation of bilateral non-information to bilateral information, but because of the unilateral incentives to choose I, they end up in a situation which is worse for both.

5. Welfare Effects

Taking the non-information as a benchmark, I will analyze the effects of the information game on consumer surplus and social welfare. Welfare will be defined as the sum of net corporate profits and consumer surplus. Consumer surplus is defined as

$$CS(x_1, x_2, y_1, y_2) = \int_0^X (\tilde{a}^A - X)dX + \int_0^Y (\tilde{a}^B - Y)dY - p^A X - p^B Y,$$

$$X = \sum_i x_i, \quad Y = \sum_i y_i$$

where prices for good x and y are calculated by inserting the equilibrium quantities in the respective inverse demand function.

As the monetary transfer cancels out when adding up consumer surplus and firms' profits, social welfare could be calculated by subtracting the production and information costs from consumers' gross surplus:

$$W(x_1, x_2, y_1, y_2) = CS + \sum_i \Pi_i =$$

$$= \int_0^X (\tilde{a}^A - X)dX + \int_0^Y (\tilde{a}^B - Y)dY - \sum_i C_i(x_i, y_i)$$

The expected values for consumer surplus and social welfare in the full-information and the non-information situation are derived by inserting the equilibrium quantities chosen by firms for each demand constellation and considering the probabilities for this demand constellation. The effects of the possibility of introducing interdivisional information sharing on consumer surplus are then:

$$E[CS^{CII}] - E[CS^{CNN}] = \frac{2\alpha(1-\alpha)(a^h - a^l)^2 g^2 (27 - g^2)}{3(9 - g^2)^2} \geq 0$$

$$E[CS^{DII}] - E[CS^{DNN}] = \frac{2\alpha(1-\alpha)(a^h - a^l)^2 g^2 (108 - g^2)}{3(36 - g^2)^2} \geq 0.$$

Consumers always gain by the information game, whereas firms only gain in the case of managers maximizing divisional profits and are worse off in the case of corporate profit maximizing managers. The effect on social welfare must therefore be positive if $\Phi = D$, whereas it is not obvious with $\Phi = C$. Adding up the effect on expected consumer surplus and

profits yields:

$$E[W^{CII}] - E[W^{CNN}] = \frac{2\alpha(1-\alpha)(a^h - a^l)^2 g^2 (81 - 5g^2)}{9(9 - g^2)^2} > 0$$

$$E[W^{DII}] - E[W^{DNN}] = \frac{10\alpha(1-\alpha)(a^h - a^l)^2 g^2 (108 - g^2)}{9(36 - g^2)^2} > 0$$

Proposition 3 : *In the model described above, regardless of the incentive scheme, the information game has a positive impact on consumer surplus and social welfare.*

6. Information Costs

The outcome of the information game changes, if one assumes, that intrafirm information flows are costly. For example, there might be fixed costs for the implementation of a computer-based reporting system or another system facilitating communication between divisions. Or there is a administrative cost of collecting information and providing each division with information from other markets.

In the following, it is assumed, that the information strategy I leads to a fixed cost

$$C_i(I) = F, \quad i = 1, 2.$$

Firms must then consider net corporate profits when selecting their information strategy. Information will only be chosen, if the unilateral incentive to choose I exceeds the costs of information. The equilibria of the information game then depend on F . As the advantage to unilaterally implement an IS is greater than the advantage of a firm with uninformed managers to induce information sharing when the other firm has already implemented an IS,

$$E[\Pi_2^{\Phi II}] - E[\Pi_2^{\Phi IN}] \leq E[\Pi_1^{\Phi IN}] - E[\Pi_1^{\Phi NN}], \quad \Phi = C, D.$$

we can derive

Proposition 4 : *Whenever there are some fixed costs F of information, the outcome of the information game depends on the importance of this costs. There are 4 possible equilibria:*

$$\begin{array}{ll} (I, I) & \text{if } F \leq E[\Pi_2^{\Phi II}] - E[\Pi_2^{\Phi N}] \\ (I, N) \text{ } ((N, I) \text{ resp.}) & \text{if } E[\Pi_2^{\Phi II}] - E[\Pi_2^{\Phi IN}] < F \leq E[\Pi_1^{\Phi IN}] - E[\Pi_1^{\Phi NN}] \\ (N, N) & \text{if } F > E[\Pi_1^{\Phi IN}] - E[\Pi_1^{\Phi NN}]. \end{array}$$

Hence, whenever information costs are low, the outcome of the information game is the full information situation, and the prisoner's dilemma in the case of corporate profit maximization remains valid. But also when managers' salary is tied to divisional profits, they might end up worse: Departing from a situation of bilateral non-information, the unilateral incentive to choose I is bigger than the advantage of bilateral information:

$$E[\Pi_i^{DII}] - E[\Pi_i^{DNN}] < F \leq E[\Pi_1^{CIN}] - E[\Pi_1^{CNN}].$$

Therefore, both firms might choose I even if they prefer (N, N) .

When information costs are in an intermediate range, the resulting equilibria imply asymmetric information strategies of firms: it pays for one firm to invest in information, but the gains for the second firm do not outweigh the costs.

Finally, for high information costs, both firms' managers do not share information and the equilibrium is (N, N) .

The effects of the information game on social welfare are not obvious any more. According to proposition 3, gross welfare is always higher with bilateral information than with bilateral non-information. It can also be shown, that unilateral information has a positive effect on consumer surplus and gross social welfare, and that the gross welfare effect is higher than the advantage of firms to unilaterally implement information:

$$\begin{aligned} E[W^{\Phi IN}] - E[W^{\Phi II}] &> E[\Pi_1^{\Phi IN}] - E[\Pi_1^{\Phi NN}] > 0 \\ E[W^{\Phi II}] - E[W^{\Phi IN}] &> E[\Pi_2^{\Phi II}] - E[\Pi_2^{\Phi IN}] > 0. \end{aligned}$$

Therefore, whenever firms choose to make divisions share information, the effect on welfare is positive. But there is a range of F , for which firms might choose non-information, when information would be socially preferred.

7. Endogeneizing the Incentive Choice?

What would happen, if firms were able to simultaneously choose the incentive scheme Φ for their managers before they decide about their information strategy and before managers play the Cournot game?

Without uncertainty ($a^h = a^l$, $\alpha = 1$ or $\alpha = 0$) or with symmetric (non-)information (I, I) or (N, N) , the outcome of the delegation game would be

- C, C in the case of economies of scope
- D, D in the case of diseconomies of scope.

This result is in accordance with results derived in the literature of strategic delegation: As products are strategic substitutes, owners choose the contract for managers which induces aggressive behavior. When there are economies of scope, managers are made to internalize the full positive spillover effect, whereas they are made to neglect part of the costs in the case of diseconomies of scope.

In the presence of demand uncertainty and the possibility to choose interdivisional information exchange, the information game must be extended with a prior stage (the delegation game) and the whole three stage game would have to be solved by backwards induction.

After having solved the second stage of the game, I can derive the reduced form of the delegation game:

$$\begin{array}{cc} & C & D \\ C & \Pi_1^{CCII}, \Pi_2^{CCII} & \Pi_1^{DCNI}, \Pi_2^{DCNI} \\ D & \Pi_1^{CDIN}, \Pi_2^{CDIN} & \Pi_1^{DDII}, \Pi_2^{DDII} \end{array}$$

The outcome of the delegation stage depends on the importance of the diseconomies of scope, on the level of insecurity (value of $\alpha, d = a^h - a^l$) and the level of demand in both markets. Numerical evaluations lead to the following first results³⁴:

- owners of both firms choose $\Phi_i = C$ in the case of economies of scope or high diseconomies of scope
- owners of both firms choose $\Phi_i = D$ in the case of low diseconomies of scope

8. Summary and Concluding Remarks

In this paper the question was raised, if and when multimarket firms have an incentive to make their divisions share information about each other's market parameters, and how profits, consumer surplus and social welfare is affected by firms' decisions about their informational situation. In the light of the importance of global multimarket firms and the ongoing discussion about optimal information flows within firms, this issue was supposed to have some empirical relevance. Nevertheless, in theory, the topic of interdivisional information sharing in the presence of multimarket contact has not been considered.

It was assumed that divisional decisions are influenced by each other. This was modeled via the assumption of a central department supplying some common services and hence a joint cost function of divisions. The situation was embedded in a context of oligopolistic competition. Whereas information would always be beneficial in a noncompetitive context, the fact that firms compete against each other was supposed to create strategic effects of information that could make interdivisional information sharing unfavorable.

I showed, that the value of information for firms consists of a positive cost effect and a negative revenue effect. The relative importance of these effects depends crucially on the incentive system used to evaluate managers. If the incentive scheme makes managers ignore part of the interdivisional cost linkages, the net value of information is positive, whereas with corporate profit maximizing managers, owners would prefer not to inform their managers. Nevertheless, in both cases the equilibrium of an information game would be both firms implementing interdivisional information sharing whenever the costs of information are not too high.

Because of the crucial importance of the incentive scheme applied, I tried to answer the question, which incentive scheme would actually be selected by owners. Even though I could not derive general results, numerical evaluations strengthened the propositions obtained in the literature of strategic delegation: Owners commit to aggressive behavior by shaping managers' incentives accordingly as long as the costs of doing so are not too high.

The results implied that average supply is higher with informed than with uninformed managers. Consequently, prices are lower and consumer surplus is higher when firms implement an information system. The gross effect of information on social welfare could be

³⁴ An analytical solution could not be obtained yet.

shown to be positive, such that the net effect depends on the costs of intradivisional information sharing.

As firms might choose to leave their managers uninformed even when social welfare is higher with information, the question must be raised, if public intervention is necessary. For example, one could think of the public provision of information about demand parameters via market research institutes. Another possibility would be to provide firms with incentives either to implement internal information systems or to make the division-specific knowledge also publicly available. However, for a sensible evaluation of the value of public intervention, the costs and benefits of possible instruments would have to be compared.

There are still a lot of open questions. It could be asked, for example, what would be the result of a game, where divisions have the possibility to share their specific knowledge not only with the divisions of their own firm, but also with the other firm. The question could be raised, which are the implications of information if there are interdivisional linkages other than cost linkages. A very topic would also be the issue of a correlation of stochastic variables of different markets. Divisional managers would then learn more about their own market by sharing information with other divisions. We will leave these questions for further research.

Appendix A: Boundary solutions

To rule out boundary solutions, at which either overproduction or zeroproduct in one market occurs, the critical values for g for the different incentive schemes, informational situations and demand realizations are calculated. To avoid a boundary solution in any possible subgame, the most restrictive critical value is selected. Given the incentive scheme of managers (influencing the degree of internalization of the spillover effect), boundary solutions are the more probable,

- the higher (expected) spillovers, determined by
 - * the importance of (dis-)economies of scope
 - * the level of the other division's (expected) supply
- the lower is demand in the considered market.

Hence, the value of g as well as the difference between high and low demand ($a^h - a^l = d$) influence the appearance of boundary solutions, which are most probable when demand in the own market is low whereas it is high in the other market.

Comparing the critical values for g , I find, that the most restrictive value for g , at which overproduction occurs (g^*), depends on α and d , whereas zeroproduct is the most probable in a situation where one firm is informed and the other firm is not informed. For corporate profit maximization, boundaries are determined by:

$$g^{*C} = \begin{cases} g^{*CNN}(a^l, E(a)) = \frac{a^h - \sqrt{3(a^l)^2 + (a^h)^2}}{a^l} & \text{for } d \geq \frac{a^h(1-4\alpha)}{2\alpha(1-\alpha)} \\ g^{*CII}(a^l, a^h) = -\frac{3a^l}{2a^h + a^l - 2\alpha(a^h - a^l)} & \text{for } d < \frac{a^h(1-4\alpha)}{2\alpha(1-\alpha)} \end{cases}$$

$$g^{**C} = g^{**CIN}(a^l, a^h) = \frac{(2+\alpha)(a^l - a^h) + \sqrt{(2+\alpha)^2(a^h - a^l)^2 + 24a^l((2-\alpha)a^h + \alpha a^l)}}{2((2-\alpha)a^h + \alpha a^l)}$$

For divisional profit maximization, the critical values are:

$$g^{*D} = \begin{cases} g^{*DNN}(a^l, E(a)) = \frac{a^h - \sqrt{3(a^l)^2 + (a^h)^2}}{a^l} & \text{for } d \geq \frac{a^h(1-4\alpha)}{2\alpha(1-\alpha)} \\ g^{*DII}(a^l, a^h) = -\frac{3a^l}{2a^h + a^l - 2\alpha(a^h - a^l)} & \text{for } d < \frac{a^h(1-4\alpha)}{2\alpha(1-\alpha)}, \end{cases}$$

where $d > 0$ implies $\alpha < \frac{1}{4}$, and

$$g^{**D} = g^{**DIN}(a^l, a^h) = \frac{2(2+\alpha)(a^l - a^h) + \sqrt{4(2+\alpha)^2(a^h - a^l)^2 + 96a^l((2-\alpha)a^h + \alpha a^l)}}{2((2-\alpha)a^h + \alpha a^l)}$$

Appendix B: Linear strategy equilibrium when uninformed managers maximize corporate profits:

I first show, that the proposed strategies

$$\begin{aligned} x_i^*(\tilde{a}^A) &= \frac{\tilde{a}^A}{3} - \frac{g E[\tilde{a}^B]}{3(3+g)} \\ y_i^*(\tilde{a}^B) &= \frac{\tilde{a}^B}{3} - \frac{g E[\tilde{a}^A]}{3(3+g)} \end{aligned}$$

are equilibrium strategies: Each divisional manager's strategy must be the best response to the strategy of the other divisional manager of its own firm as well as to the competitor's divisional managers. First order conditions are

$$\begin{aligned} \frac{\partial E^A[\Pi_i^A]}{\partial x_i} &= a^A - 2x_i - x_j - g E[y_i] = 0 \\ \frac{\partial E^B[\Pi_i^B]}{\partial y_i} &= a^B - 2y_i - y_j - g E[x_i] = 0. \end{aligned}$$

Given, the divisional manager of firm i and division B plays $y_i^*(\tilde{a}^B)$, the manager of division A can calculate the expected quantity produced by B:

$$E[y_i^*(\tilde{a}^B)] = E\left[\frac{\tilde{a}^B}{3} - \frac{g E[\tilde{a}^A]}{3(3+g)}\right] = \frac{E[\tilde{a}^B]}{3} - \frac{g E[\tilde{a}^A]}{3(3+g)} = \frac{E[\tilde{a}^k]}{3+g}.$$

Inserting this into his FOC and solving for x_i yield:

$$x_i(\tilde{a}^A) = \frac{\tilde{a}^A}{3} - \frac{g E[\tilde{a}^k]}{3(3+g)} = \frac{\tilde{a}^A}{3} - \frac{g E[\tilde{a}^B]}{3(3+g)} = x_i^*(\tilde{a}^A).$$

Therefore, $x_i^*(\tilde{a}^A)$ is the best response to $y_i^*(\tilde{a}^B)$.

Given the divisional manager of firm i and division A plays $x_i^*(\tilde{a}^A)$, the best response of manager of division B can be calculated in the same way to show that

$$y_i(\tilde{a}^B) = \frac{\tilde{a}^B}{3} - \frac{g E[\tilde{a}^k]}{3(3+g)} = \frac{\tilde{a}^B}{3} - \frac{g E[\tilde{a}^A]}{3(3+g)} = y_i^*(\tilde{a}^B).$$

Thus, $y_i^*(\tilde{a}^B)$ is also the best response to $x_i^*(\tilde{a}^A)$ and the proposed strategies are equilibrium strategies of the game.

To show, that it is the only linear strategy equilibrium, assume there is another linear strategy equilibrium of the following form:

$$\begin{aligned} x_i^{**}(\tilde{a}^A) &= \frac{\tilde{a}^A}{3} - \frac{g E[\tilde{a}^B]}{3(3+g)} + d_{ia} \\ y_i^{**}(\tilde{a}^B) &= \frac{\tilde{a}^B}{3} - \frac{g E[\tilde{a}^A]}{3(3+g)} + d_{ib} \end{aligned}$$

where d_1 (d_2) can be any linear term containing a^k and $E[a^k]$. Inserting $x_i^{**}(\tilde{a}^A)$ and $y_i^{**}(\tilde{a}^B)$ in

the FOC of each divisional manager yields

$$\begin{aligned}\tilde{a}^A - 3\left(\frac{\tilde{a}^A}{3} - \frac{g E[a^B]}{3(3+g)} + d_{ia}\right) - g\left(\frac{E[\tilde{a}^k]}{3+g} + E[d_{ib}]\right) &= 0 \\ \tilde{a}^B - 3\left(\frac{\tilde{a}^B}{3} - \frac{g E[a^A]}{3(3+g)} + d_{ib}\right) - g\left(\frac{E[\tilde{a}^k]}{3+g} + E[d_{ia}]\right) &= 0\end{aligned}$$

and

$$\begin{aligned}d_{ia} &= -\frac{gE[d_{ib}]}{3} \\ d_{ib} &= -\frac{gE[d_{ia}]}{3}.\end{aligned}$$

As d_{ik} must be constant, $E[d_{ik}] = d_{ik}$. This implies $d_{ia} = d_{ib} = 0$. Consequently $x_i^{**}(\tilde{a}^A) = x_i^*(\tilde{a}^A)$ and $y_i^{**}(\tilde{a}^B) = y_i^*(\tilde{a}^B)$. Therefore, the only linear strategy equilibrium is the one proposed above.

Appendix C: Linear strategy equilibrium when asymmetrically informed managers maximize corporate profits:

To derive the equilibrium I assume that strategies are linear in \tilde{a}^A and \tilde{a}^B :

$$\begin{aligned}x_1(\tilde{a}^A, \tilde{a}^B) &= x_1^S + b_1\tilde{a}^A + d_1\tilde{a}^B \\y_1(\tilde{a}^A, \tilde{a}^B) &= y_1^S + \beta_1\tilde{a}^A + \delta_1\tilde{a}^B \\x_2(\tilde{a}^A) &= x_2^S + b_2\tilde{a}^A \\y_2(\tilde{a}^B) &= y_2^S + \delta_2\tilde{a}^B\end{aligned}$$

This leads to the proposed linear strategy equilibrium:

$$\begin{aligned}x_1^*(\tilde{a}^A, \tilde{a}^B) &= \frac{2\tilde{a}^A - g\tilde{a}^B}{2(3 - g^2)} + \frac{g(1 - g)E[a^k]}{2(3 + g)(3 - g^2)} \\y_1^*(\tilde{a}^A, \tilde{a}^B) &= \frac{2\tilde{a}^B - g\tilde{a}^A}{2(3 - g^2)} + \frac{g(1 - g)E[a^k]}{2(3 + g)(3 - g^2)} \\x_2^*(\tilde{a}^A) &= \frac{\tilde{a}^A(2 - g^2)}{2(3 - g^2)} - \frac{g(2 - g - g^2)E[a^k]}{2(3 + g)(3 - g^2)} \\y_2^*(\tilde{a}^B) &= \frac{\tilde{a}^B(2 - g^2)}{2(3 - g^2)} - \frac{g(2 - g - g^2)E[a^k]}{2(3 + g)(3 - g^2)}.\end{aligned}$$

Inserting the equilibrium strategies of firm j in the FOC of firm i and solving for x_i and y_i resp. yields

$$\begin{aligned}x_1(\tilde{a}^A, \tilde{a}^B) &= x_1^*(\tilde{a}^A, \tilde{a}^B) & y_1(\tilde{a}^A, \tilde{a}^B) &= y_1^*(\tilde{a}^A, \tilde{a}^B) & \text{and} \\x_2(\tilde{a}^A, \tilde{a}^B) &= x_2^*(\tilde{a}^A, \tilde{a}^B) & y_2(\tilde{a}^A, \tilde{a}^B) &= y_2^*(\tilde{a}^A, \tilde{a}^B).\end{aligned}$$

Hence, the proposed equilibrium is an equilibrium of the game.

To show, that it is the only linear strategy equilibrium, assume again there is another linear strategy equilibrium of the following form:

$$\begin{aligned}x_1^{**}(\tilde{a}^A, \tilde{a}^B) &= \frac{2\tilde{a}^A - g\tilde{a}^B}{2(3 - g^2)} + \frac{g(1 - g)E[a^k]}{2(3 + g)(3 - g^2)} + d_{1a} \\y_1^{**}(\tilde{a}^A, \tilde{a}^B) &= \frac{2\tilde{a}^B - g\tilde{a}^A}{2(3 - g^2)} + \frac{g(1 - g)E[a^k]}{2(3 + g)(3 - g^2)} + d_{1b} \\x_2^{**}(\tilde{a}^A) &= \frac{\tilde{a}^A(2 - g^2)}{2(3 - g^2)} - \frac{g(2 - g - g^2)E[a^k]}{2(3 + g)(3 - g^2)} + d_{2a} \\y_2^{**}(\tilde{a}^B) &= \frac{\tilde{a}^B(2 - g^2)}{2(3 - g^2)} - \frac{g(2 - g - g^2)E[a^k]}{2(3 + g)(3 - g^2)} + d_{2b}.\end{aligned}$$

where d_{ik} can be any linear term containing a^k and $E[a^k]$. The only strategy combination

fulfilling the FOC of both firms implies

$$d_{ia} = d_{ib} = 0.$$

Consequently $x_i^{**}(\tilde{a}^A) = x_i^*(\tilde{a}^A)$ and $y_i^{**}(\tilde{a}^B) = y_i^*(\tilde{a}^B)$. Therefore, the only linear strategy equilibrium is the one proposed above.

Appendix D: Calculations leading to proposition 3:

Expected profits when there is asymmetric-information are

$$\begin{aligned}
 E[\Pi_1^{CIN}] &= \alpha^2 \Pi_1^{CIN}(a^l, a^l) + \alpha(1 - \alpha) \Pi_1^{CIN}(a^l, a^h) + \\
 &\quad + \alpha(1 - \alpha) \Pi_1^{CIN}(a^h, a^l) + (1 - \alpha)^2 \Pi_1^{CIN}(a^h, a^h) \\
 E[\Pi_2^{CIN}] &= \alpha^2 \Pi_2^{CIN}(a^l, a^l) + \alpha(1 - \alpha) \Pi_2^{CIN}(a^l, a^h) + \\
 &\quad + \alpha(1 - \alpha) \Pi_2^{CIN}(a^h, a^l) + (1 - \alpha)^2 \Pi_2^{CIN}(a^h, a^h).
 \end{aligned}$$

Inserting the equilibrium values (eq. 5) in the profit function for expected profits of firm 1 (the informed firm) and firm 2 yields profits when there is asymmetric information. Calculating the relevant profit-differences leads to the following results (for $g < 1$):

$$\begin{aligned}
 E[\Pi_1^{CIN}] - E[\Pi_1^{CNN}] &= \frac{\alpha(1 - \alpha)(a^h - a^l)^2}{2(3 - g^2)} \geq 0 & (a) \\
 E[\Pi_2^{CII}] - E[\Pi_2^{CIN}] &= \frac{\alpha(1 - \alpha)(a^h - a^l)^2(108 - 73g^2 + 14g^4 + g^6)}{2(27 - 12g^2 + g^4)^2} \geq 0 & (b) \\
 E[\Pi_2^{CIN}] - E[\Pi_2^{CNN}] &= \frac{\alpha(1 - \alpha)(a^h - a^l)^2(12 - 5g^2)}{18(3 - g^2)} \geq 0 & (c) \\
 E[\Pi_1^{CIN}] - E[\Pi_2^{CIN}] &= \frac{\alpha(1 - \alpha)(a^h - a^l)^2}{2(3 - g^2)} \geq 0 & (d)
 \end{aligned}$$

From (a) follows, that player i has an incentive to play I given that j plays N.³⁵ From (b) it can be derived that, that -given player i plays I- player j should also play I. (c) shows us, that player j would like player i to play I departing from (N,N). From (d) it can be seen, that the asymmetrically informed player is better off than the asymmetrically uninformed player.

³⁵ Symmetry between players profits allows to interchange player 1's and 2's profits.

Appendix E: Calculations leading to Proposition 6

Expected profits with asymmetric information and cost sharing are

$$\begin{aligned}
 E[\Pi_1^{CIN}] &= \alpha^2 \Pi_1^{DIN}(a^l, a^l) + \alpha(1 - \alpha) \Pi_1^{DIN}(a^l, a^h) + \alpha(1 - \alpha) \Pi_1^{DIN}(a^h, a^l) + \\
 &\quad + (1 - \alpha)^2 \Pi_1^{DIN}(a^h, a^h) \\
 E[\Pi_2^{CIN}] &= \alpha^2 \Pi_2^{DIN}(a^l, a^l) + \alpha(1 - \alpha) \Pi_2^{DIN}(a^l, a^h) + \alpha(1 - \alpha) \Pi_2^{DIN}(a^h, a^l) + \\
 &\quad + (1 - \alpha)^2 \Pi_2^{DIN}(a^h, a^h).
 \end{aligned}$$

Equilibrium quantities are

$$\begin{aligned}
 x_1^* &= \frac{4\tilde{a}^A - g\tilde{a}^B}{12 - g^2} + \frac{g(2 - g)E[a^k]}{(6 + g)(12 - g^2)} \\
 y_1^* &= \frac{4\tilde{a}^B - g\tilde{a}^A}{12 - g^2} + \frac{g(2 - g)E[a^k]}{(6 + g)(12 - g^2)} \\
 x_2^* &= \frac{\tilde{a}^A(8 - g^2)}{2(12 - g^2)} + \frac{g(8 - 2g - g^2)E[a^k]}{2(6 + g)(12 - g^2)} \\
 y_2^* &= \frac{\tilde{a}^B(8 - g^2)}{2(12 - g^2)} + \frac{g(8 - 2g - g^2)E[a^k]}{2(6 + g)(12 - g^2)}.
 \end{aligned}$$

Inserting these values in the profit function for expected profits of firm 1 (the informed firm) and firm 2 (the uninformed firm), one finds:

$$\begin{aligned}
 E[\Pi_1^{DIN}] - E[\Pi_1^{DNN}] &= \frac{2\alpha(1 - \alpha)(a^h - a^l)^2(33 - g^2)}{9(12 - g^2)^2} \geq 0 \quad (e) \\
 E[\Pi_2^{DII}] - E[\Pi_2^{DIN}] &= \frac{\alpha(1 - \alpha)(a^h - a^l)^2(13824 - 2320g^2 + 104g^4 - g^6)}{2(432 - 48g^2 + g^4)^2} \geq 0 \quad (f) \\
 E[\Pi_2^{CIN}] - E[\Pi_2^{CNN}] &= -\frac{\alpha(1 - \alpha)(a^h - a^l)^2g^2(48 - 5g^2)}{18(12 - g^2)^2} \leq 0 \quad (g) \\
 E[\Pi_1^{DIN}] - E[\Pi_2^{DIN}] &= \frac{\alpha(1 - \alpha)(a^h - a^l)^2(20 - g^2)}{2(12 - g^2)^2} \geq 0 \quad (h)
 \end{aligned}$$

The results are only slightly different to the results with corporate profit maximization: Player *i* always has an incentive to play I from (e) and (f).³⁶ Being asymmetrically informed yields higher profits than being asymmetrically uninformed (h). Nevertheless, given player *j* plays N he is not interested that player *i* plays I (g).

³⁶ Again the fact that players' profits are symmetric is used.

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