Rev Account Stud (2011) 16:219–246
DOI 10.1007/s11142-011-9140-0

Cost-based transfer pricing

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Published online: 21 April 2011

Abstract This paper compares the performance of alternative cost-based transfer pricing methods. We adopt an incomplete contracting framework with asymmetric information at the trading stage. Transfer pricing guides intra-company trade and provides incentives for value-enhancing specific investments. We compare actual-cost transfer prices that include a markup over marginal costs with standard-cost transfer prices that are determined either by the central office ex ante (centralized standard-cost transfer pricing) or by the supplying division at the trading stage (reported standard-cost transfer pricing). For the actual-cost methods, we show that markups based on the joint contribution margin (contribution-margin transfer pricing) dominate purely additive markups (cost-plus transfer pricing). We obtain the following results. (1) Centralized standard-cost transfer pricing dominates the other methods if the central office and the divisions ex ante face low cost uncertainty. (2) The actual-cost methods dominate the other methods if the central office and the divisions ex ante face high cost uncertainty and later, at the trading stage, the buying division receives sufficient cost information. (3) Reported standard-cost transfer pricing dominates the other methods if the central office and the divisions ex ante face high cost uncertainty, and the buyer has insufficient cost information at the trading stage.

Keywords Transfer pricing · Specific investments · Actual costs · Standard costs

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JEL Classification D24 · D82 · L23 · M41

1 Introduction

Many firms base their intra-company trade on cost-based transfer prices.[1] However, cost-based transfer pricing encompasses a range of different methods. These methods are based on either standard or actual costs, often including markups. While the rules and procedures of these methods have been extensively described, managerial accounting textbooks provide only scant descriptions of their efficiency properties and their relative performance. Up to now, for instance, the literature does not provide a coherent analysis showing under which circumstances a firm should use actual or standard cost-based transfer prices, even though this is an essential topic in managerial accounting (for example, Eccles 1983).

Using an incomplete contracting framework, we conduct a performance comparison of actual versus standard cost-based transfer prices. Transfer pricing serves the dual role of providing incentives for value-enhancing investment decisions and guiding intra-company trade under asymmetric cost information. Our analysis synthesizes and generalizes results from earlier studies that assume either that the divisions have symmetric cost information (Baldenius et al. 1999; Sahay 2003) or that the buying division has no cost information at the trading stage (Baldenius 2000). We use two key explanatory variables to characterize the effectiveness of commonly used cost-based transfer pricing methods: (a) the cost uncertainty faced by the central office and the divisions ex ante and (b) the buyer's updated cost information at the trading stage.

We start with an analysis of the effectiveness of actual cost-based transfer prices that include a markup over marginal costs. Consistent with textbooks, we compare purely additive markups (cost-plus transfer pricing) with markups that are based on the joint contribution margin (contribution-margin transfer pricing).[2] Under cost-plus transfer pricing, the firm-wide contribution margin is split such that the supplying division obtains a constant markup per unit, while the buying division receives the remaining part of the firm-wide contribution margin. A positive markup is needed to provide cost-reducing investment incentives for the supplying division which, in turn, induces inefficient trade (Sahay 2003).[3] In contrast, under contribution-margin pricing, each division receives a share of the firm-wide contribution margin. Accordingly, contribution-margin pricing induces ex post efficient trade but is prone to underinvestment because each division must bear the full investment costs.[4] As a first result, we find that contribution-margin pricing

[1] See, for instance, Ernst & Young (2008, p. 17).

[2] For an illustration of additive markups see, for instance, Solomons (1965, pp. 167–171). For the practical use of the contribution-margin method, see Feinschreiber (2004) and Moses (2007).

[3] Our analysis complements Sahay (2003) who investigates cost-plus transfer pricing for a one-sided supplier investment setting in which both divisions do not have any cost information at the trading stage.

[4] Related, Feinschreiber (2004, p. 24) recognizes that the contribution-margin method "may lead to cooperation between the divisions" but "a division that reduces its cost is not entitled to the entire benefit and must share this benefit with other divisions."

dominates cost-plus pricing because it provides better investment and trade incentives.[5]

Given this dominance result, we proceed by comparing contribution-margin transfer pricing with centralized standard cost-based transfer pricing. In the latter method, the central office determines the intra-company price a priori. At first glance, contribution-margin pricing seems to have the major advantage that actual cost information is incorporated into the trade decision. However, practical evidence challenges this argument. For instance, Eccles (1983) states: "The major difficulty with actual … cost transfers is that the price of the intermediate good fluctuates. … Also, buying units do not know the price until the period is finished and the selling unit can calculate actual costs (p. 8)." Thus, the buyer's cost information at the trading stage is crucial in determining whether actual cost information enters the intra-company trade decision and the firm can exploit a flexibility advantage.

In contrast, the trade decision is inflexible with centralized standard-cost transfer pricing because the intra-company price is determined before the investment and trade decisions are made. Accordingly, the expected firm-wide profit remains constant in the buyer's cost information and also does not respond to increased cost uncertainty. However, centralized standard-cost pricing yields efficient investment incentives because each division receives the full marginal return of its investment (Baldenius 2000).[6,7] Consequently, centralized standard-cost pricing induces the first-best solution if the supplier's costs are deterministic. Accordingly, as a second result, we find that contribution-margin pricing dominates centralized standard-cost transfer pricing if and only if the ex ante cost uncertainty is sufficiently high and the buyer has sufficient cost information at the trading stage.

To apply the contribution-margin pricing method, the central office must condition the markup on the buyer's revenues. In practice, firms sometimes have difficulties in allocating revenues properly to a specific product; or revenues might even be exposed to manipulation. Accordingly, firms might use the cost-plus transfer pricing method instead. Similar to our second result, we find that cost-plus transfer pricing outperforms centralized standard-cost transfer pricing if and only if the ex ante cost uncertainty is sufficiently high and the buyer has sufficient cost information.

To sum up, centralized standard-cost pricing performs rather well if the ex ante cost uncertainty is low, while contribution-margin pricing (or cost-plus pricing, respectively) performs rather well in risky cost environments if the buyer has sufficient cost information at the trading stage. Unfortunately, all these methods

[5] Our result extends Sahay's (2003, Proposition 1) finding that cost-plus pricing dominates an entire class of actual cost-based transfer pricing methods with markups that are not conditioned on the buyer's revenues.

[6] Similarly, some textbooks observe that standard cost-based transfer prices do not properly incorporate actual cost information, thus leading to inefficient trade (e.g., Zimmerman 2006, p. 635). Other textbooks observe that divisions have no incentive to control their costs if they get exactly reimbursed their actual costs. In contrast, these textbooks also recognize that standard cost-based transfer prices provide incentives for divisions to control their costs (e.g., Atkinson et al. 2001, p. 537; Belkaoui 1992, p. 111).

[7] These key forces have already been identified by Baldenius (2000, Section 5) for a binary trade setting where the buyer has no cost information at the trading stage.

perform relatively poorly in risky cost environments if the buyer has insufficient cost information.

Consequently, we extend our analysis and examine whether the central office can improve the firm's performance by exploiting decentralized cost information. In particular, we investigate reported standard-cost transfer prices that are based on the supplier's cost report. The supplier exaggerates his cost, which induces inefficient trade and holds up the buyer's investment (Baldenius et al. 1999). Nevertheless, reported standard-cost transfer pricing has the major advantage that the trade decision conveys the supplier's cost information and thus exploits decentralized cost information (Anthony and Govindarajan 2007, p. 242). As a final result, we find that reported standard-cost transfer pricing outperforms the other methods if the ex ante cost uncertainty is sufficiently high and the buyer does not have sufficient cost information.

Earlier studies have identified optimal contractual agreements that induce the first-best solution (for example, Edlin and Reichelstein 1995; Nöldeke and Schmidt 1995). Recent work departs from this literature by investigating transfer pricing methods that are observed in practice, but not necessarily optimal. Our results build on the following recent studies.[8] First, our analysis complements Baldenius' (2000) finding that centralized standard-cost pricing always dominates reported standard-cost pricing when trade is binary.[9] Second, contribution margin pricing is technically equivalent to negotiated transfer pricing if both divisions have symmetric information at the trading stage. Our result is thus related to Baldenius et al. (1999) who demonstrate that negotiated transfer pricing frequently outperforms reported standard-cost transfer pricing. Third, Baldenius (2000) demonstrates that there is a tradeoff between investment holdups and trade efficiency if negotiated transfer pricing is compared with centralized standard-cost transfer pricing and the buyer has no cost information at the trading stage. We obtain a similar result, depending on the ex ante cost uncertainty and the buyer's cost information at the trading stage.[10] Finally, Baldenius et al. (1999) show that negotiated transfer pricing dominates reported standard-cost pricing if there is one-sided supplier investment and the supplier's cost report is restricted. Then, reported standard-cost pricing is technically identical to cost-plus pricing.

Extending the basic framework, Holmström and Tirole (1991) and Anctil and Dutta (1999) study how the interplay between investment and trading incentives is affected by an additional moral hazard problem. Anctil and Dutta (1999) compare firm-wide versus division-specific performance measurement in a negotiated versus actual cost-based transfer pricing setting.[11] Baldenius (2006) shows that low-

8 For surveys on transfer pricing, see Göx and Schiller (2007) and Baldenius (2009).

9 In Baldenius' (2000) binary setting, the maximum cost variance is below the cut-off level above which reported standard-cost pricing dominates centralized standard-cost pricing. Related, Baldenius (2000, Footnote 23) notes that reported standard-cost pricing may dominate centralized standard-cost pricing if the central office observes a sufficiently noisier signal about the support of the cost interval.

10 A related result can be found in Bajari and Tadelis (2001) who consider inter-company, not intra-company pricing.

11 Anctil and Dutta (1999) find that cost-based transfer pricing without markup dominates negotiated transfer pricing if there is no cost uncertainty and only the buyer invests. However, negotiated transfer

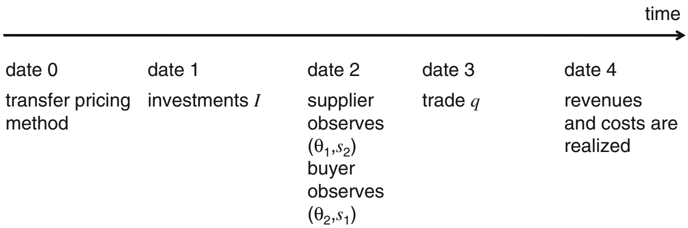

Fig. 1 Time line

powered incentives encourage internal trade when divisions bargain over trade under asymmetric information. Dutta and Reichelstein (2010) demonstrate how to alleviate a dynamic hold-up problem with a cost-based transfer price that includes a capital charge rate based on the book value of historic investment costs.[12]

The remainder of this paper is organized as follows. Section 2 introduces the basic set-up and the centralized transfer pricing methods and characterizes their properties. Section 3 provides a performance comparison of these methods. In Section 4, we analyze the performance of reported standard-cost transfer pricing. Section 5 concludes our paper. All proofs are outlined in the Appendix.

2 The model

2.1 Set-up

We consider a decentralized firm that consists of two divisions. Division 1 (the supplier) produces a specialized intermediate good and transfers it to Division 2 (the buyer). The buyer processes the intermediate good into a final product and sells it to the external market. The supplier can reduce the production costs by undertaking specific investments—for instance, installing more efficient equipment. The buyer can enhance (net) revenues through investments—for example, promoting sales for the final product. These investment decisions must be made upfront, when costs and revenues are still uncertain. Figure 1 depicts the sequence of events.

At date 0, the central office specifies the particular transfer pricing method. We will discuss the various methods in more detail later. At date 1, the supplier undertakes the specific investment $I_1 \in [0, \bar{I}_1]$ and, similarly, the buyer chooses the investment level $I_2 \in [0, \bar{I}_2]$. Investments generate divisional fixed costs $w_1(I_1)$ or $w_2(I_2)$ respectively. Investment costs are increasing and strictly convex, $w_i'(I_i) > 0$

Footnote 11 continued
prices become more favorable if the cost uncertainty increases because negotiated transfer prices improve risk sharing.

[12] Our study is also related to agency-theoretic studies about the effectiveness of different transfer pricing methods (e.g., Harris et al. 1982; Amershi and Cheng 1990; Vaysman 1996). Wagenhofer (1994) compares cost-based versus negotiated transfer pricing with and without communication. Dikolli and Vaysman (2006) find that cost-based transfer pricing dominates negotiated transfer pricing if the firm's information technology is sufficiently fine.

and $w_i''(I_i) > 0$ for $i = 1, 2$. Each division observes the other division's investment level.

At date 2, the supplier observes the realization of a random variable θ_1 that parameterizes the cost of the intermediate product, while the buyer makes only an imperfect observation of θ_1 in that he observes a parameter s_1. We assume that the parameter θ_1 equals $s_1+\eta_1$ where η_1 is an additive noise term with $E[\eta_1] = 0$ and $Cov[s_1, \eta_1] = 0$. There is symmetric cost information if $Var[\eta_1] = 0$ or, equivalently, $Var[\theta_1] = Var[s_1]$. The buyer has no cost information if $Var[s_1] = 0$. A greater variance $Var[s_1]$ indicates, ceteris paribus, that the buyer has better cost information. Analogously, the buyer observes a parameter θ_2 that parameterizes his revenues, while the supplier makes only an imperfect observation s_2, with $\theta_2 = s_2 + \eta_2$, s_2 and η_2 independently distributed, and $E[\eta_2] = 0$. The random variables θ_1 and θ_2 are distributed independently.

Throughout our analysis we study a pull system under which the quantity produced by the seller is dictated by the buyer's demand. That is, the buyer orders a quantity q at date 3 that must be delivered by the supplier. For simplicity, we assume that the buyer transforms one unit of the intermediate product into one unit of the final product. Finally, at date 4, revenues and production costs are realized. Profits are calculated according to the transfer pricing rule. Since the state variables, signals, and investment levels cannot be verified by the central office, the transfer pricing rules cannot be contingent on $(\theta, s, I) = (\theta_1, \theta_2, s_1, s_2, I_1, I_2)$.[13]

The supplier's cost is $c(\theta_1, I_1)q = (\theta_1 - yI_1)q$, where y denotes the productivity of investment I_1 and q is the quantity of the intermediate product. We denote the buyer's revenue by $R(q, \theta_2, I_2) = r(q, \theta_2) + xI_2q$, where x is the productivity of investment I_2 and q is the quantity of the final product. We assume that marginal revenues are positive, decreasing, and convex in q, $r_q(\cdot) > 0$, $r_{qq}(\cdot) < 0$, and $r_{qqq}(\cdot) \geq 0$. Some of our results require the additional assumptions that demand is linear and investment costs are quadratic,

$$R(q, \theta_2, I_2) = p(q, \theta_2, I_2)q = \left(\theta_2 + xI_2 - \frac{\beta}{2}q\right)q \quad \text{and} \quad w_i(I_i) = \frac{I_i^2}{2},$$

where $p(\cdot)$ denotes the price per unit. When our results depend on this *linear-quadratic setting*, this will be explicitly noted. In the first-best situation, the risk-neutral central office determines investment and quantity decisions so that the expected firm-wide profit is maximized

$$E\left[\Pi^{FB}\right] = \max_{(q(\theta,I),I)} E[R(q(\theta, I), \theta_2, I_2) - c(\theta_1, I_1)q(\theta, I)] - \sum_{i=1}^{2} w_i(I_i).$$

Assuming interior solutions, the first-best solution is characterized by $R_q(q, \theta_2, I_2) = c(\theta_1, I_1)$, $yE[q(\cdot)] = w_1'(I_1)$, and $xE[q(\cdot)] = w_2'(I_2)$.

In the linear-quadratic setting, the expected firm-wide profit $E[\Pi^{FB}]$ can be expressed as:

[13] This assumption may be understood as a shortcut to a setting where the variables R, C, w_i are verifiable, subject to the realizations of white noise variables. Our results are unaffected by this alternative model formulation.

$$E[\Pi^{FB}] = \frac{E\,[\theta_2 - \theta_1]^2}{2(\beta - x^2 - y^2)} + \frac{Var[\theta_2] + Var[\theta_1]}{2\beta} = H^{FB} + \frac{Var[\theta_2] + Var[\theta_1]}{2\beta}.$$

Here, expression H^{FB} reflects the maximum expected firm-wide profit that would be attained if the firm was to ignore the information about the realized state θ at the trading stage. Expression $(Var[\theta_2] + Var[\theta_1])/2\beta$ measures the flexibility gain that can be achieved by adjusting the quantity to the state θ.

In the following sections, we compare the first-best solution to a setting in which each division is run by a risk-neutral manager who seeks to maximize the expected profit of his division. Given a transfer price t, the divisions' contribution margins are $M_1(\cdot) = (t - c(\theta_1, I_1))q$ and $M_2(\cdot) = R(q, \theta_2, I_2) - tq$. The alternative transfer pricing methods examined in this paper differ in the trading and investment incentives that they provide.

2.2 Centralized transfer pricing methods

Throughout our analysis, we investigate four cost-based transfer pricing methods that are frequently discussed by practitioners and in various textbooks.[14] In this subsection, we introduce the first three methods. These transfer pricing schemes can be regarded as centralized because the central office considerably controls the pricing rule or even the transfer price itself. In Section 4, we introduce the decentralized transfer pricing method (reported standard-cost transfer pricing).

The three centralized methods differ in their use of accounting information. According to Anthony and Govindarajan (2007), the usual basis for transfer prices is standard costs. If standard costs are used, the transfer price is determined ex ante, that is, before the investment and trade decisions are made. On the contrary, if actual costs are used, the transfer price is determined after trade has taken place and costs have been realized. At date 0, the central office announces a markup rule over the supplier's marginal actual costs. Such markup rules may be conditioned on the buyer's revenues or not. We consider both cases.

2.2.1 Centralized standard-cost transfer pricing (CSC)

Under this method, the central office uses its ex ante expectations to determine a fixed transfer price t at date 0. Since the divisions' contribution margins are given by

$$M_1(\cdot) = (t - c(\theta_1, I_1))q \quad \text{and} \quad M_2(\cdot) = R(q, \theta_2, I_2) - tq,$$

the buyer does not have an incentive to use his cost information s_1 at the trading stage. Furthermore, each division is residual claimant of the return from its investments (given the ex post traded quantity).

Using backward induction, we obtain the following trade and investment decisions: the buyer maximizes his divisional contribution margin by ordering a quantity $q(\theta_2, I_2, t)$ so that the marginal revenue equals the transfer price,

[14] A summary of the four alternative transfer pricing methods considered in this paper is provided in Table 1 of Appendix 1.

$$R_q(q, \theta_2, I_2) = t. \tag{1}$$

Consistent with textbook statements, trade is ex post inefficient because centralized standard-cost transfer prices do not properly reflect actual cost information (for example, Zimmerman 2006). Trade is efficient only if the supplier's costs are deterministic or, by coincidence, actual marginal costs equal the transfer price.

Taking the trade decision into account, each division invests so that its expected divisional profit is maximized,

$$\max_{I_i}\{ E[M_i(q(\theta_2, I_2, t), \theta, I)] - w_i(I_i)\}.$$

Textbooks point out that a major advantage of this method is that it provides incentives for divisions to control their costs (for example, Atkinson et al. 2001; Belkaoui 1992). In fact, using the Envelope Theorem we find that each division invests so that the marginal return from investment equals marginal investment costs,

$$E\left[\frac{\partial M_1(\cdot)}{\partial I_1}\right] = yE[q(\cdot)] = w_1'(I_1) \quad \text{and} \quad E\left[\frac{\partial M_2(\cdot)}{\partial I_2}\right] = xE[q(\cdot)] = w_2'(I_2). \tag{2}$$

Since each division receives the entire marginal return from its investment, centralized standard-cost pricing triggers efficient investments (given expected trade). The investment levels depend directly on the expected traded quantity and only indirectly on the transfer price. The investment decisions constitute a unique pure-strategy Nash equilibrium because I_2 does not depend on I_1 and the two investment problems are well-behaved. The investment levels are first-best only if the expected traded quantity equals the expected first-best quantity.

At date 0, the central office sets the transfer price in order to maximize the expected firm-wide profit, taking the division's trade and investment decisions, (1) and (2), into account,

$$\max_t \left\{ E[M(q(\theta_2, I_2, t), \theta, I)] - \sum_{i=1}^{2} w_i(I_i) \right\}.$$

We obtain the following first order condition

$$E\left[M_q(\cdot)\frac{\partial q(\cdot)}{\partial t}\right] = E\left[(t - c(\cdot))\frac{\partial q(\cdot)}{\partial t}\right] = 0 \text{ or, equivalently, } t = E[c(\theta_1, I_1)]$$

(note that $R_q(\cdot) = t, \partial q(\cdot)/\partial t = 1/r_{qq}(q(\theta_2, I_2, t), \theta_2)$, and ($\theta_1$, θ_2) are independently distributed). Since the supplier's investment level I_1 is efficient (given expected trade), the optimal transfer price equals expected marginal costs at the efficient investment level, $t = E[c(\theta_1, I_1^{eff})]$.[15] This avoids a double marginalization problem in expectation. The transfer pricing rule coincides with the well-known Hirshleifer

[15] The efficient investment level I_1^{eff} need not coincide with the first-best investment level. Since the optimal transfer price equals expected marginal costs, the expected traded quantity equals the expected first-best quantity if $r_q(\cdot)$ is linear in q. In that case, the efficient investment level I_1^{eff} and the buyer's investment level equal the first-best values. If $r_q(\cdot)$ is strictly convex in q, $r_{qqq}(\cdot) > 0$, the expected traded quantity is greater than the expected first-best quantity, as are the investment levels.

(1956) prescription if the supplier's costs are deterministic and cannot be influenced by the investment. Our analysis demonstrates that most of the tensions for centralized standard-cost pricing (for example, inefficient trade, efficient investments) that arise in Baldenius' (2000) binary trade setting carry over to our continuous trade setting. However, the structure of our optimal transfer price is different from Baldenius' (2000) optimal transfer price that includes a positive markup. The reason for the difference is that the traded quantities are continuous in our model, while trade is binary in Baldenius' set-up.[16]

Overall, centralized standard-cost pricing induces ex post inefficient trade incentives while efficient investment incentives (given the expected traded quantity). The effectiveness of this method does not depend on the buyer's cost information s_1 or the supplier's revenue information s_2. As a straightforward conclusion, centralized standard-cost pricing induces the first-best solution if there is no ex ante cost uncertainty.[17]

2.2.2 *Transfer prices based on actual costs*

Under actual cost-based transfer pricing, the intra-company price is determined when costs have been realized after trade has taken place. The transfer price is set equal to actual marginal costs plus a markup $m(\cdot)$, $t(\cdot) = c(\theta_1, I_1) + m(\cdot)$. The markup $m(\cdot)$ is specified by the central office at date 0. At the trading stage, the buyer estimates actual costs using his cost information s_1. Accordingly, marginal revenue equals the expected transfer price given the cost information s_1, $R_q(q, \theta_2, I_2) = E[t(\cdot)|s_1]$. Thus, actual cost information enters the trade decision properly only if there is symmetric cost information. Consistently, practitioners point out that actual cost-based transfer pricing has deficits if the buyer has poor cost information when deciding upon trade (Eccles 1983, Feinschreiber 2004). In the following, we consider two different markup rules $m(\cdot)$.

2.2.2.1 Cost-plus transfer pricing (AC+) First, we investigate additive markups, $m = \delta$, which are discussed in several textbooks (for example, Solomons 1965). Under this method, the divisions' contribution margins are given by:

$$M_1(\cdot) = \delta q \quad \text{and} \quad M_2(\cdot) = R(\cdot) - (c(\cdot) + \delta)q.$$

If the central office does not apply a markup, $\delta = 0$, the buyer receives the firm-wide contribution margin, while the supplier's contribution margin equals zero. Accordingly, the buyer has efficient trade incentives given his cost information s_1.

[16] Like us, Baldenius (2000) assumes that θ_1 and θ_2 are independently distributed. If the random variables are not independently distributed, our optimal transfer price also includes a markup, $t = E\left[c(\cdot)r_{qq}^{-1}(\cdot)\right] \Big/ E\left[r_{qq}^{-1}(\cdot)\right] = E[c(\cdot)] + Cov\left[c(\cdot), r_{qq}^{-1}(\cdot)\right] \Big/ E\left[r_{qq}^{-1}(\cdot)\right]$.

[17] One might argue that there is no need for decentralization if costs are deterministic. For the linear-quadratic setting, Pfeiffer and Wagner (2007) show that centralized standard-cost transfer pricing strictly dominates the centralized solution if costs are deterministic and revenues are uncertain.

However, the supplier does not have an incentive to invest, $I_1 = 0$. This is consistent with observations in textbooks that state that divisions have no incentive to control their costs if their costs are reimbursed exactly (for example, Atkinson et al. 2001; Belkaoui 1992). A positive markup, $\delta > 0$, is needed to trigger investment incentives for the supplier. In fact, the buyer orders a quantity so that marginal revenues equal expected marginal costs plus the markup given his cost information s_1,

$$R_q(q, \theta_2, I_2) = E[t(\cdot)|s_1] = E[c(\cdot)|s_1] + \delta. \tag{3}$$

Without loss of generality we simplify our notation and write $t(\cdot)$ instead of $E[t(\cdot)|s_1]$. Taking the trade decision $q(\theta_2, I_2, t)$ into account, each division maximizes its expected divisional profit,

$$\max_{I_1}\{\delta E[q(\cdot)] - w_1(\cdot)\} \quad \text{and} \quad \max_{I_2}\{E[M(\cdot) - \delta q(\cdot)] - w_2(\cdot)\}.$$

Applying the Envelope Theorem, the investment decisions are characterized by the following first order conditions ($\partial q(\cdot)/\partial t = 1/r_{qq}(\cdot)$, and $\partial t(\cdot)/\partial I_1 = -y$)

$$\delta E\left[\frac{\partial q(\cdot)}{\partial t}\frac{\partial t(\cdot)}{\partial I_1}\right] = -\delta E\left[\frac{y}{r_{qq}(\cdot)}\right] = w_1'(I_1) \quad \text{and} \quad E\left[\frac{\partial M_2(\cdot)}{\partial I_2}\right] = xE[q(\cdot)] = w_2'(\cdot). \tag{4}$$

That is, the supplier's investment decision depends on the marginal impact of his investment I_1 on the expected trade level that equals marginal investment costs. In contrast, the buyer receives the entire return from his investment and invests so that the marginal return from investment equals marginal investment costs. Note that the supplier's investment $I_1(\delta)$ depends directly on the markup, while the buyer's investment I_2 depends only indirectly on the markup via the trade decision $q(\cdot, \delta)$.

Anticipating the subsequent trading and investment decisions, (3) and (4), the central office sets the markup to maximize the expected firm-wide profit

$$\max_{\delta}\{E[M(q(\theta_2, I_2, t(I_1(\delta), \delta)), \theta, I_1(\delta), I_2)] - w_1(I_1(\delta)) - w_2(I_2)\}.$$

Before we characterize the optimal solution, recall that any markup $\delta > 0$ has a negative impact on trade efficiency. Nevertheless, a positive markup raises the supplier's investment, while markups have no direct effect on the buyer's investment. Applying the Envelope Theorem, we find that the optimal markup balances the expected trade distortions against the expected improved supplier investment incentives. The markup is determined so that the expected marginal impact on trade equals the expected marginal impact on the supplier's investment

$$-\delta E\left[\frac{\partial q(\cdot)}{\partial t}\frac{\partial t(\cdot)}{\partial \delta}\right] = yE[q(\cdot)] \cdot \frac{\partial I_1(\cdot)}{\partial \delta}.$$

The optimal markup is strictly positive if the supplier's investment has a positive impact on the production costs, $y > 0$. Our analysis complements Sahay's (2003) analysis in that we analyze bilateral investments, introduce the resolution of uncertainty at the trading stage, and depart from the assumption of symmetric information.

Whenever there is asymmetric cost information at the trading stage, $Var[s_1] < Var[\theta_1]$, cost-plus transfer pricing induces inefficient trade and investment incentives. Under this method, the first-best solution can be achieved only if (a) the buyer has perfect cost information and (b) the supplier cannot influence his cost with his investment. The effectiveness of cost-plus transfer pricing does not depend on the supplier's revenue information s_2 at the trading stage.

2.2.2.2 Contribution-margin transfer pricing (ACM) In contrast to the method outlined above, many firms use revenue information to determine the markup over the actual unit variable cost. Practitioners sometimes propose a markup that assigns a share γ of the firm-wide contribution margin to the supplier, $m(\cdot)q = \gamma(R(\cdot) - c(\cdot)q)$ and $\gamma \in [0, 1]$.[18]

Since each division receives a share of the firm-wide contribution margin,

$$M_1(\cdot) = \gamma(R(\cdot) - c(\cdot)q) \quad \text{and} \quad M_2(\cdot) = (1-\gamma)(R(\cdot) - c(\cdot)q),$$

the division's contribution margins are split in a similar manner as under negotiated transfer pricing with symmetric information.[19] However, both approaches differ in that under negotiated transfer pricing the divisions simultaneously bargain over the quantity and intra-company price while under contribution-margin transfer pricing the buyer dictates the quantity and the transfer pricing rule is specified by the central office. Furthermore, under negotiated transfer pricing the sharing parameter reflects the division's individual bargaining power, while under contribution-margin transfer pricing the central office determines the sharing parameter γ as part of the markup rule.

As a major advantage of this approach, Feinschreiber (2004) notes that the divisions tend to cooperate because each division's contribution margin is proportional to that of the entire firm. In fact, taking into account that there is asymmetric cost information at the trading stage, we find that trade is ex post efficient with respect to the buyer's cost information s_1,[20]

$$R_q(q, \theta_2, I_2) = E[c(\cdot)|s_1]. \tag{5}$$

[18] The contribution margin approach has widely entered transfer pricing practice (e.g., Moses 2007). It was first applied in the DuPont case (E.I. DuPont de Nemours & Co. v. United States, 608 F.2d 445 (Ct. Cl. 1979)) to test whether DuPont's Swiss subsidiary benefited from profit shifting. The test consists of a computation of whether each partner receives roughly the same profit-over-variable-cost ratio (Berry ratio). Feinschreiber (2004, p. 23) calls this the equal contribution margin approach and describes several alternatives to determine the sharing parameter in managerial accounting practice.

[19] For negotiated transfer prices under symmetric information see, for instance, Baldenius et al. (1999). However, negotiated transfer prices do not lead to contribution margin sharing under asymmetric information, as pointed out, for instance, by Baldenius (2000).

[20] Note that since the two divisions have perfectly aligned interests after the investments are undertaken, contribution-margin transfer pricing also has the advantage that the supplier has an incentive to voluntarily share his perfect cost information with the partially-informed buyer if communication is not blocked, as assumed in our analysis.

Taking the trade decision into account, each division undertakes its investment decision so that its expected divisional profit is maximized, $\max_{I_i}\{E[M_i(q(\theta_2, I_2, t), \theta, I)] - w_i(I_i)\}$. Applying the Envelope Theorem shows that each division's investment decision is given by

$$E\left[\frac{\partial M_1(\cdot)}{\partial I_1}\right] = \gamma y E[q(\cdot)] = w_1'(I_1) \quad \text{and} \quad E\left[\frac{\partial M_2(\cdot)}{\partial I_2}\right] = (1-\gamma)xE[q(\cdot)] = w_2'(I_2). \tag{6}$$

Since each division receives only a share of the return from its investments and has to bear the investment costs, a bilateral hold-up problem arises. Accordingly, Feinschreiber (2004) points out that "a division that reduces its costs is not entitled to the entire benefit, and must share this benefit with other divisions" (p. 24). The first order conditions constitute a unique pure-strategy Nash equilibrium (Baldenius et al. 1999, Lemma 4).

Taking the trade and investment decisions (5) and (6) into account, the central office sets the sharing parameter γ in order to maximize the expected firm-wide profit

$$\max_{\gamma}\left\{E[M(q(\theta_2, s_1, I(\gamma)), \theta, I(\gamma))] - \sum_{i=1}^{2} w_i(I_i(\gamma))\right\}.$$

Since the sharing rule affects the investment decisions directly but the trading decision only indirectly, the optimal sharing rule balances the impact of the individual investment decisions. Applying the Envelope Theorem, we can rewrite the first order condition as follows (using $\partial M(\cdot)/\partial I_1(\cdot) = yq(\cdot), \partial M(\cdot)/\partial I_2(\cdot) = xq(\cdot)$, and (6))

$$\sum_{i=1}^{2}\left(E\left[\frac{\partial M(\cdot)}{\partial I_i}\right] - w_i'(\cdot)\right)\frac{\partial I_i(\cdot)}{\partial \gamma} = \left((1-\gamma)y \cdot \frac{\partial I_1(\cdot)}{\partial \gamma} + \gamma x \cdot \frac{\partial I_2(\cdot)}{\partial \gamma}\right)E[q(\cdot)] = 0.$$

Hence, the optimal sharing parameter must be set according to its impact on the individual investments

$$(1-\gamma)y \cdot \frac{\partial I_1(\cdot)}{\partial \gamma} = -\gamma x \cdot \frac{\partial I_2(\cdot)}{\partial \gamma}.$$

For instance, one division receives the entire contribution margin, $\gamma = 0$ (=1), if the other division's investment has no impact on the contribution margin, $y = 0$ ($x = 0$). In that case, the optimal sharing rule is consistent with the entire benefit approach that is sometimes proposed by practitioners (for example, Feinschreiber 2004).[21]

In summary, contribution-margin pricing induces ex post efficient trade (given the buyer's cost information) but also induces a bilateral hold-up problem.[22]

[21] If both divisions have the same productivity of investment, $x = y$ and $w_1(I_1) = w_2(I_2)$, the central office sets $\gamma = 1/2$. This is consistent with the equal contribution margin approach (Feinschreiber 2004, p. 23).

[22] These tensions also arise with respect to negotiated transfer pricing under symmetric information (see, for instance, Baldenius et al. 1999).

Accordingly, the first-best solution can be achieved only if (a) the buyer has perfect cost information and (b) there is one-sided investment. The effectiveness of contribution-margin pricing does not depend on the supplier's revenue information s_2.

3 Performance comparisons of the centralized transfer pricing methods

This section compares the effectiveness of the three centralized transfer pricing methods. Contribution-margin pricing is the more elaborate of the two actual cost-based schemes in that the markup is conditioned on the buyer's revenues. In a first step, we investigate whether the central office can indeed improve the effectiveness of actual cost-based transfer pricing by using contribution-margin pricing instead of cost-plus transfer pricing. In a second step, we ask if there are circumstances under which centralized standard-cost pricing dominates the other two methods, although it is the least elaborate of the three.

3.1 Contribution-margin versus cost-plus transfer pricing

Since contribution-margin pricing induces efficient trade, it dominates cost-plus transfer pricing if it induces at least the same investment levels I_1 and I_2. To compare the investment decisions of the two methods, we investigate the trade decision that influences the investment decisions.

In the Appendix, we show that the relative loss in trade volume $q^{AC+}(\cdot)$ under cost-plus transfer pricing as compared with the trade volume $q^{ACM}(\cdot)$ under contribution-margin pricing is given by

$$q^{ACM}(\cdot) \geq q^{AC+}(\cdot) - \frac{\delta}{r_{qq}(q^{AC+}(\cdot), \cdot)} \quad \text{for all } \theta_2, s_1, I. \tag{7}$$

That is, for any given investments I the relative loss in the trade volume depends on the curvature of the marginal revenue $r_{qq}(\cdot)$ and the markup δ. The relative loss increases if the central office applies a larger markup δ. (Recall that $r_{qq}(\cdot) < 0$ and $r_{qqq}(\cdot) \geq 0$.)

The central office can ensure that the buyer chooses the identical investment level under both methods by setting the sharing parameter γ such that $(1-\gamma)xE[q^{ACM}(\cdot)] = xE[q^{AC+}(\cdot)]$. Inequality (7) shows that contribution-margin pricing provides at least the same investment incentives for the supplier as cost-plus transfer pricing,

$$\begin{aligned} w_1'(I_1^{ACM}) &= \gamma y E[q^{ACM}(\cdot)] = y(E[q^{ACM}(\cdot)] - E[q^{AC+}(\cdot)]) \geq -\delta y E\left[\frac{1}{r_{qq}(q^{AC+}(\cdot), \cdot)}\right] \\ &= w_1'\left(I_1^{AC+}\right). \end{aligned}$$

Combining these findings, we obtain the following result.[23]

[23] Technically, we use a similar approach for our proof as Baldenius et al. (1999, Propositions 1 and 2).

Proposition 1 *Contribution-margin transfer pricing dominates cost-plus transfer pricing.*

Our finding complements Sahay's (2003, Proposition 1) finding that cost-plus transfer pricing dominates an entire class of actual cost-based transfer pricing methods with markups that are not conditioned on the buyer's revenues. Proposition 1 is also related to Baldenius et al. (1999, Propositions 4 and 5), who show for each of the two one-sided investment cases that negotiated transfer pricing (which technically equals contribution-margin transfer pricing with exogenous γ) dominates reported standard-cost transfer pricing under constrained cost reporting (which technically equals cost-plus transfer pricing). Re-interpreting Proposition 1 shows that negotiated transfer pricing dominates constrained reported standard-cost transfer pricing also for the bilateral investment case if the bargaining power is distributed as outlined in Proposition 1.

3.2 Contribution-margin versus centralized standard-cost transfer pricing

Having identified contribution-margin pricing as being superior to cost-plus transfer pricing, we now compare contribution-margin transfer pricing with centralized standard-cost transfer pricing. The two methods differ significantly in that, under centralized standard-cost pricing the buyer neglects his cost information s_1 at the trading stage, while under contribution-margin pricing there is a flexibility advantage as the buyer bases his trade decision on his cost information.

Centralized standard-cost pricing dominates contribution-margin pricing if the buyer has no cost information, $Var[s_1] = 0$, because under centralized standard-cost pricing investments are efficient, while contribution-margin pricing induces a bilateral hold-up problem. We conjecture that this result is reversed and contribution-margin pricing dominates centralized standard-cost pricing if the buyer receives sufficient cost information and ex ante cost information becomes important as cost uncertainty increases.

To formalize this intuition, we show that, ceteris paribus, the expected firm-wide profit under contribution-margin pricing increases if the buyer obtains better cost information s_1, while under centralized standard-cost pricing the expected firm-wide profit is not altered. As previously outlined, the buyer receives better information if, ceteris paribus, the variance $Var[s_1]$ increases.

First, we consider centralized standard-cost pricing. Recall that the trade and investment decisions depend solely on the ex ante specified transfer price that is calculated as expected production costs given the supplier's efficient investment level, $t = E[c(\theta_1, I_1^{eff})] = E[\theta_1 - yI_1^{eff}]$. Since the expected value $E[\theta_1]$ does not change if the buyer has better information, the optimal transfer price and, thus, the trade and investment decisions, do not change. Accordingly, as conjectured, the expected firm-wide profit

$$E[R(q(\theta_2, I, t), \theta_2, I_2) - (s_1 + \eta_1 - yI_1)q(\theta_2, I, t)] - \sum_{i=1}^{2} w_i(I_i)$$

ceteris paribus does not change with $Var[s_1]$.

Under contribution-margin transfer pricing, the quantity $q(\cdot)$ demanded by the buyer depends on the cost information s_1, $R_q(q, \theta_2, I_2) = E[c(\cdot)|s_1]$. Since the buyer receives a share of the firm-wide contribution margin, he increases the expected firm-wide contribution margin if he receives better information.[24]

We now turn our attention to the investment decisions that are given by the conditions $\gamma y E[q(\cdot)] = w_1'(I_1)$ and $(1-\gamma)xE[q(\cdot)] = w_2'(I_2)$. For any fixed sharing parameter γ, the investments depend solely on the expected traded quantity. Since the marginal revenue is convex in q, $r_{qqq}(\cdot) \geq 0$, the quantity is convex in s_1 for fixed I (recall that $R_q(\cdot) = s_1 + \eta_1 - yI_1$). Thus, using Jensen's inequality, the expected quantity increases in $Var[s_1]$ for fixed I. Accordingly, both divisions' investment levels increase in $Var[s_1]$. Since the divisions underinvest, it follows that the expected firm-wide profit is strictly increasing in $Var[s_1]$. As a final step, the central office can set another sharing parameter γ to increase the expected firm-wide profit. In sum, we obtain the following result.

Proposition 2 *Contribution-margin transfer pricing dominates centralized standard-cost transfer pricing if and only if Var[s_1] exceeds a cut-off level T_1, that is, Var[s_1] $\geq T_1$.*

Notice that the variance $Var[s_1]$ is bounded above by the ex ante cost uncertainty $Var[\theta_1]$. A necessary condition for contribution-margin pricing to outperform centralized standard-cost pricing is that the ex ante cost uncertainty is sufficiently large.

In the linear-quadratic setting, the expected firm-wide profit under centralized standard-cost pricing, $E[\Pi^{CSC}]$, and under contribution-margin pricing, $E[\Pi^{ACM}]$, can be stated as follows:

$$E[\Pi^{CSC}] = H^{FB} + \frac{Var[\theta_2]}{2\beta} \quad \text{and} \quad E[\Pi^{ACM}] = \alpha^{ACM} H^{FB} + \frac{Var[\theta_2] + Var[s_1]}{2\beta} \tag{8}$$

with $\alpha^{ACM} < 1$.[25] The value H^{FB} measures the expected firm-wide profit in the first-best solution if the central office ignores any information about θ at the trading stage. Analogously, $\alpha^{ACM} H^{FB}$ measures the expected firm-wide profit for the contribution-margin pricing method if the trade decision is not based on any cost information. The expressions $Var[\theta_2]/2\beta$ and $(Var[\theta_1] + Var[s_1])/2\beta$ measure the flexibility gains under either transfer pricing method because the buyer can use his information (θ_2, s_1) at the trading stage. As shown, the expected firm-wide profit $E[\Pi^{ACM}]$ increases in $Var[s_1]$, while the expected firm-wide profit $E[\Pi^{CSC}]$ is constant in $Var[s_1]$. Comparing the expected firm-wide profits, we obtain the following Corollary 1. This result also enters Fig. 2 below where we illustrate the relative superiority of our alternative transfer pricing methods for the linear-quadratic setting.

[24] In the Appendix, we prove this claim by using Jensen's inequality and showing that the firm-wide profit margin is convex in s_1.

[25] Recall that if there is no ex ante cost uncertainty, $Var[\theta_1] = 0$, centralized standard-cost pricing induces the first-best solution, but not contribution-margin pricing. Thus, we can conclude that $\alpha^{ACM} < 1$.

Corollary 1 *In the linear-quadratic setting, contribution-margin transfer pricing dominates centralized standard-cost transfer pricing if and only if*

$$Var[s_1] \geq T_1 = 2\beta H^{FB}(1 - \alpha^{ACM}).$$

To sum up, in contrast to Proposition 1, Proposition 2 shows that invoking less accounting information into the transfer pricing method may be advantageous. Establishing the more elaborated actual cost-based transfer pricing system is only beneficial if the buyer is sufficiently well informed and cost information becomes important in that the ex ante cost uncertainty is sufficiently large.

3.3 Cost-plus versus centralized standard-cost transfer pricing

Proposition 1 demonstrated that contribution-margin transfer pricing dominates cost-plus transfer pricing. However, in order to use the contribution-margin method the firm must condition the markup on the buyer's revenues, which in some cases may prove impossible in practice—for instance, revenues can be manipulated or it might not be possible to allocate them properly to a particular division or product due to synergies.

Taking this into account, we now compare centralized standard-cost pricing and cost-plus transfer pricing. Although the latter method leads to underinvestment and inefficient trade, cost-plus transfer pricing incorporates the buyer's cost information into the trade decision. Similar to Proposition 2, we thus conjecture that cost-plus transfer pricing dominates centralized standard-cost pricing if the variance $Var[s_1]$ exceeds a cut-off level $\hat{T}_1$.

As before, we prove our intuition by verifying that under cost-plus transfer pricing the expected firm-wide profit increases with the variance $Var[s_1]$. Accordingly, we show in a first step that for fixed investments and markup, (I, δ), the expected firm-wide contribution margin increases in $Var[s_1]$.[26] In a second step, we turn our attention to the investment decisions that are given by $\delta E[(\partial q(\cdot)/\partial t) \cdot (\partial t(\cdot)/\partial I_1)] = -\delta y E[1/r_{qq}(\cdot)] = w_1'(I_1)$ and $xE[q(\cdot)] = w_2'(I_2)$. If $-1/r_{qq}(\cdot)$ is convex in q, the investments I are convex in s_1 and the investment levels increase strictly in $Var[s_1]$. Since cost-plus transfer pricing induces an underinvestment problem, we can conclude that the expected firm-wide profit increases in $Var[s_1]$ for any given markup. Finally, the central office can set another markup to increase the expected firm-wide profit. The following proposition summarizes our finding.[27]

Proposition 3 *Assume $-1/r_{qq}(\cdot)$ is convex in q. Cost-plus transfer pricing then dominates centralized standard-cost transfer pricing if and only if $Var[s_1]$ exceeds a cut-off level $\hat{T}_1$ which satisfies $\hat{T}_1 \geq T_1$.*

[26] Technically, we show that for fixed (I, δ) the firm-wide contribution margin is convex in s_1. Applying Jensen's inequality proves the first step.

[27] Lengsfeld et al. (2006) prove this result for the linear-quadratic setting with symmetric information.

Notice, for instance, that the linear-quadratic setting satisfies the assumption of Proposition 3.[28] Overall, Proposition 3 shows that our previous finding remains stable, namely, that the actual cost-based transfer price system is beneficial in a highly uncertain cost environment if the buyer has sufficient cost information at the trading stage.

4 Performance comparison with reported standard-cost transfer pricing (RSC)

According to our previous analysis, contribution-margin pricing performs poorly if $Var[s_1]$ is low. Since $Var[s_1] \leq Var[\theta_1]$, such a situation can arise if (a) either the ex ante cost uncertainty $Var[\theta_1]$ is low, or (b) the ex ante cost uncertainty is high and the buyer has insufficient cost information. In the first case, centralized standard-cost pricing performs well. This method even induces the first-best solution if costs are deterministic. In the second case, neither centralized standard-cost pricing nor contribution-margin pricing perform well. In such a situation, decentralization might be beneficial. The central office may base the transfer price on the supplier's cost report to exploit decentralized cost information (Anthony and Govindarajan 2007).

Similar to Baldenius et al. (1999) and Baldenius (2000), we assume that the transfer price is based solely on the supplier's undisputed cost report. Given the supplier's private information (θ_1, s_2, I), the supplier effectively quotes a monopoly price, taking the buyer's expected trade decision into account, $t(\theta_1, s_2, I) \in \arg\max\{(t - c(\theta_1, I_1))E[q(\theta_2, I_2, t)|s_2]\}$. Accordingly, the transfer price

$$t(\theta_1, s_2, I) = c(\theta_1, I_1) - \frac{E[q(\cdot)|s_2]}{E\left[\frac{1}{r_{qq}(\cdot)}|s_2\right]},$$

has a cost-plus structure where the markup reflects the supplier's monopoly power (Zimmerman 2006, p. 216).[29] Due to the double marginalization problem, reported standard-cost pricing leads to inefficient trade. Nevertheless, the trade decision entails actual cost information θ_1 because the transfer price is based on a monopoly price that reflects actual costs.

Since the supplier is the residual claimant of his cost-reducing investment, he invests efficiently, $yE[q(\cdot)] = w_1'(I_1)$, relative to the expected trading quantity. In contrast, the buyer invests inefficiently because the supplier can hold up the buyer's

[28] A sufficient (but not necessary) condition that ensures the convexity of $-1/r_{qq}(\cdot)$ is that the ratio $P(\cdot) = -r_{qqq}(\cdot)/r_{qq}(\cdot)$ increases, $P'(\cdot) \geq 0$. Note that $r_{qqq}(\cdot) \geq 0$ implies that the ratio $P(\cdot)$ is positive, $P(\cdot) \geq 0$. Since central office's utility function is represented by the firm-wide profit function $\Pi(\cdot)$, we can interpret the ratio $P(\cdot)$ as the absolute prudence measure for utility functions (Kimball 1990), $\Pi_{qq}(\cdot) = r_{qq}(\cdot)$ and $\Pi_{qqq}(\cdot) = r_{qqq}(\cdot)$, that is often used to derive comparative static insights in risky environments (e.g., Eeckhoudt et al. 1996).

[29] Our characterization of the transfer price is consistent with that in Baldenius et al. (1999) if the supplier has perfect revenue information.

investment by adjusting the transfer price, $E[(x - \partial t(\cdot)/\partial I_2)q(\cdot)] = w_2'(I_2)$. Since the hold-up term $\partial t(\cdot)/\partial I_2$ is a function of the investment decision I_2, non-concavities in the buyer's objective function may arise. Accordingly, the investment problem might not be well-behaved.[30]

For simplicity, we restrict our subsequent analysis to the linear-quadratic setting which results in the following outcomes:

$$t(\theta_1, s_2, I) = c(\theta_1, I_1) + \beta E[q(\cdot)|s_2] = \frac{\theta_1 + E[\theta_2|s_2] + yI_1 + xI_2}{2},$$

$$q(\cdot) = \frac{2\theta_2 - E[\theta_2|s_2] + xI_2 - c(\theta_1, I_1)}{2\beta}, yE[q(\cdot)] = w_1'(I_1) \text{ and } \frac{xE[q(\cdot)]}{2} = w_2'(I_2).$$

The expected firm-wide profit is given by

$$E[\Pi^{RSC}] = \alpha^{RSC} H^{FB} + \frac{4Var[\theta_2] - Var[s_2] + 3Var[\theta_1]}{8\beta}. \tag{9}$$

The expression $\alpha^{RSC} H^{FB}$ denotes the basic profit, $\alpha^{RSC} < 1$.[31] In contrast to our three centralized methods, the expected firm-wide profit depends on the supplier's revenue information s_2. The expected firm-wide profit decreases in $Var[s_2]$ because the supplier can misuse his information s_2 to extract rents from the buyer on the firm's expense. However, more essentially, the expected firm-wide profit increases with the ex ante cost uncertainty $Var[\theta_1]$.

4.1 Centralized standard-cost versus reported standard-cost transfer pricing

We first analyze under which circumstances reported standard-cost pricing outperforms centralized standard-cost pricing. Similar to Propositions 2 and 3, we might suspect that reported standard-cost pricing outperforms centralized standard-cost pricing if the ex ante cost uncertainty $Var[\theta_1]$ is sufficiently high.

Comparing the expected firm-wide profit of the two methods, (8) and (9), we find that reported standard-cost pricing dominates centralized standard-cost pricing if and only if the ex ante cost uncertainty $Var[\theta_1]$ exceeds the cut-off level T_2[32]

$$Var[\theta_1] \geq T_2 = \frac{8}{3}\beta H^{FB}(1 - \alpha^{RSC}) + \frac{Var[s_2]}{3}.$$

This result complements Baldenius (2000, Proposition 6), who analyzes a binary trade setting and finds that centralized standard-cost pricing always dominates reported standard-cost pricing for the one-sided supplier investment scenario.[33]

[30] As outlined in our previous version, we need conditions for the revenue function up to the fifth derivative to characterize a set of sufficient conditions for non-linear demand functions (see also Baldenius et al. 1999, for the symmetric information case).

[31] Since reported standard-cost pricing never induces the first-best solution, even when costs and revenues are deterministic, $Var[\theta_1] = Var[\theta_2] = 0$, we can conclude that $\alpha^{RSC} < 1$.

[32] See Lengsfeld et al. (2006, Proposition 2) for such a result under symmetric information.

[33] As previously mentioned, the reason for this result is that in the binary setting the maximum variance is below the cut-off value.

4.2 Contribution-margin versus reported standard-cost transfer pricing

We now compare reported standard-cost pricing with contribution-margin pricing. The two methods differ in that under contribution-margin pricing the trade decision is based on the buyer's cost information s_1, while reported standard-cost pricing conveys the actual cost information θ_1. Furthermore, under contribution-margin pricing the central office determines the markup, while under reported standard-cost pricing the markup reflects the supplier's monopoly power. Broadly stated, reported standard-cost pricing entails a flexibility advantage relative to contribution-margin pricing when the supplier has better cost information than the buyer. However, reported standard-cost pricing also entails a loss of control.

Comparing the expected firm-wide profits, (8) and (9), we find that contribution-margin pricing dominates reported standard-cost pricing if and only if

$$Var[s_1] \geq \frac{3}{4} Var[\theta_1] - T_3$$

where $\alpha^{ACM} > \alpha^{RSC}$ and $T_3 = 2\beta H^{FB}(\alpha^{ACM} - \alpha^{RSC}) + \frac{1}{4}Var[s_2] > 0.$[34] If there is symmetric cost information, $Var[s_1] = Var[\theta_1]$, contribution-margin pricing dominates because both methods are based on the same cost information, but the reported standard-cost pricing method entails a loss of control. This dominance vanishes if the ex ante cost uncertainty is high and the buyer has insufficient cost information.

4.3 Overall performance comparison

Figure 2 summarizes our findings and illustrates under which circumstances, in terms of the ex ante cost uncertainty $Var[\theta_1]$ and the buyer's cost information $Var[s_1]$, one particular method dominates the other two.

The horizontal axis, $Var[s_1] = 0$, represents the scenario in which the buyer has no cost information. The 45-degree line, $Var[s_1] = Var[\theta_1]$, corresponds to the symmetric information setting. Furthermore, the line $Var[s_1] = \frac{3}{4}Var[\theta_1] - T_3$ intersects with the crossing point of T_1 and T_2.

Formally, we obtain the following result:

Proposition 4 *In the linear-quadratic setting*

(i) *reported standard-cost transfer pricing dominates if the ex-ante cost uncertainty is sufficiently high and the buyer has insufficient cost information, that is, (a)* $Var[\theta_1] \geq T_2$, *and (b)* $\frac{3}{4}Var[\theta_1] \geq T_3 + Var[s_1]$,

[34] If the buyer has complete cost information, contribution-margin pricing and negotiated transfer pricing induce identical trading and investment decisions and the same expected firm-wide profit. For linear demand functions, Baldenius et al. (1999, Proposition 3) have shown that negotiated transfer pricing dominates reported standard-cost pricing if both divisions have symmetric information and the bargaining power is distributed equally. Since this result encompasses the case where costs and revenues are deterministic, $Var[\theta_1] = Var[\theta_2] = 0$, we can conclude that $\alpha^{ACM} > \alpha^{RSC}$ and, thus, $T_3 > 0$.

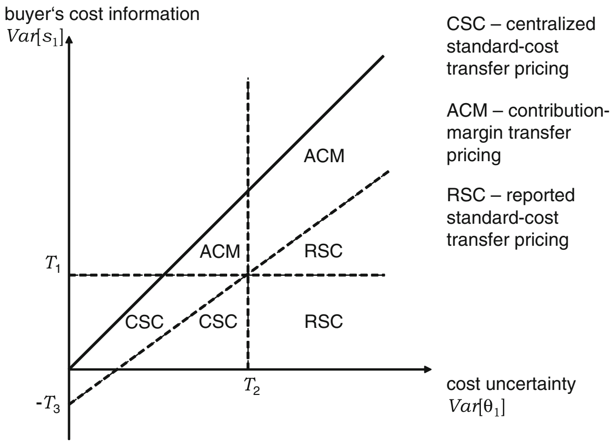

Fig. 2 Dominance of transfer pricing methods

(ii) *contribution-margin transfer pricing dominates if the ex-ante cost uncertainty is sufficiently high and the buyer has sufficient cost information, that is, (a)* $Var[s_1] \geq T_1$, *and (b)* $\frac{3}{4}Var[\theta_1] \leq T_3 + Var[s_1]$,

(iii) *otherwise, centralized standard-cost transfer pricing dominates, that is, (a)* $Var[s_1] \leq T_1$, *and (b)* $Var[\theta_1] \leq T_2$.

Finally, it is instructive to ask how our result changes if the central office is restricted using cost-plus transfer pricing rather than contribution-margin pricing, as assumed in Proposition 2. The expected firm-wide profit under cost-plus transfer pricing is given by

$$E[\Pi^{AC+}] = \alpha^{AC+}H^{FB} + \frac{Var[\theta_2] + Var[s_1]}{2\beta} \quad \text{with } \alpha^{RSC} < \alpha^{AC+} < \alpha^{ACM}.$$

Since $E[\Pi^{ACM}] = \alpha^{ACM}H^{FB} + (Var[\theta_2] + Var[s_1])/2\beta$, we have to replace α^{ACM} with $\alpha^{AC+}$to obtain a result similar to Proposition 4.

5 Concluding remarks

This paper examines the performance of various cost-based transfer pricing methods if there is asymmetric information at the trading stage. These methods must protect the specific investments of the individual divisions and ensure efficient trade. We find that (a) centralized standard-cost transfer pricing dominates other methods if the ex ante cost uncertainty is sufficiently low; (b) reported standard-cost transfer pricing dominates if the ex ante cost uncertainty is sufficiently high and the buyer does not obtain sufficient cost information at the trading stage. (c) Finally, actual cost-based transfer pricing becomes the superior method if ex ante cost uncertainty is sufficiently high and the buyer is sufficiently well informed about the supplier's costs. In particular, if the central office can condition the markup on the joint contribution margin, contribution-margin transfer pricing dominates cost-plus transfer pricing.

Overall, our findings illustrate the effectiveness of various transfer pricing methods that require different accounting information. Depending on the performance of the individual methods, the firm may use verified or self-reported (unverified) cost information, exploit early information and ignore late (but more precise) cost information. Thus, our analysis might be helpful in explaining why various firms use extremely divergent cost information when pricing their intracompany trade, as highlighted in various empirical studies.

As an extension to our analysis, practitioners sometimes suggest that cost-plus markups should be determined by individual divisions through negotiations, and not by the central office, as in our model. One advantage of this approach might be that the supplier transmits some cost information to the buyer during the negotiation process.[35] Alternatively, firms sometimes try to approximate the market price for an intermediate good by basing the markup on the average gross profit of a comparable good or on the average return on assets (Eccles 1983). Similarly, firms sometimes use adjustments of the buyer's external market price for their intra-company transfer payment (Baldenius and Reichelstein 2006).

An interesting avenue for further research would be to consider a dynamic version of our static framework. The firm would then have to specify how long a particular standard or markup will be valid. Depending on the frequency of adjustment, a sound distinction between actual and standard costing becomes blurred. As Feinschreiber (2004) notes: "Frequent changes in the standard cost system mean that the standards are not standard" (p. 29). Thus, aspects of commitment play a crucial role when a repeated framework is considered.

Finally, there will be tensions relating to taxation issues. The OECD guidelines provide recommendations on the choice between actual and standard cost-based transfer prices that are diametrically opposed to ours; they allow for (centralized) standard cost-based transfer prices if ex ante (cost) uncertainty is high. However, if uncertainty is low, firms have to use transfer prices based on historical (actual) costs (see OECD 2001, paragraph 2.42). Hence, we might follow Feinschreiber (2004) who concludes that "[a]lthough fiscal authorities believe that worldwide tax optimization is always the driver behind transfer pricing policies, other variables enter the picture" (p. 38).

Acknowledgments We thank Anil Arya, Tim Baldenius, Sabine Böckem, Jörg Budde, Robert Göx, Stefan Reichelstein (the editor), Savita Sahay, two anonymous referees, and, especially, Stephan Lengsfeld. We are also grateful to seminar participants at London School of Economics, the University of Bielefeld, Swiss IO Day in Berne, the 2007 EAA conference in Lisbon, Ausschuss Unternehmensrechnung im Verein für Socialpolitik 2010, and Controllertagung 2010 at WHU.

[35] For instance, Vaysman (1998) and Baldenius (2000) show how negotiated transfer prices transmit information between uninformed divisions.

Appendix 1: Characterization of the transfer pricing methods

Centralized standard-cost transfer pricing

For the linear-quadratic setting, we obtain: $q(\cdot) = (\theta_2 + xI_2 - t)/\beta$,

$$I_1 = yE[q(\cdot)] = y\frac{E[\theta_2] - t}{\beta - x^2} \quad \text{and} \quad I_2 = xE[q(\cdot)] = x\frac{E[\theta_2] - t}{\beta - x^2},$$

and for the transfer price $t = E[\theta_1] - yI_1^{eff} = E[\theta_1] - y^2E[\theta_2 - \theta_1]/(\beta - x^2 - y^2)$, yielding:

$$E[M(\cdot)] = \frac{E\,[\theta_2 - \theta_1]^2}{2(\beta - x^2 - y^2)} + \frac{Var[\theta_2]}{2\beta} + \frac{x^2 + y^2}{2}\frac{E\,[\theta_2 - \theta_1]^2}{(\beta - x^2 - y^2)^2}$$

$$E\left[\Pi^{CSC}\right] = \frac{E\,[\theta_2 - \theta_1]^2}{2(\beta - x^2 - y^2)} + \frac{Var[\theta_2]}{2\beta} = H^{FB} + \frac{Var[\theta_2]}{2\beta}.$$

Cost-plus transfer pricing

Anticipating the trade and investment decisions, (3) and (4), the central office sets the markup to maximize the expected firm-wide profit

$$\max_{\delta}\{E[M(q(\theta_2, I_2, t(I_1(\delta), \delta)), \theta, I_1(\delta), I_2)] - w_1(I_1(\delta)) - w_2(I_2)\}.$$

We obtain the following first order condition:

$$E\left[\frac{\partial M(\cdot)}{\partial q}\frac{\partial q(\cdot)}{\partial t}\left(\frac{\partial t(\cdot)}{\partial \delta} + \frac{\partial t(\cdot)}{\partial I_1}\frac{\partial I_1(\cdot)}{\partial \delta}\right) + \frac{\partial M(\cdot)}{\partial I_1}\frac{\partial I_1(\cdot)}{\partial \delta}\right] - w_1'(\cdot)\frac{\partial I_1(\cdot)}{\partial \delta} = 0.$$

Using the first order conditions for the trade and investment decision, $\partial M(\cdot)/\partial q = \delta$ and $\delta E[(\partial q(\cdot)/\partial t)\cdot(\partial t(\cdot)/\partial I_1)] = w_1'(\cdot)$, we obtain:

$$E\left[\delta\frac{\partial q(\cdot)}{\partial t}\left(\frac{\partial t}{\partial \delta} + \frac{\partial t(\cdot)}{\partial I_1}\frac{\partial I_1(\cdot)}{\partial \delta}\right) + \frac{\partial M(\cdot)}{\partial I_1}\frac{\partial I_1(\cdot)}{\partial \delta} - \delta\frac{\partial q(\cdot)}{\partial t}\frac{\partial t(\cdot)}{\partial I_1}\frac{\partial I_1(\cdot)}{\partial \delta}\right]$$
$$= \delta E\left[\frac{\partial q(\cdot)}{\partial t}\frac{\partial t}{\partial \delta}\right] + E\left[\frac{\partial M(\cdot)}{\partial I_1}\frac{\partial I_1(\cdot)}{\partial \delta}\right] = 0.$$

Recalling that $\partial M(\cdot)/\partial I_1 = yq(\cdot)$, we obtain the optimal markup.

Finally, an equilibrium exists since the supplier's and buyer's profit function are supermodular (Milgrom and Roberts 1990, Corollary to Theorem 6).

For the linear-quadratic setting we get: $q(\cdot) = (\theta_2 - E[\theta_1|s_1] + yI_1 + xI_2 - \delta)/\beta$,

$$I_1 = \delta\frac{y}{\beta}, \quad I_2 = xE[q(\cdot)] = x\frac{\beta E[\theta_2 - \theta_1] - \delta(\beta - y^2)}{\beta(\beta - x^2)}, \quad \delta = \frac{y^2\beta E[\theta_2 - \theta_1]}{\beta^2 + y^2(\beta - x^2 - y^2)}.$$

Direct substitution yields an expected firm-wide profit of

$$E[\Pi^{AC+}] = \frac{(\beta - x^2 - y^2)(\beta^2 + y^2(\beta - x^2))}{(\beta - x^2)(\beta^2 + y^2(\beta - x^2 - y^2))} \cdot \frac{E[\theta_2 - \theta_1]^2}{2(\beta - x^2 - y^2)} + \frac{Var[\theta_2] + Var[s_1]}{2\beta}.$$

Since the first fraction is smaller than one and $H^{FB} = E[\theta_2 - \theta_1]^2/[2(\beta - x^2 - y^2)]$, we obtain $E[\Pi^{AC+}] = \alpha^{AC+}H^{FB} + (Var[\theta_2] + Var[s_1])/2\beta$ with $0 < \alpha^{AC+} < 1$.

Contribution-margin transfer pricing

For the linear-quadratic setting we obtain $q(\cdot) = (\theta_2 - E[\theta_1|s_1] + yI_1 + xI_2)/\beta$,

$$I_1 = \frac{\gamma y E[\theta_2 - \theta_1]}{\beta - (1-\gamma)x^2 - \gamma y^2} \quad \text{and} \quad I_2 = \frac{(1-\gamma)xE[\theta_2 - \theta_1]}{\beta - (1-\gamma)x^2 - \gamma y^2},$$

and for the optimal sharing parameter $\gamma = (y^2\beta - x^2y^2)/(x^2\beta + y^2\beta - 2x^2y^2)$.

Overall, we find an expected firm-wide profit of

$$E[\Pi^{ACM}] = \frac{(\beta - x^2)(\beta - y^2)(x^2 + y^2) - \beta x^2 y^2}{(\beta - x^2)(\beta^2 - y^2)(x^2 + y^2)} \cdot H^{FB} + \frac{Var[\theta_2] + Var[s_1]}{2\beta}$$

where H^{FB} is defined as before. The first expression is positive and smaller than one. Hence, we obtain $E[\Pi^{ACM}] = \alpha^{ACM}H^{FB} + (Var[\theta_2] + Var[s_1])/2\beta$ with $0 < \alpha^{ACM} < 1$.

Reported standard-cost transfer pricing

The trade decision $q(\theta_2, I_2, t)$ is given by $R_q(\cdot) = t$. Thus, we get $\partial q(\cdot)/\partial t = 1/r_{qq}(\cdot)$. The supplier sets the transfer price according to $\max_t\{(t - c(\theta_1, I_1)) E[q(\theta_2, I_2, t)|s_2]\}$. The first order condition is given by

$$E[q(\cdot)|s_2] + (t(\cdot) - c(\cdot))E\left[\frac{\partial q(\cdot)}{\partial t}|s_2\right] = 0, \quad \text{and hence } t(\cdot) = c(\cdot) - \frac{E[q(\cdot)|s_2]}{E\left[\frac{1}{r_{qq}(\cdot)}|s_2\right]}.$$

The divisions undertake the investments to maximize their expected divisional profit, $\max_{I_1}\{E[(t - c(\cdot))q(\cdot)] - w_1(I_1)\}$ and $\max_{I_2}\{E[R(\cdot) - t(\cdot)q(\cdot)] - w_2(I_2)\}$. We obtain the following first order conditions:

$$E\left[-c_{I_1}(\cdot)q(\cdot) + \frac{\partial t(\cdot)}{\partial I_1}q(\cdot) + (t(\cdot) - c(\cdot))\frac{\partial q(\cdot)}{\partial t}\frac{\partial t(\cdot)}{\partial I_1}\right] = E[-c_{I_1}(\cdot)q(\cdot)] = w_1'(I_1)$$

and

$$E\left[R_{I_2}(\cdot) - \frac{\partial t(\cdot)}{\partial I_2}q(\cdot) + \left(R_q(\cdot) - t\right)\frac{\partial q(\cdot)}{\partial t}\frac{\partial t(\cdot)}{\partial I_2}\right] = E\left[R_{I_2}(\cdot) - \frac{\partial t(\cdot)}{\partial I_2}q(\cdot)\right] = w_2'(I_2).$$

Recall that $-c_{I_1}(\cdot)q(\cdot) = yq(\cdot)$ and $R_{I_2}(\cdot) = xq(\cdot)$. Since the term $\partial t(\cdot)/\partial I_2$ is a function of I_2, nonconcavities in the buyer's objective function may arise. Accordingly, the investment problem might not be well-behaved. See Baldenius et al. (1999).

Table 1 Overview of results for the transfer pricing methods

	Centralized standard-cost transfer pricing	Cost-plus transfer pricing	Contribution-margin transfer pricing	Reported standard-cost transfer pricing
Transfer price	$t = E[c(\theta_1, I_1^{eff})]$	$t(\theta_1, I_1) = c(\theta_1, I_1) + \delta$	$t(\theta, I) = c(\theta_1, I_1) + m(\theta, I)$ $m(\theta, I)q = \lambda(R(q, \theta_2, I_2) - c(\theta_1, I_1)q)$	$t(\theta_1, s_2, I) = c(\theta_1, I_1) - \frac{E[q(\cdot)\|s_2]}{E\left[\frac{1}{r_{qq}(\cdot)}\|s_2\right]}$
Trade decision	$R_q(q, \theta_2, I_2) = t$	$R_q(q, \theta_2, I_2) = E[c(\cdot)\|s_1] + \delta$	$R_q(q, \theta_2, I_2) = E[c(\cdot)\|s_1]$	$R_q(q, \theta_2, I_2) = t$
Investment decisions	$yE[q(\cdot)] = w_1'(I_1)$ $xE[q(\cdot)] = w_2'(I_2)$	$\delta E\left[\frac{\partial q(\cdot)}{\partial t}\frac{\partial t(\cdot)}{\partial I_1}\right] = w_1'(I_1)$ $xE[q(\cdot)] = w_2'(I_2)$	$\gamma y E[q(\cdot)] = w_1'(I_1)$ $(1-\gamma)xE[q(\cdot)] = w_2'(I_2)$	$yE[q(\cdot)] = w_1'(I_1)$ $E\left[\left(x - \frac{\partial t(\cdot)}{\partial I_2}\right)q(\cdot)\right] = w_2'(I_2)$
Expected profit for linear-quadratic setting	$E[\Pi^{CSC}] = H^{FB} + \frac{Var[\theta_2]}{2\beta}$	$E[\Pi^{AC+}] = \alpha^{AC+}H^{FB} + \frac{Var[\theta_2] + Var[s_1]}{2\beta}$	$E[\Pi^{ACM}] = \alpha^{ACM}H^{FB} + \frac{Var[\theta_2] + Var[s_1]}{2\beta}$	$E[\Pi^{RSC}] = \alpha^{RSC}H^{FB} + \frac{4Var[\theta_2] - Var[s_2] + 3Var[\theta_1]}{8\beta}$

As outlined, we thus proceed with the linear-quadratic setting for which we obtain $q(\cdot) = (\theta_2 + xI_2 - t)/\beta$, $t = c(\theta_1, I_1) + \beta E[q(\cdot)|s_2] = (\theta_1 + E[\theta_2|s_2] + yI_1 + xI_2)/2$, and $q(\cdot) = (2\theta_2 - s_2 - \theta_1 + yI_1 + xI_2)/2\beta$, and for the investment decision

$$I_1 = yE[q(\cdot)] = \frac{2yE[\theta_2 - \theta_1]}{4\beta - x^2 - 2y^2},$$
$$I_2 = E\left[\left(x - \frac{\partial t(\cdot)}{\partial I_2}\right) q(\cdot)\right] = \frac{xE[q(\cdot)]}{2} = \frac{xE[\theta_2 - \theta_1]}{2(4\beta - x^2 - 2y^2)},$$

and for the expected firm-wide profit

$$E[\Pi^{RSC}] = \alpha^{RSC} H^{FB} + \frac{4Var[\theta_2] - Var[s_2] + 3Var[\theta_1]}{8\beta},$$
$$\text{with } \alpha^{RSC} = (12\beta - x^2 - 4y^2)(\beta - x^2 - y^2)/(4\beta - x^2 - 2y^2)^2 < 1.$$

Table 1 summarizes these results.

Appendix 2: Proofs of propositions

Proposition 1 First, we compare the trade decisions under cost-plus transfer pricing and contribution-margin pricing, $R_q(q^{AC+}(\cdot), \cdot) = E[c(\theta_1, I_1)|s_1] + \delta$ and $R_q(q^{ACM}(\cdot), \cdot) = E[c(\theta_1, I_1)|s_1]$, which yields for fixed (θ, s_1, I)

$$\delta = R_q(q^{AC+}(\cdot), \cdot) - R_q(q^{ACM}(\cdot), \cdot) = \int_{q^{ACM}(\cdot)}^{q^{AC+}(\cdot)} r_{qq}(u, \cdot)\mathrm{d}u.$$

Since $r_q(\cdot)$ is decreasing and convex, $r_{qq}(\cdot) < 0$ and $r_{qqq}(\cdot) \geq 0$, for fixed (θ, s_1, I) we obtain:

$$\delta \leq \left(q^{AC+}(\cdot) - q^{ACM}(\cdot)\right) r_{qq}(q^{AC+}(\cdot), \cdot)$$

and thus

$$q^{ACM}(\cdot) + \frac{\delta}{r_{qq}(q^{AC+}(\cdot), \cdot)} \geq q^{AC+}(\cdot).$$

The rest follows as outlined in the text.

Proposition 2 It remains to be shown that the expected firm-wide profit under contribution-margin pricing increases in $Var[s_1]$.

Recall that the trade decision $q(\theta_2, I_2, E[t(\cdot)|s])$ is given by the first order condition: $R_q(q(\theta_2, I_2, E[t(\cdot)|s_1]), \theta_2, I_2) = E[c(\theta_1, I_1)|s_1] = s_1 - yI_1$. As outlined previously, we compress our previous notation and write w.l.o.g. $q(\theta_2, s_1, I)$. First we show that the firm-wide contribution margin $M(q(\theta_2, s_1, I), \theta_2, s_1, I)$ is convex in s_1 for any given I:

$$\frac{dM(\cdot)}{ds_1} = \frac{\partial M(\cdot)}{\partial q}\frac{\partial q(\cdot)}{\partial s_1} + \frac{\partial M(\cdot)}{\partial s_1} = \frac{\partial M(\cdot)}{\partial s_1} = -q(\cdot) \text{ and } \frac{d^2M(\cdot)}{d^2s_1} = -\frac{\partial q(\cdot)}{\partial s_1} = -\frac{1}{r_{qq}(\cdot)}.$$

Applying Jensen's inequality, we can conclude that the expected contribution margin $E[M(\cdot)]$ increases in $Var[s_1]$.

Next, we turn our attention to the investment decisions, $\gamma y E[q(\cdot)] = w_1'(\cdot)$ and $(1-\gamma)xE[q(\cdot)] = w_2'(\cdot)$. As outlined in the text, it remains to be shown that the quantity is convex in s_1,

$$\frac{d^2q(\cdot)}{d^2s_1} = \frac{d}{ds_1}\left(\frac{1}{r_{qq}(\cdot)}\right) = -\frac{1}{r_{qq}^2(\cdot)}r_{qqq}(\cdot)\frac{\partial q(\cdot)}{\partial s_1} = -\frac{r_{qqq}(\cdot)}{r_{qq}^3(\cdot)}.$$

Hence, the proposition is proven.

Proposition 3 It remains to be shown that the expected firm-wide profit under cost-plus transfer pricing increases with $Var[s_1]$. Recall that the trade decision $q(\theta_2, I_2, E[t(\cdot)|s_1])$ is given by

$$R_q(q(\theta_2, I_2, E[t(\cdot)|s_1]), \theta_2, I_2) = E[c(\cdot) + \delta|s_1] = s_1 - yI_1 + \delta.$$

For the sake of simplicity, we compress our notation and use $q(\theta_2, s_1, I, \delta)$.

First, we show that for any given (I, δ) the firm-wide contribution margin $M(q(\theta_2, s_1, I, \delta), \theta_2, s_1, I)$ is convex in s_1 (recall $M_q(\cdot) = \delta$),

$$\frac{dM(\cdot)}{ds_1} = \frac{\partial M(\cdot)}{\partial q}\frac{\partial q(\cdot)}{\partial s_1} + \frac{\partial M(\cdot)}{\partial s_1} = \delta\frac{\partial q(\cdot)}{\partial s_1} - q(\cdot) \quad \text{and} \quad \frac{d^2M(\cdot)}{d^2s_1} = \delta\frac{\partial^2 q(\cdot)}{\partial^2 s_1} - \frac{\partial q(\cdot)}{\partial s_1}.$$

Since $r_q(\cdot)$ is decreasing and convex, the quantity is decreasing and convex in s_1, $\partial q(\cdot)/\partial s_1 = 1/r_{qq}(\cdot) < 0$ and $\partial^2 q(\cdot)/\partial^2 s_1 = -(r_{qq}(\cdot)^{-2} \cdot r_{qqq}(\cdot) \cdot (\partial q(\cdot)/\partial s_1)) \geq 0$. Hence, $M(\cdot)$ is convex in s_1.

Now, we consider the investment decisions, $\delta x E[q(\cdot)] = w_2'(I_2)$ and $-\delta y E\left[1/r_{qq}(\cdot)\right] = w_1'(I_1)$. Hence, if $-r_{qq}^{-1}(\cdot)$ is convex, the investment decisions are convex in s_1 for any given markup. The rest of the proof follows as outlined in the text.

Proposition 4 Comparing the cut-off values reveals that $Var[s_1] = \frac{3}{4}Var[\theta_1] - T_3$ intersects with T_1 and T_2. The rest follows as outlined in the text.

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