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Michael Kopel, Christian Riegler & Georg Schneider

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# Providing Managerial Accounting Information in the Presence of a Supplier

Michael Kopel\*, Christian Riegler\*\* and Georg Schneider  <sup>†</sup>

\*Institute of Organization and Economics of Institutions and Center for Accounting Research, University of Graz, Graz, Austria; \*\*Institute for Accounting and Auditing, WU Vienna University of Economics and Business, Vienna, Austria;

<sup>†</sup>Institute of Accounting and Reporting and Center for Accounting Research, University of Graz, Graz, Austria

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**ABSTRACT** This paper identifies a novel effect which is crucial for the design of a management accounting information system. In contrast to prior literature, we explicitly model the firm's relationship to a supplier. We show that in addition to the previously identified trade-off – benefits of more information versus indirect or direct (agency) costs of information acquisition – another effect occurs: the input price effect. This effect influences the optimal design of the management accounting information system and changes the regimes where information acquisition is optimal for the principal. Also, in case of endogenous input prices we demonstrate that – perhaps surprisingly – paying an information rent to the agent can be beneficial because it works as a commitment towards an over-charging supplier to exploit the input price effect.

**Keywords:** Information systems; Agency conflicts; Supply side; Input price effect

## 1. Introduction

Accounting research frequently studies the optimal design of a firm's information system which determines the allocation and the flow of information. Providing superior information to a self-interested manager might or might not be beneficial for the owner (e.g., Christensen, 1981). While better information improves decision-making and increases profits, private information can be used by the manager against the owner's best interest. To induce goal-congruent behavior, the owner must pay an information rent to the manager (e.g., Antle & Fellingham, 1995). As a consequence, the owner might prefer a less informed agent by not installing an information system (Rajan & Saouma, 2006). For example, if the owner designs the firm's budgeting mechanism, either top-down budgeting or participative budgeting might be beneficial (e.g., Baiman & Evans, 1983; Heinle, Ross, & Saouma, 2014; Magee, 1980; Weiskirchner-Merten, 2019). Although the owner benefits from a manager's truthful report under participative budgeting, it is associated with slack building. Hence, top-down budgeting might be favored by the owner to avoid such real costs.

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\*Correspondence Address: Christian Riegler, Institute for Accounting and Auditing, WU Vienna University of Economics and Business, Vienna, Austria. Email: [christian.riegler@wu.ac.at](mailto:christian.riegler@wu.ac.at)

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Research addresses this issue by focusing exclusively on the owner–manager relationship. The novelty of our paper is that we add a supplier who sells an input to the firm. We use this three-party setting to advance our understanding of the interplay between the choice of the firm’s managerial accounting information system and the supplier’s decision. Our economic model considers a firm that offers a final product in a monopolistic market. The owner makes the production decision and a manager implements production. To produce the final product, the firm purchases an input from a monopoly supplier. The supplier chooses a wholesale price and maximizes his expected profit. In addition to the input price, the firm faces stochastic marginal costs of production, which can be either low or high. Without an information system, production decisions must be based on expected marginal costs. If the owner installs an information system, the true marginal production costs are revealed only to the manager. The manager reports the costs to the owner and the manager receives a corresponding cost budget for production and a production schedule. To elicit a truthful report, the owner designs an incentive-compatible (direct) mechanism. Information about marginal costs enables the owner to ‘fine-tune’ the production schedule to the firm’s true marginal costs (‘owner’s value of true information’). At the same time, the owner must pay an information rent to the manager to elicit a truthful cost report (‘agent’s information rent’).

To highlight the influence of the supplier, we first consider the equilibrium of our model for an exogenous input price. This benchmark case abstracts from any possible interplay between the firm’s choice of installing an information system and the supplier’s price response. In line with the literature, we find that if the owner’s value of learning the true marginal costs dominates the agent’s information rent, the owner prefers to install the information system and asks the manager for a cost report (and vice versa). The owner’s decision is simple since providing superior private information for the manager is only profitable if the ‘value’ of information is high, i.e., if the spread between the realizations of marginal costs is sufficiently large.

We then assume that the firm purchases the input from a supplier. In contrast to the benchmark case of a fixed input price, we find that the owner’s decision loses its simplicity since installing an information system can be optimal for a low as well as for a high spread between marginal costs. Intuitively, the owner’s decision of installing an information system determines the firm’s expected production quantity since the agent’s information rent is reflected as an increase in production costs. A lower production quantity of the firm directly affects the supplier’s expected profit and induces the supplier to decrease the input price. Hence, in addition to the two counter-vailing effects in the benchmark case, the owner benefits from this ‘input price effect’. The firm’s commitment to install an information system and ask the manager for a cost report softens the supplier’s pricing behavior. As a further consequence, even if the owner could install a perfect information system for free and learn the true marginal costs without involving the manager, the owner might still prefer to involve the manager and ask for a cost report to exploit this input price effect.

Our paper is most closely related to research on information system design where the principal controls the extent of information provided to the agent.<sup>1</sup> For example, Lewis and Sappington (1991) analyze an adverse selection setting, where an owner can control the precision of the information the manager can learn. They show that it is optimal for the owner to either offer perfect (‘high-quality’) information or no (‘low-quality’) information. In Rajan and Saouma (2006), the owner controls the flow of information to managers in the managerial accounting system.

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<sup>1</sup>In our setting, while the principal controls the information flow, information is exogenous. For work on endogenous information structure where the agent can expend costly effort to acquire information, see, e.g., Kessler (1998), Hoppe (2013), Cremer, Khalil, and Rochet (1998). However, these papers do not consider the influence of an external party on optimal information provision.

However, the owner lacks the expertise to interpret the accounting information. Consistent with Lewis and Sappington (1991), they demonstrate that the owner always prefers an either perfectly informed or a perfectly uninformed manager.<sup>2</sup> If uncertainty is high, the benefit of having an informed manager exceeds the information rent paid to the manager (and vice versa). Rajan and Saouma (2006) further study the optimal incentive intensity and the preferences of a manager regarding the choice of information system. Our paper contributes to this literature by studying the interplay between the firm's observable choice of information system and the decisions of an external third party. We identify a new effect, the input price effect, and show that the presence of the supplier has a crucial influence on the firm's choice of the information system.

Research on organizational design highlights that the optimal allocation of decision rights often balances the benefits from delegation against the control losses that are due to information asymmetries (e.g., Böckem & Schiller, 2014). Arya, Glover, and Sivaramakrishnan (1997) study information system design in a model of double moral hazard and address the decision-facilitating role and the decision-influencing (control) role of information. In line with our results, they show that the principal can be better off with less information.<sup>3</sup> However, in their model the main driver for this result is the interaction between the two roles of information such that less information serves as a commitment for the principal to reduce the bonus payments to the agent. In our setting, the firm is better off with less information since the supplier reacts to the firm's information problem by decreasing its input price. Arya, Fellingham, Glover, and Sivaramakrishnan (2000) argue that managerial slack can work as a motivational device for the manager to spend more effort on the search for valuable projects. Therefore, the firm installs an information system that provides coarser and late information. Again, this paper focuses exclusively on players within the firm.

Finally, our paper is also related to work that studies the interplay between a firm's organizational design and the firm's input market (see, e.g., Arya & Mittendorf, 2010 for a survey). In our model, the firm faces an internal information problem and the economic consequences of double marginalization by the supplier who charges an input price above marginal costs. We show that paying the manager an information rent works as a pledge against an overcharging supplier.

The paper proceeds as follows. Section 2 provides the model setup. Section 3 studies the owner's choice of the firm's information system under the assumption of a fixed input price. Section 4 continues the analysis by considering a monopoly supplier. Section 5 discusses the robustness of our findings. Finally, Section 6 concludes. Proofs of the results are relegated to an Appendix, unless stated otherwise.

## 2. The Model

We consider the relationship between a firm owner (principal) and a manager (agent). The risk-neutral owner makes the production decision and the risk-neutral manager implements it. The firm serves a monopolistic output market. The demand for the product is described by the linear demand function  $p = a - x$ , where  $p$  denotes the market price and  $x$  the market quantity of the final product. Owner and manager know the demand function. The firm's marginal production costs  $c$  are stochastic where  $c = 0$  with probability  $\phi$  and  $c = C$  with probability  $1 - \phi$ .<sup>4</sup> Owner and manager (ex ante) share the same expectation about the marginal production costs. In what

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<sup>2</sup>See Taylor and Xiao (2010) for a similar result in a manufacturer–retailer setting.

<sup>3</sup>Likewise Cremer (1995, 2010) demonstrates that in agency settings lowering the costs of information acquisition can actually worsen the situation of the principal.

<sup>4</sup>Our results qualitatively hold for realizations  $c_1 > 0$  and  $c_2 > 0$ . Furthermore, they also hold for three possible cost levels, e.g.,  $c_1 = 0, c_2 = C/2, c_3 = C$  with positive probabilities  $\phi_1, \phi_2, 1 - \phi_1 - \phi_2$ . In Section 5, we provide more

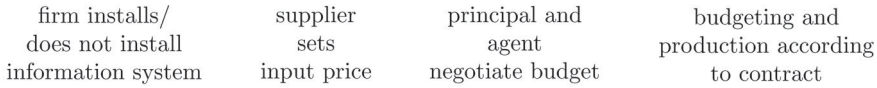


Figure 1. Timeline.

follows, we assume that  $a > C/(1 - \phi)$ , i.e., the highest willingness-to-pay in the market is sufficiently large compared to the adjusted marginal costs. This assumption avoids unnecessary case distinctions and guarantees that production quantities are positive.

To enable production, an input must be purchased from a monopolistic supplier. We assume that the supplier knows the demand function and the distribution of the firm's marginal costs. Given this information, the supplier charges a wholesale input price,  $w$ , to maximize its profit based on the firm's expected production quantity. For simplicity, we assume that each unit of the final product requires one unit of the input and w.l.o.g. we normalize the supplier's marginal costs to zero.

We study three scenarios. In the first scenario, the firm does not install an information system and information about the firm's marginal costs is symmetric for all players throughout the game. This scenario serves as a benchmark case for the other two scenarios where information about marginal cost is asymmetric. In the second information environment, the owner installs (at no additional costs) an information system which provides information about true marginal costs to the manager. The owner asks the manager to submit a report  $m$  about the true marginal costs. Based on the report  $m$ , the manager obtains a budget  $B(m)$  and is obliged to produce  $x(m)$  units. The manager might use private information to overstate marginal costs and consume resources not needed for production.<sup>5</sup> The third information environment assumes that the firm owner installs a perfect information system which reveals the true marginal costs to the owner at costs  $K$  without involving the manager. In this case, the owner saves the information rent paid to the manager but has to burden the costs  $K$  of perfect information. Summarizing, we consider one scenario with no additional information and two scenarios in which obtaining information is (directly or indirectly) costly. In the subsequent analysis, we will focus on the owner's design of an optimal (truth-telling) mechanism and we will derive conditions (on the marginal costs  $C$ ) such that either information system is preferred.

The timing of decisions is as follows (see Figure 1). First, the owner decides whether to install an information system or not. This decision is observed by the supplier. Second, the supplier anticipates the firm's cost of production (including possible agency costs) and calculates the firm's expected quantity. Based on this prediction, the supplier determines the corresponding profit-maximizing input price  $w$ . Third, the owner asks the manager for a report and fixes the production budget and the associated production quantity. The manager receives the cost budget for production based on the budgeted production costs per unit. Finally, the production quantity is produced and sold in the market and profits are realized.

A key assumption of our analysis is that the transaction between the firm and its supplier is governed by a linear contract. If the supplier could, e.g., use a two-part tariff involving a unit price equal to marginal cost and a fixed fee to extract the entire surplus, then input market considerations seem to be moot (see also the discussion in Mittendorf, Shin, & Yoon, 2013, p. 282).

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details and further describe the changes for the case where realizations of marginal costs are continuously distributed over an interval  $[0, C]$ .

<sup>5</sup>This is in line with the general idea of slack in the literature captured by paying an information rent to the manager to induce truthful reporting of the manager's private information (e.g., Schiff & Lewin, 1970).

However, Arya and Mittendorf (2010, p. 79) provide various reasons why under nonlinear pricing arrangements the input price might not be equal to marginal costs. Hence, the assumption that contractual imperfections govern firm–supplier relationships seems reasonable.

A further critical assumption in our model is that the supplier is able to observe the owner’s choice of information system, but not the details of the communication process that governs the interaction between the owner and manager. For example, based on a firm’s reputation, the market might obtain a signal about the firm’s internal controls or corporate governance structure but commonly external parties do not have access to detailed information about internal communications. This assumption is in line with the criticism raised about strategic transfer prices where observability of the chosen transfer prices is key. It has been argued (e.g., Göx, 2000) that this issue can be resolved if the choice of the method of setting transfer prices (full cost versus marginal cost) can be observed instead of the exact values of the transfer prices. To summarize, suppliers must be privy to the internal controls and said controls must be sticky or costly to change.

### 3. Equilibrium with Exogenous Input Price

In this section, we study a situation where the price of the input,  $w$ , is exogenously fixed. Intuitively, this situation arises if the input is made in-house by the firm at marginal production costs of  $w$  or if the supplier market is perfectly competitive and input is supplied at a constant market price of  $w$ . Put differently, we abstract from any double marginalization issue between the firm and the monopoly supplier.

#### 3.1. No Information System

If no information system is installed, the owner has to make an uninformed decision, i.e., the production quantity has to be based on expected costs,  $(1 - \phi)C$ . The firm solves the following unconstrained optimization problem:

$$\max_x \Pi = (1 - \phi)(a - C - w - x)x + \phi(a - w - x)x.$$

The solution to this problem is  $x_n = \frac{1}{2}(a - w - C(1 - \phi))$  and the firm’s expected profit is  $\Pi_n = x_n^2$  as long as  $a - w - C(1 - \phi) \geq 0$  and both are 0 otherwise.<sup>6</sup> It is important to note that  $x_n$  depends on the exogenous input price  $w$  and  $x_n = E[x_n]$ , i.e., the quantity  $x_n$  is deterministic since production can be based only on the expected marginal costs.

#### 3.2. Firm Installs Information System

If the owner installs an information system, the manager is privately informed about the true marginal costs. The owner asks the manager for a report ( $m$ ) about the observed marginal costs. To elicit the manager’s private information, the owner can design a menu of contracts that specifies a production budget  $B(m)$  and an associated quantity  $x(m)$ . According to the revelation principle, the owner can restrict attention to mechanisms that induce truth-telling, i.e., to mechanisms that induce the manager to report the true marginal costs  $c = 0$  or  $c = C$ . Given that the manager reports truthfully, the firm’s production quantity can be conditioned on the true marginal costs. However, to induce the manager to report the observed marginal costs truthfully, the owner

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<sup>6</sup>The subscript  $n$  denotes the information scenario where no player has information about the true marginal costs.

has to pay an information rent to the manager. The principal's mechanism design problem can be written as

$$\max_{B(\cdot), x(\cdot)} \Pi = \phi((a - x(0) - w)x(0) - B(0)) + (1 - \phi)((a - x(C) - w)x(C) - B(C)) \quad (1)$$

subject to

$$(PC_1) \quad B(C) - Cx(C) \geq 0$$

$$(PC_2) \quad B(0) \geq 0$$

$$(IC_1) \quad B(C) - Cx(C) \geq B(0) - Cx(0)$$

$$(IC_2) \quad B(0) \geq B(C).$$

In addition to the manager's participation constraints ( $PC_1$ ) and ( $PC_2$ ), the owner's mechanism design problem has to include the incentive compatibility constraints ( $IC_1$ ) and ( $IC_2$ ) which ensure that the manager reports truthfully if the true marginal cost are  $C$  and  $0$  respectively.

From standard analysis, it follows that the participation constraint ( $PC_1$ ) and the incentive compatibility constraint ( $IC_2$ ) are binding. The remaining two inequalities can be ignored.<sup>7</sup> This leads to  $B(C) = Cx(C)$  and  $B(0) = B(C) = Cx(C)$ . If the manager observes low marginal costs,  $c = 0$ , he receives an information rent since  $B(0) = Cx(C) > 0$ . Inserting  $B(C)$  and  $B(0)$  into the principal's objective function yields the unconstrained problem

$$\max_{x(\cdot)} \phi(a - x(0) - w)x(0) + (1 - \phi) \left( a - x(C) - w - \frac{C}{1 - \phi} \right) x(C), \quad (2)$$

and solving leads to  $x_i(0) = \frac{1}{2}(a - w)$  and  $x_i(C) = \frac{1}{2}(a - w - C/(1 - \phi))$ .<sup>8</sup> Note that we have  $x_i(0) = 0$  if and only if  $w > a$  and  $x_i(C) = 0$  if and only if  $w > a - C/(1 - \phi)$ .

Assuming that all quantities are positive, we have  $\Pi_i = \phi x_i(0)^2 + (1 - \phi)x_i(C)^2$ . If  $x_i(C) = 0$  (or equivalently  $w > a - C/(1 - \phi)$ ), we obtain  $\Pi_i = \phi x_i(0)^2$ .

Alternatively, the owner can install a perfect information system. In this case, the owner learns the true marginal costs at costs  $K$  without involving the manager. The owner's maximization problem is the same as in (2) with the difference that the expected marginal costs  $C/(1 - \phi)$  are replaced by the true marginal costs  $C$ . It is easy to see that the optimal production quantities are  $x_I(0) = \frac{1}{2}(a - w)$  and  $x_I(C) = \frac{1}{2}(a - w - C)$ .<sup>9</sup> Assuming that both production quantities are positive, the firm's expected profit is  $\Pi_I = \phi x_I(0)^2 + (1 - \phi)x_I(C)^2 - K$ . If the firm only produces in case of low costs ( $C > a - w$ ), we have  $\Pi_I = \phi x_I(0)^2 - K$ .

### 3.3. Comparison of the Information Regimes

A simple comparison of the expected profit without information,  $\Pi_n$ , and the expected profit with information,  $\Pi_i$ , yields conditions on  $C$  under which the firm prefers to obtain information about the true marginal production costs.

We start the analysis assuming  $w < a - C/(1 - \phi)$  such that the firm's quantity is positive even if marginal costs turn out to be high. Notice first that the owner's derived objective function in (2) is identical to the expected profit of an *informed* firm owner who faces marginal

<sup>7</sup>See, for example, Laffont and Martimort (2002).

<sup>8</sup>The subscript  $i$  denotes the information scenario where the owner obtains information about the true marginal costs from the manager.

<sup>9</sup>The subscript  $I$  denotes the information scenario where the owner obtains information about the true marginal costs by installing a perfect information system.

production costs of  $c = 0$  with probability  $\phi$  and  $c = C/(1 - \phi)$  with probability  $1 - \phi$ . Denoting the random variable that captures these marginal production costs by  $\hat{c}$ , we conclude that  $\text{Var}(\hat{c}) = C^2\phi/(1 - \phi)$ . Then, the firm's expected profit  $\Pi_i$  in the case where production is positive independent of the realization of marginal costs (see Section 3.2) can be decomposed as

$$\Pi_i = \bar{x}_n^2 + \frac{1}{4}\text{Var}(\hat{c}).$$

Here,  $\bar{x}_n$  denotes the quantity an *uninformed* owner would choose given a cost structure that incorporates the agency costs. In other words,  $\bar{x}_n$  is the solution to the maximization problem  $\max_x (a - x - w - C)x$  where the quantity cannot be conditioned on true marginal costs and expected production costs are  $E[\hat{c}] = C > C(1 - \phi)$ , i.e., larger than the (ex-ante) expected marginal production costs due to the information problem. The term  $\frac{1}{4}\text{Var}(\hat{c})$  arises from the possibility of the owner to condition his production decision on the true cost and is therefore equivalent to the expected value of perfect information (see, e.g., Hirshleifer & Riley, 1992). Using this decomposition, installing the information system is preferred by the owner if and only if  $\bar{x}_n^2 + \frac{1}{4}\text{Var}(\hat{c}) > x_n^2$ . This condition captures the trade-off the owner faces in the decision to install an information system. On the one hand, installing an information system enables the owner to condition the production decision on the true marginal costs and this benefit is captured by the expected value of perfect information (*EVPI*). On the other hand, the manager uses the information system to obtain private information and to learn the true costs, the owner has to pay an information rent to the manager. The situation is akin to a firm being confronted with increased expected production costs. Hence, the resulting quantity  $\bar{x}_n$  is strictly smaller than  $x_n$ . However, since the *EVPI* is strictly increasing in  $C$ , the firm can be better off if  $C$  is sufficiently large. In fact, it can be shown that for

$$C > C_b := \frac{2(a - w)(1 - \phi)}{3 - 3\phi + \phi^2}$$

installing an information system is beneficial. The cut-off value  $C_b$  in the case of a fixed input price satisfies the assumption that the firm produces in both states if and only if  $\phi \leq \frac{1}{2}(3 - \sqrt{5})$ . Figure 2 illustrates the situation.

In the alternative case where the firm does not produce in case of high costs ( $x_i(C) = 0$ ), i.e., if  $w > a - C/(1 - \phi)$ , the firm's expected profit can be decomposed as  $\Pi_i = \bar{x}_n^2 + \text{EVPI}$ , with  $\text{EVPI} := \frac{1}{4}\phi(a - w)^2 - \frac{1}{4}(a - C - w)^2$ . The expected value of perfect information is again increasing in  $C$ . Installing an information system is preferred by the owner if  $C > C_b = (a - w)/(1 + \sqrt{\phi})$  and the cut-off value  $C_b$  satisfies the assumption that the firm only produces if marginal costs are low (i.e.,  $C_b > (a - w)(1 - \phi)$ ) if and only if  $\phi > \frac{1}{2}(3 - \sqrt{5})$ .<sup>10</sup>

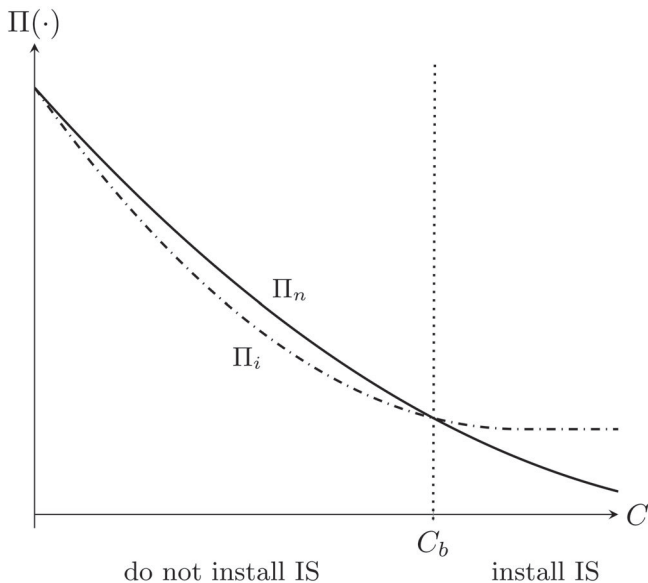
The following proposition summarizes our results.

**PROPOSITION 3.1** *Consider the benchmark case of a fixed input price. Let  $C_b = 2(a - w)(1 - \phi)/(3 - 3\phi + \phi^2)$  for  $\phi \leq \frac{1}{2}(3 - \sqrt{5})$  and  $C_b = (a - w)/(\sqrt{\phi} + 1)$  for  $\phi > \frac{1}{2}(3 - \sqrt{5})$ . The firm earns a higher profit if the owner installs an information system and asks the manager for a report if and only if  $C > C_b$ . For  $C < C_b$ , installing no information system is more profitable for the firm. For  $C = 0$  or  $C = C_b$ , the owner is indifferent between installing an information system or not.*

The first main take-away from our analysis of the case with a fixed input price is that the decision to install an information system is quite straightforward. The owner should install an

<sup>10</sup>In order to guarantee that  $C_b < C_{\max} = a(1 - \phi)$ , the condition  $(1 - \phi)(1 + \sqrt{\phi}) - 1 > -w/a$  has to be fulfilled.





**Figure 2.** The figure shows the firm’s expected profits  $\Pi_n$  (solid curve) and  $\Pi_i$  (dash-dotted curve) in the benchmark case as functions of  $C$  for  $a = 6$ ,  $\phi = 0.2$ , and  $w = 1$ . Below  $C_b$  it is not optimal to install an information system and above  $C_b$  it is strictly better to install an information system. For the parameter values used here, we have  $C_b = 2(1 - \phi)(a - w)/(\phi - 3)(\phi + 3)$  because of  $\phi \leq \frac{1}{2}(3 - \sqrt{5})$ .

information system if the marginal cost  $C$  (or the cost spread between the two states) is sufficiently large while no information system should be installed otherwise. In the case of a large marginal cost spread, the value of learning the true marginal costs is large and dominates the loss due to agency costs.

The second main take-away from our analysis concerns the owner’s possibility to install a perfect information system. Assume that the owner can learn the true costs for free ( $K = 0$ ) and, for simplicity, assume that all production quantities are positive. The firm’s expected profits are given by  $\Pi_n$ ,  $\Pi_i$ , and  $\Pi_I$  (see Sections 3.1 and 3.2). The case where the owner relies on ex-ante information is dominated by the case where the owner can obtain perfect information at no additional costs since the owner prefers to condition production quantities on true (and not expected) marginal costs. Likewise, the case where the owner installs an information system and asks the manager for a report is dominated by the case where the owner can obtain perfect information at no additional costs ( $K = 0$ ) since the owner prefers to save the manager’s information rent. The bottom line of these arguments is that if the input price is exogenous, then the owner always prefers to have perfect information if it comes at no costs.

For strictly positive values of  $K$ , a comparison of  $\Pi_i$  and  $\Pi_I$  shows that it is better to install a perfect information system for intermediate values of  $C$  and to install an information system and ask the manager for a cost report for low and high values of  $C$ . Intuitively, for  $C = 0$  there is no uncertainty and therefore both information systems are equivalent. For large values of  $C$ , there is no production in case of high costs for both information systems and, hence, expected profits are equal except for the costs  $K$ . Therefore, for low and high values of  $C$  the imperfect information system dominates  $\Pi_i > \Pi_I$ . It is not difficult to show that  $\Pi_I - \Pi_i$  is single-peaked and, therefore, for medium values of  $C$  the perfect information system dominates as long as  $K$  is not too large. If  $K$  is too large, then obviously the perfect information system is too expensive and therefore never optimal.

#### 4. Optimal Information in Presence of a Supplier

We now analyze the influence of a monopoly supplier on the owner's decision to install an information system. In line with the previous section, we first derive the firm's expected profit if no information system is installed and the firm has to rely on ex-ante information about its marginal production costs. We will build on the results obtained for an exogenous input price and additionally consider the endogenous price choice of a monopoly supplier. Then we analyze a situation where the owner installs an information system and asks the manager for a report about marginal costs. By comparing the expected profits, we can determine under which condition on  $C$  it is profitable for the owner to install an information system and how endogenous supplier pricing affects the conditions for optimality.

##### 4.1. No Information System

The analysis of the case with a monopoly supplier is similar to the case with an exogenous supplier price with the difference that there is an additional stage where the monopoly supplier endogenously chooses its profit-maximizing input price. As in Section 3.1, backward induction yields the firm's quantity  $x_n = \frac{1}{2}(a - w - C(1 - \phi))$  and the firm's expected profit  $\Pi_n = x_n^2 = \frac{1}{4}(a - w - C(1 - \phi))^2$  as long as  $a - w - C(1 - \phi) \geq 0$  and both are 0 otherwise. The quantity is always positive in equilibrium due to the assumption that  $a > C/(1 - \phi)$ . The monopoly supplier anticipates the firm's quantity choice  $x_n$  and (given our assumption that the supplier's marginal costs are zero) determines the input price  $w$  such that  $\Pi_n^s = wx_n(w)$  is maximized. This yields the input price  $w_n^* = \frac{1}{2}(a - (1 - \phi)C)$ . Note that  $w_n^* > 0$ . We can now obtain the firm's and supplier's equilibrium profits by inserting the optimal input price  $w_n^*$  and the firm's optimal quantity  $x_n$  evaluated at  $w = w_n^*$  into  $\Pi_n$  and  $\Pi_n^s$ . The following lemma summarizes our findings. The proof of the lemma is straightforward and is therefore omitted.

**LEMMA 4.1** *If the owner does not install an information system, the quantity  $x_n^* = (a - (1 - \phi)C)/4$  is optimal. The supplier charges the price  $w_n^* = (a - (1 - \phi)C)/2$  for the input. The firm's equilibrium profit is  $\Pi_n^* = ((a - (1 - \phi)C)^2)/16$  and the supplier's equilibrium profit is  $\Pi_n^{s*} = (a - (1 - \phi)C)^2/8$ .*

Obviously, we have the identity  $\Pi_n^* = \Pi_n(w = w_n^*)$ , where  $\Pi_n(w = w_n^*)$  denotes the firm's expected profit with an exogenous input price (see Section 3.1) evaluated at the optimal input price  $w_n^*$  given in lemma 4.1. We will use this identity later in our analysis.

##### 4.2. Firm Installs Information System

Again, in the case with a monopoly supplier there is an additional stage where the monopoly supplier endogenously chooses its profit-maximizing input price. Therefore, as in Section 3.2, backward induction yields the firm's quantities  $x_i(0) = \frac{1}{2}(a - w)$  and  $x_i(C) = \frac{1}{2}(a - w - C/(1 - \phi))$ , where  $x_i(C) = 0$  if and only if  $w > a - C/(1 - \phi)$ . The corresponding expected profit  $\Pi_i$  of the firm is given in Section 3.2. The monopoly supplier anticipates the firm's quantity choices  $x_i(0)$  and  $x_i(C)$  and determines the input price  $w$ . Although the supplier can anticipate the quantities that are induced by the firm's truth-telling mechanism in case of low ( $c = 0$ ) and high ( $c = C$ ) marginal costs, since the input price is chosen before marginal costs are revealed the supplier is not able to condition the input price on the true marginal costs. Therefore, the supplier charges an input price based on the expected quantity and the supplier maximizes

$\Pi_i^s = w(\phi x_i(0) + (1 - \phi)x_i(C))$ . In detail, the supplier's profit is now given by<sup>11</sup>

$$\Pi_i^s = \begin{cases} w \left( \phi \frac{a-w}{2} + (1-\phi) \frac{a-w-C/(1-\phi)}{2} \right) & 0 < w \leq a - \frac{C}{1-\phi}, \\ w\phi \frac{a-w}{2} & a - \frac{C}{1-\phi} < w \leq a. \end{cases} \quad (3)$$

The optimal input price of the supplier can be determined by finding the *globally* optimal values of  $w$  for the two cases  $0 < w \leq a - C/(1 - \phi)$  and  $a - C/(1 - \phi) < w \leq a$ . Note that in the first case the firm produces under high and low marginal costs and the resulting supplier's profit is given by the first line in (3). In the second case, the firm only produces under low marginal costs and the supplier's profit is given by the second line in (3). At the threshold value  $w = a - C/(1 - \phi)$ , the two profits coincide and, therefore, the supplier's expected profit is continuous in  $w$  (but not differentiable). The following lemma gives the supplier's optimal input price as a function of  $C$  and the firm's optimal quantities and the expected profits of the parties. A proof of the first part of the lemma can be found in the mathematical appendix. The derivation of the second part is straightforward and is therefore omitted.<sup>12</sup>

LEMMA 4.2 *There exists a value  $\widehat{C} = a(1 - \sqrt{\phi})$  such that the following results hold.*

- (i) *For  $C < \widehat{C}$  the supplier charges  $w_i^* = (a - C)/2$  and for  $C > \widehat{C}$  the supplier charges  $w_i^* = a/2$ . In the boundary case  $C = \widehat{C}$  the supplier is indifferent between  $w = (a - C)/2$  and  $w = a/2$ .*
- (ii) *For  $C < \widehat{C}$ , the firm's quantities are  $x_i^*(0) = (a + C)/4$  and  $x_i^*(C) = (a(1 - \phi) - C(1 + \phi))/4(1 - \phi)$ . The resulting expected profit of the firm is  $\Pi_i^* = ((a - C)^2 - \phi(a - 3C)(a + C))/16(1 - \phi)$  and the expected profit of the supplier is  $\Pi_i^{s*} = (a - C)^2/8$ .*
- (iii) *For  $C > \widehat{C}$ , the firm's quantities are  $x_i^*(0) = a/4$  and  $x_i^*(C) = 0$ . The resulting expected profit of the firm is  $\Pi_i^* = \phi a^2/16$  and the expected profit of the supplier is  $\Pi_i^{s*} = \phi a^2/8$ .*

Figure 3 further illustrates part (i) of the lemma. The figure depicts the supplier's expected profit as a function of  $C$  for the case where the firm produces a positive quantity even if  $c = C$  and for the case where the firm stops production if marginal costs are high. It is shown that the supplier's input price increases from  $w_i^* = (a - C)/2$  to  $w_i^* = a/2$  before the firm's quantity in case of high costs becomes zero.

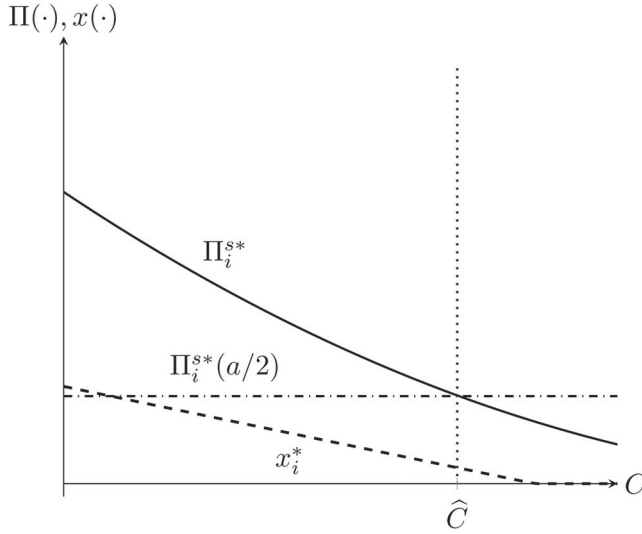
Obviously, due to the backward induction procedure we have the identity  $\Pi_i^* = \Pi_i(w_i = w_i^*)$  where for  $C < \widehat{C}$  the expression  $\Pi_i(w_i = w_i^*)$  denotes the firm's expected profit  $\Pi_i$  where production is positive for high and low marginal costs evaluated at the input price  $w_i^* = (a - C)/2$ . For  $C > \widehat{C}$ , the expected profit  $\Pi_i = \phi x_i(0)^2$  and  $w_i^* = a/2$  have to be used.

#### 4.3. Comparison of Information Regimes

To determine under which conditions the owner benefits from a truthful report on the marginal production costs under the presence of a monopoly supplier, we compare the firm's expected

<sup>11</sup>In the case  $w > a$ , the supplier's expected profit is zero. Such a high input price is never optimal, however, since the supplier could achieve a positive profit by setting an input price  $w < a$ . Therefore, we can restrict our analysis to the interval  $0 < w < a$ .

<sup>12</sup>The firm's quantities follow from inserting the input price  $w_i^*$  into  $x_i(0) = \frac{1}{2}(a - w)$  and  $x_i(C) = \frac{1}{2}(a - w - C/(1 - \phi))$ , where  $x_i(C) = 0$  for  $C > \widehat{C}$ . Using the input price and the firm's quantities, the expected profits can be derived.



**Figure 3.** The figure shows the supplier's expected profit as a function of  $C$  for  $a = 6$  and  $\phi = 0.3$ . The solid curve represents the expected profit  $\Pi_i^{s*} = \frac{1}{8}(a - C)^2$  given that the firm produces a positive quantity in both states. The optimal input price in this case is  $w_i^* = (a - C)/2$ . The dash-dotted horizontal line represents the expected profit  $\Pi_i^{s*} = \phi(a^2/8)$  ( $\Pi_i^{s*}(a/2)$ ) given that the firm does not produce in case of high costs. In this case,  $w_i^* = a/2$ . At  $\widehat{C}$  where the two curves intersect, the supplier's optimal input price jumps upwards from  $w_i^* = (a - C)/2$  to  $w_i^* = a/2$ . The dashed line depicts the firm's quantity  $x_i^*$  in case of high costs given an input price of  $w_i^* = (a - C)/2$ . The figure reveals that the jump in the input price at  $\widehat{C}$  occurs in an admissible region (i.e., before the firm's quantity in case of high costs becomes 0).

profits for the two information regimes. Installing an information system is profitable, if and only if

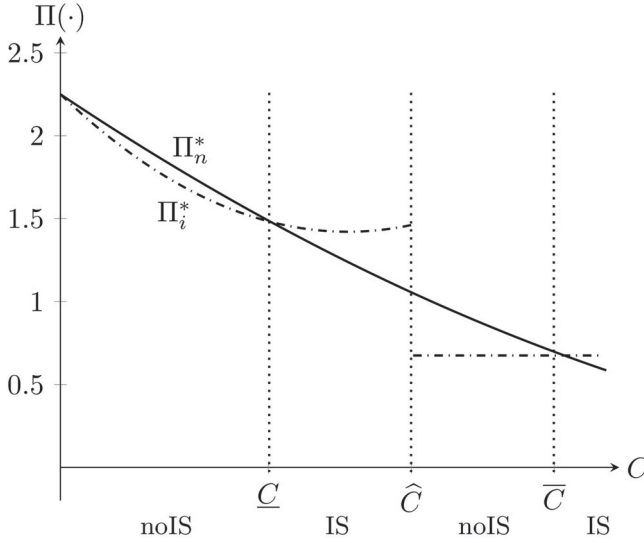
$$\Pi_i^* = \Pi_i(w_i = w_i^*) \geq \Pi_n^* = \Pi_n(w_n = w_n^*).$$

We first consider the case where  $C < \widehat{C}$ . Comparing the expected profits  $\Pi_i^*$  in Lemma 4.2, (ii) and  $\Pi_n^*$  in Lemma 4.1 shows that there exists a cutoff value,  $\underline{C} = 2a(1 - \phi)/(6 - (3 - \phi)\phi)$ , with  $0 < \underline{C} < \widehat{C} = a(1 - \sqrt{\phi})$  such that  $\Pi_i^* < \Pi_n^*$  for  $0 < C < \underline{C}$  and  $\Pi_i^* > \Pi_n^*$  for  $\underline{C} < C < \widehat{C}$ .<sup>13</sup> The following proposition summarizes our findings. Again, the proof is straightforward and is, therefore, omitted.

**PROPOSITION 4.3** *Consider the range of marginal costs  $C$  where  $0 \leq C \leq \widehat{C}$ . Then, there exists a value  $\underline{C} = 2a(1 - \phi)/(6 - (3 - \phi)\phi)$  with  $0 < \underline{C} < \widehat{C} = a(1 - \sqrt{\phi})$  such that the following results hold.*

- (i) If  $C < \underline{C}$ , the firm's expected profit with a monopoly supplier is higher if the owner does not install an information system and relies on ex-ante information about marginal costs, i.e.,  $\Pi_n^* > \Pi_i^*$ .
- (ii) If  $C > \underline{C}$ , the firm's expected profit is higher if the owner installs an information system and asks the manager for a cost report, i.e.,  $\Pi_n^* < \Pi_i^*$ .
- (iii) For  $C = 0$  and  $C = \underline{C}$  the owner is indifferent between these two options.

<sup>13</sup>The observation that  $\underline{C} < \widehat{C}$  follows easily from  $\widehat{C} - \underline{C} = a(1 - \sqrt{\phi})^2(4 - \phi + (2 - \phi)\sqrt{\phi})/(6 - 3\phi + \phi^2) > 0$ . While in the region  $\underline{C} < C < \widehat{C}$  the owner benefits from installing an information system, the supplier and the consumers are worse off. Nevertheless, it can be shown that there exists a threshold  $C_w$  such that the total supply chain profit and welfare are higher if the firm installs the information system if  $C_w < C < \widehat{C}$ . Details are available upon request.



**Figure 4.** The figure depicts the firm's expected profits  $\Pi_n^*$  (solid curve) and  $\Pi_i^*$  (dash-dotted curve) under endogenous supplier pricing as functions of  $C$  for  $a = 6$  and  $\phi = 0.3$ . Between  $\underline{C}$  and  $\widehat{C}$  and above  $\bar{C}$ , we have  $\Pi_i^* > \Pi_n^*$ . Hence, it is optimal to install an information system (IS). In the regions between 0 and  $\underline{C}$  and between  $\widehat{C}$  and  $\bar{C}$ , it is optimal not to install the information system (noIS).

Next, we consider the case where  $C > \widehat{C}$ . A comparison of the expected profits  $\Pi_i^*$  in Lemma 4.2, (iii) and  $\Pi_n^*$  in Lemma 4.1 shows that there exists a cutoff value,  $\bar{C} = a/(1 + \sqrt{\phi})$  which is smaller than  $C_{\max} = a(1 - \phi)$  only if  $\phi < (3 - \sqrt{5})/2$ . In this case, the firm prefers to install an information system if  $C > \bar{C}$  and prefers not to install an information system if  $C < \bar{C}$ . The next proposition summarizes our findings.

**PROPOSITION 4.4** Consider the range of costs  $C$  where  $\widehat{C} < C \leq a(1 - \phi)$ . Then, the following results hold.

- (i) If the probability  $\phi$  of low marginal cost  $c = 0$  is sufficiently low, i.e.,  $\phi < (3 - \sqrt{5})/2 \approx 0.38197$ , then there exists a value  $\bar{C} = a/(1 + \sqrt{\phi}) < C_{\max} = a(1 - \phi)$  such that for  $C < \bar{C}$  the firm's expected profit is higher if the owner does not install an information system and for  $C > \bar{C}$  the firm's expected profit is higher if the owner installs an information system and asks the manager for a cost report. For  $C = \bar{C}$  there is indifference.
- (ii) If the probability  $\phi$  is sufficiently high, i.e.,  $\phi > (3 - \sqrt{5})/2$ , the firm's expected profit is always higher if the owner does not install an information system.
- (iii) If the probability  $\phi$  satisfies  $\phi = (3 - \sqrt{5})/2$ , the firm's expected profit is always higher if the owner does not install an information system for all  $C \neq a(1 - \phi)$ . For  $C = a(1 - \phi)$ , the firm's expected profit is identical under both systems.

The full range of the owner's choice of information system in the first stage of our game is obtained by combining the results provided in Propositions 4.3 and 4.4. Figure 4 illustrates the situation for  $\phi < (3 - \sqrt{5})/2$ .

If marginal costs  $C$  are small,  $C < \underline{C}$ , it is optimal not to install an information system since  $\Pi_n^* > \Pi_i^*$ . If  $C$  is medium-low, i.e.,  $\underline{C} < C \leq \widehat{C}$ , it is optimal to install an information system and ask the manager for a cost report. For  $C = \underline{C}$  both information regimes yield the same expected profit for the firm. For  $\widehat{C} < C < \bar{C}$ , it is again optimal not to install an information system.

Finally, if marginal costs are very high, i.e.,  $C > \bar{C}$ , it is again optimal to install an information system and ask the manager for a cost report. For  $C = \bar{C}$  both information regimes again yield the same expected profit for the firm.

#### 4.4. Influence of Monopoly Supplier Pricing on the Choice of Information System

There are two major differences that occur due to endogenous supplier pricing.<sup>14</sup> First, the structure of the optimal choice of the information system changes. While for a fixed input price there is a single threshold such that installing an information system and asking the manager for a cost report is beneficial if marginal costs are sufficiently large, this sort of ‘monotonicity’ is lost with an endogenous supplier price. Second, installing an information system and involving the manager might be beneficial more or less frequently depending on the range of marginal costs.

Consider the change in structure first. As described in Proposition 3.1, with an exogenous input price installing an information system is beneficial if and only if the marginal costs  $C$  are sufficiently high, i.e.,  $C > C_b$ . Intuitively, this is the case if the value of obtaining true information about marginal costs dominates the negative effect of the manager’s information rent. With an endogenous supplier price, Propositions 4.3 and 4.4 jointly show that for  $\phi < (3 - \sqrt{5})/2$  there are two disconnected regions,  $\underline{C} < C < \hat{C}$  and  $\bar{C} < C < a(1 - \phi)$ , in which it is optimal to install the information system.

To understand the influence of the monopoly supplier on the design of the information system, we reconsider the composition of expected profits (see Section 3.3) but with endogenous input prices instead of exogenous input costs. The owner benefits from installing an information system if and only if

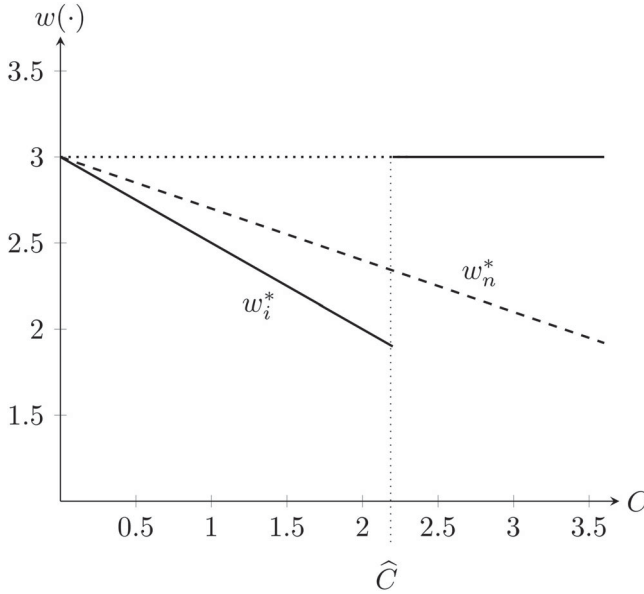
$$\Pi_i^* = (\bar{x}_n(w_i = w_i^*))^2 + \frac{1}{4} \text{Var}(\hat{c}) > (x_n^*(w_n = w_n^*))^2 = \Pi_n^*,$$

where we recall that  $\bar{x}_n$  denotes the quantity an uninformed firm owner would produce given a cost structure that incorporates the agency costs. In the case of an exogenous input price  $w$ , the expressions on both sides of the inequality are evaluated at the *same* input price while in the case of an endogenous supplier price, the two sides of the inequality have to be evaluated with *different* input prices,  $w_i^*$  and  $w_n^*$ . Figure 5 depicts the input prices charged by the supplier depending on the firm’s choice of installing an information system (see also Lemmas 4.2, (i) and 4.1). The dashed line represents the input price if the owner does not install an information system and relies on ex-ante cost information,  $w_n^*$ . The bold line represents the input price if the owner installs an information system and asks the manager for a cost report,  $w_i^*$ . For  $C \leq \hat{C}$ , the input price is lower if the owner installs an information system, while the opposite holds for  $C > \hat{C}$ .

Under endogenous supplier pricing, in addition to the value of learning the true marginal costs and the information rent effect discussed earlier, there is a third effect – the *input price effect*. The input price  $w_i^*$  is discontinuous in the marginal costs  $C$ , i.e., it jumps upwards at  $C = \hat{C}$ . Therefore, the input price effect of installing an information system is positive for  $C \leq \hat{C}$  and negative for  $C > \hat{C}$ . In the region  $C \leq \hat{C}$ , the supplier anticipates that the owner faces agency costs if an information system is installed. In effect, this leads to higher marginal production costs and to a decrease in the expected production quantity,  $\phi x_i^*(0) + (1 - \phi)x_i^*(C) = (a - C)/4 < (a - (1 - \phi)C)/4 = x_n^*$ . Therefore, the supplier reduces its input price to increase demand for

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<sup>14</sup>We consider the scenario under a perfect information system separately in the next section.



**Figure 5.** The figure shows the input price  $w_n^*$  if no information system is installed (dashed line) and the input price  $w_i^*$  if an information system is installed (bold line) as a function of the costs  $C$  for  $a = 6$  and  $\phi = 0.4$ .

the input. The result is that  $\underline{C} < C_b$ .<sup>15</sup> For  $C > \widehat{C}$ , the supplier accepts that the firm does not produce in case of high costs if the information system is installed. Therefore, it charges the monopoly input price given that  $c = 0$ . This input price is higher than if the owner does not install an information system. Now the owner’s value of learning the true marginal costs has to be sufficiently large to dominate this negative input price effect and the agent’s information rent which is the case if  $C > \overline{C}$  and  $\overline{C} > \widehat{C}$ . To summarize, the input price effect causes a structural change in the owner’s decision to install an information system.

Consider next the question whether the firm would want to install an information system more or less frequently in the presence of a monopoly supplier. The arguments above show that for  $C \leq \widehat{C}$ , we have  $\underline{C} < C_b = 2(1 - \phi)(a - w)/((\phi - 3)\phi + 3)$ . Consequently, we can predict that installing an information system is beneficial more frequently. Consider next the case  $C > \widehat{C}$ . Obviously,  $C_b = (a - w)/(1 + \sqrt{\phi}) < \overline{C} = a/(1 + \sqrt{\phi})$ . Therefore, we can predict that installing the information system is beneficial less frequently.

#### 4.5. Firm Installs Perfect Information System

In this section, we want to address another main point of our analysis: would the firm owner prefer installing a perfect information system and learn the true cost information at cost  $K$  without involving the manager? Recall that in the case of an exogenous supplier price the owner would certainly prefer such a system if  $K = 0$ . Here we want to demonstrate that an endogenous supplier price changes this result. Notice that this research question is somehow opposite to our analysis so far as well as Rajan and Saouma (2006). In Rajan and Saouma (2006), the question is how much the principal would want to inform the manager given that the principal does not have

<sup>15</sup>Assume the opposite, i.e  $\underline{C} > C_b$ . Rewrite the inequality  $\Pi_i(w_i = w_i^*) < \Pi_n(w_n = w_n^*)$  as  $\Pi_i(w_i = w_i^*) - \Pi_i(w_n = w_n^*) + \Pi_i(w_n = w_n^*) < \Pi_n(w_n = w_n^*)$  and evaluate at  $C = C_b$ . Since  $\Pi_i(w_n = w_n^*) = \Pi_n(w_n = w_n^*)$ , it follows that  $\Pi_i(w_i = w_i^*) - \Pi_i(w_n = w_n^*) < 0$ , which is a contradiction because of  $w_i^* < w_n^*$ .

information while here we ask whether the principal prefers to be informed taking into account that if the principal does not obtain the information, the manager could be asked for a cost report instead. The following result can be shown.

**LEMMA 4.5** *If the firm owner installs a perfect information system at costs  $K$ , then there exists a value  $\widehat{C}^* = a/(1 + \sqrt{\phi})$  such that the following holds.*

- (i) *For  $C \leq \widehat{C}^*$  the firm's optimal quantities are given by  $x_1^*(0) = (a + (1 - \phi)C)/4$  and  $x_1^*(C) = (a - (1 + \phi)C)/4$ . The supplier charges the input price  $w_1^* = (a - (1 - \phi)C)/2$ . The firm's equilibrium profit is  $\Pi_1^* = \phi(x_1^*(0))^2 + (1 - \phi)(x_1^*(C))^2 - K$  and the supplier's equilibrium profit is  $\Pi_1^{s*} = w_1^*(\phi x_1^*(0) + (1 - \phi)x_1^*(C))$ .*
- (ii) *For  $C > \widehat{C}^*$ , the firm's optimal quantities are given by  $x_1^*(0) = a/4$  and  $x_1^*(C) = 0$ . The supplier charges the input price  $w_1^* = a/2$ . The firm's equilibrium profit is  $\Pi_1^* = \phi(x_1^*(0))^2 - K$  and the supplier's equilibrium profit is  $\Pi_1^{s*} = w_1^*(\phi x_1^*(0))$ .*

Note that  $\widehat{C}^* \geq \widehat{C} = a(1 - \sqrt{\phi})$  with strict inequality for  $\phi \neq 0$ . In fact,  $\widehat{C}^* < a(1 - \phi)$  if and only if  $\phi < \frac{1}{2}(3 - \sqrt{5}) \approx 0.38197$ . So the second case of Lemma 4.5 only occurs for  $\phi < \frac{1}{2}(3 - \sqrt{5})$ .

Using Lemma 4.5, we can now demonstrate that although the firm owner has to pay an information rent if only the manager can observe the firm's marginal costs, in the presence of a third party (here a supplier) the owner might nevertheless prefer this situation rather than installing a perfect information system which grants the owner access to cost information. Intuitively, the firm's "handicap" works to the owner's advantage since the commitment to rely on the manager's cost report influences the supplier's price response.

To elaborate, consider the range  $C \leq \widehat{C}$  and compare the firm's expected profit if a perfect information system is installed,  $\Pi_1^*$ , with the expected profit if the owner relies on the manager's cost report,  $\Pi_i^*$ ; see Lemmas 4.5 and (4.2), respectively. We get

$$\Pi_1^* - \Pi_i^* = \frac{\phi C (2a(1 - \phi) - C (2 + 5\phi - 3\phi^2))}{16(1 - \phi)} - K.$$

Assume that  $K = 0$  as in the case with exogenous supplier price. The expression on the right-hand side is concave in  $C$  and is zero at  $C = 0$  and  $\widetilde{C} = 2a(1 - \phi)/(2 - \phi)(1 + 3\phi)$ . Since  $\underline{C} < \widetilde{C}$  and  $\widetilde{C} < \widehat{C}$  if  $\phi > (7 - \sqrt{33})/6 \approx 0.2092$ , if the probability  $\phi$  of marginal costs  $c = 0$  is sufficiently high there is a range of marginal costs,  $\widetilde{C} < C < \widehat{C}$ , where the firm's expected profit is higher if it relies on the manager's cost report. The surprising conclusion which contrasts conventional wisdom is that even if the owner could learn the true marginal costs by installing a perfect information system at no costs, it might not be beneficial.

**PROPOSITION 4.6** *If the probability  $\phi$  is sufficiently large, i.e.,  $\phi > (7 - \sqrt{33})/6$ , then there exists a value  $\widetilde{C} = 2a(1 - \phi)/(2 - \phi)(1 + 3\phi) > \underline{C}$  such that for  $\widetilde{C} < C \leq \widehat{C}$  the firm prefers to install an information system and ask the manager for a cost report even if perfect information would be available at no costs (i.e.,  $\Pi_1^* > \Pi_i^*$  for  $K = 0$ ). For  $C = 0$  the owner is indifferent and for  $0 < C < \widetilde{C}$ , the owner prefers a perfect information system.*

To end this section, we briefly comment on the case of positive information costs  $K$  and still assume  $\phi > (7 - \sqrt{33})/6$  for simplicity. The difference  $\Pi_1^* - \Pi_i^*$  is concave in  $C$  and has a unique maximum. Obviously, if  $K$  is larger than the maximum, it is never optimal to install a perfect information system. However, if  $K$  is sufficiently small, there exist values  $\widetilde{C}_1(K)$  and  $\widetilde{C}_2(K)$  such that it is optimal to install an information system and ask the manager for a cost



report if and only if  $\tilde{C}_1(K) < C < \tilde{C}_2(K)$ . If  $C < \tilde{C}_1(K)$  or  $C > \tilde{C}_2(K)$ , it is optimal to install a perfect information system.<sup>16</sup> Finally, due to the concavity of the difference  $\Pi_I^* - \Pi_i^*$  it follows that  $\tilde{C}_1(K)$  is increasing in  $K$ , while  $\tilde{C}_2(K)$  is decreasing in  $K$ .

## 5. Robustness and Extensions

Our results have been derived in a parsimonious setting with a binary cost structure assuming  $c = 0$  and  $c = C > 0$ . This raises the question how robust the main insights of this paper are with regard to modifications of the cost structure. We first report our findings if both marginal cost realizations are positive. Then we briefly summarize the results for the case of three possible cost realizations. Finally, we illustrate how our results are affected if cost realizations are continuously distributed over an entire interval.<sup>17</sup>

### 5.1. Positive binary cost realizations

Assume that marginal costs can be  $0 < c_1 < c_2$  with probabilities  $\phi$  and  $1 - \phi$ . Then it can be shown that  $w_n^* = (a - \phi c_1 - (1 - \phi)c_2)/2$ . Fixing  $c_1$ , we get  $w_i^* = (a - c_2)/2$  if  $c_2 < \hat{c}_2$  and  $w_i^* = (a - c_1)/2$  if  $c_2 > \hat{c}_2$  where the threshold  $\hat{c}_2 = a - (a - c_1)\sqrt{\phi}$ . It can now be shown that there exist  $\underline{c}_2$  and  $\bar{c}_2$  such that identical statements as in Propositions 4.3 and 4.4 can be made. Moreover, if the probability of low costs is sufficiently large, the owner is better off installing an information system and asking the manager for a cost report rather than installing a perfect information system.

### 5.2. Three possible cost realizations

Assume that marginal costs can be  $c_1 = 0$ ,  $c_2 = C/2$ , and  $c_3 = C$  with probabilities  $\phi_1$ ,  $\phi_2$  and  $1 - \phi_1 - \phi_2$  respectively, so that the expected marginal costs are  $E(c) = C(1 - \phi_1 - \phi_2/2)$ . Then  $w_n^* = (a - E(c))/2$ . The case where the owner installs an information system and asks the manager for a cost report can be analyzed using standard textbook methods (e.g., Laffont & Martimort, 2002).<sup>18</sup> We find that there are three intervals for  $C$ .<sup>19</sup> For low  $C$ , the firm produces no matter what the cost realization is and the supplier charges  $w_i^* = (a - C)/2$ . If  $C$  is intermediate, then the firm shuts down production only if costs are  $C$  and the input price is  $w_i^* = (2a - C)/4$ . Finally, if marginal costs are high, then the firm only produces if marginal costs are low and the input price is  $w_i^* = a/2$ . In each of the intervals, the owner prefers not to install an information system if  $C$  is small, but prefers to install an information system and asks the manager for a report if  $C$  is sufficiently large.<sup>20</sup> Finally, if we restrict ourselves to the case where all quantities are positive, then in line with our simple case considered in the main text, we can find situations where the owner might prefer to install an information system and ask the manager for a cost report rather than install a perfect information system. The conclusion of our analysis is that the main messages of our paper carry over to the case of three possible cost realizations.

<sup>16</sup>Note that the difference is negative at  $C = 0$  and also at  $C = \hat{C}$  (because of  $\phi > (7 - \sqrt{33})/6$ ). If  $\phi > (7 - \sqrt{33})/6$  and  $K$  sufficiently small, installing a perfect information system is optimal for  $C \in (\tilde{C}_1(K), \hat{C})$ . For larger values of  $K$ , installing a perfect information system is optimal if and only if  $\tilde{C}_1(K) < C < \tilde{C}_2(K)$ .

<sup>17</sup>To save space, we will not provide the full details of the derivations. They are, however, available upon request.

<sup>18</sup>To guarantee that the monotonicity condition  $x(0) < x(C/2) < x(C)$  holds, we need  $\phi_2 \geq \phi_1(1 - \phi_1 - \phi_2)$ .

<sup>19</sup>For example, if  $\phi_1 = \phi_2 = 1/3$ , then the thresholds where the input price changes are  $\hat{C}_1 \approx 0.31a$  and  $\hat{C}_2 \approx 0.5857a$ .

<sup>20</sup>In the case of equal probabilities, the thresholds where the transition occurs are  $C \approx 0.293a$ ,  $C \approx 0.522a$  and  $C \approx 0.845a$ . Hence, for example in the case where all quantities are positive, if  $C < 0.293a$  the owner prefers not to install the information system while it is profitable to install an information system for  $0.293a < C < 0.31a$ .

### 5.3. Continuous distribution of marginal costs

We assume that marginal costs  $c$  are uniformly distributed on the interval  $[0, C]$ . If the firm owner *does not install an information system*, the production decision can only be conditioned on the expected marginal costs,  $E(c) = C/2$ . The optimal quantity is, hence,  $x_n^* = \frac{1}{4}(2a - C - 2w)$ . The supplier maximizes  $\Pi_i^s = wx_n^*$ , which yields  $w_n^* = \frac{1}{4}(2a - C)$ . The firm's resulting expected profit is  $\Pi_n^* = \frac{1}{16}(a - \frac{C}{2})^2$ .

If the firm owner *installs an information system*, then it is again standard to show that if the manager obtains the cost information, the owner's problem can be simplified to<sup>21</sup>

$$\max_{x(\cdot)} \int_0^C (a - x(c) - 2c - w)x(c) \frac{1}{C} dc.$$

Pointwise optimization yields  $x_i(c) = \frac{1}{2}(a - 2c - w)$  as long as  $x_i(c) > 0$  (i.e., for  $c < (a - w)/2$ ) and 0 otherwise. Anticipating the firm's demand  $x(c)$ , the supplier's objective function is

$$\frac{1}{C} \int_0^{(a-w)/2} \frac{1}{2} w(a - 2c - w) dc = \frac{w(a - w)^2}{8C} \quad \text{for } a > w > a - 2C$$

and

$$\frac{1}{C} \int_0^C \frac{1}{2} w(a - 2c - w) dc = \frac{1}{2} w(a - C - w) \quad \text{for } w \leq a - 2C,$$

and 0 for  $w > a$ . Using the corresponding first-order conditions, it can be shown that  $w_i^* = (a - C)/2$  for  $C \leq \frac{a}{3}$  and  $w_i^* = \frac{a}{3}$  for  $C > \frac{a}{3}$ . In contrast to the case of a discrete probability distribution, the input price  $w_i^*(C)$  depends continuously on  $C$ .

The owner's objective function can be written as  $\int_0^C (x(c))^2 (1/C) dc$  and inserting the corresponding input price  $w_i^*$ , the firm's expected profit is  $\Pi_i^* = \frac{1}{48}(3a^2 - 6aC + 7C^2)$  for  $C < a/3$  and  $\Pi_i^* = (a^3/81C)$  for  $C \geq a/3$ . Since the input price  $w_i(\cdot)$  is continuous, the firm's expected profit  $\Pi_i^*(\cdot)$  is continuous in  $C$  as well.

It is easy to see that for  $C < a/3$ , the firm's corresponding profit  $\Pi_i^*$  is always strictly smaller than  $\Pi_n^*$  (except for  $C = 0$  where they are equal). For  $C \geq a/3$ , it can be shown that there is a unique intersection  $\bar{C}$  of  $\Pi_n^*$  and  $\Pi_i^*$  between  $a$  and  $2a$ .<sup>22</sup>

The following proposition summarizes the result.

**PROPOSITION 5.1** *There exists a value  $\bar{C} \in (a, 2a)$  such that for  $C < \bar{C}$  the firm's expected profit is higher if the firm owner does not install an information system and for  $C > \bar{C}$  the firm's expected profit is higher if the firm owner installs an information system and asks the manager for a cost report.*

This result differs qualitatively from the more complex result in the discrete case (cf. Proposition 4.4). To identify the reason for this difference, let  $\phi = \frac{1}{2}$  in Proposition 4.4 which corresponds to a discrete uniform distribution. First, notice that in both cases of cost distributions

<sup>21</sup>In the case where the owner installs a perfect information system, the optimization problem is  $\max_{x(\cdot)} \int_0^C (a - x(c) - c - w)x(c) (1/C) dc$ . The difference to the present situation where the owner installs an information system and asks the manager for a cost report, is that here we have costs of  $2c$  instead of  $c$ .

<sup>22</sup>To see this, note that the profit difference  $\Pi_n^* - \Pi_i^*$  is a polynomial of order 3 and is positive for  $C = a/3$  while it goes to  $-\infty$  for  $C \rightarrow 0$ . Hence, there is one root in  $(0, a/3)$ . The difference is negative for  $C = 2a$  and positive for  $C = 3a$ . Hence, one further root is in  $(2a, 3a)$ . Since the difference is positive for  $C = a$ , the final root is in  $(a, 2a)$ .

(discrete or continuous), the firm's expected profit if it does not install an information system is  $\Pi_n^* = \frac{1}{16}(a - C/2)^2$ . Only expected marginal costs matter here, and they are identical in both models (given  $\phi = \frac{1}{2}$ ). If the firm installs an information system, examining the respective optimization problem shows that the expected costs (taking into account the agency problem) are the same (and equal to  $C$ ) in both models. For both cases, we find two regimes (the role of  $\widehat{C}$  where the supplier changes the input price due to rationing is played by  $C = a/3$  here) where in the first regime the firm always produces in equilibrium independent of marginal costs while in the second regime the firm stops producing for high values of  $c$ . Also notice that for  $C < \frac{a}{3}$ , in both cases the input price is  $w_i^* = \frac{a-C}{2}$  and, hence, is smaller than the input price  $w_n^* = \frac{1}{4}(2a - C)$ . The input price effect of installing an information system is positive. If  $C \geq a/3$ , then the input price is larger than  $w_n^*$  if  $C > 2a/3$ . Consequently, if  $C$  is sufficiently large, the input price effect of installing an information system is negative just like in the discrete distribution model.

Despite these parallels, in the case of a continuous cost distribution it is not profitable for the owner to install an information system for  $C < a/3$  and only if  $C$  is sufficiently large is it profitable to do so (akin to the discrete distribution model for  $C > \widehat{C}$ ). The difference in the results is caused by a smaller expected value of perfect information in the continuous model. In the continuous model, the variance is  $\int_0^C (c - C)^2 (1/C) dc = \frac{C^2}{3}$  while in the discrete model the variance equals  $\frac{1}{2}(0 - C)^2 + \frac{1}{2}(2C - C)^2 = C^2$ . Since the expected value of perfect information increases with the variance, the claim follows. Intuitively, the distance to the expected value is always maximal in the discrete case ( $C$ ), while it can be rather small in the continuous case. Consequently, for  $C < a/3$  the function  $\Pi_i^*$  is (point-wise) larger in the discrete case than in the continuous case.

To conclude our analysis, we would like to comment on the relation between the continuous model and the model with a discrete distribution of marginal costs. Although we believe that it is theoretically paying to study the continuous model, we also think that the discrete model is more in line with the real world. Note that in the continuous model it is assumed that the manager obtains perfect cost information for any possible cost realization in the considered interval. One possible way to model an information environment which is less demanding and requires less precise information, is via a partition (for example, the interval  $[0, C]$  could be partitioned into the two intervals  $[0, z]$  and  $(z, C]$  with  $0 < z < C$ ). The information system then tells the agent only the interval in which the true costs lie. Such a partition transfers the continuous model into a discrete model. Since information systems are in general not completely precise (and often take the form of partitions), it seems plausible that in most cases information will be discrete.<sup>23</sup>

## 6. Conclusion

Management accounting research has mainly focused on questions concerning the design of control and incentives within firm boundaries. Broadly speaking, our paper makes the point that a firm interacts with a variety of external non-financial stakeholders like customers, suppliers, and rivals. The decisions that are made within the firm have an impact on the behavior of other stakeholders and, vice versa, decisions made by these external stakeholders influence decisions within the organization. In this sense, we contribute to the emerging line of – mainly empirical – accounting research that studies the interaction between a firm's corporate policy and the firm's non-financial stakeholders (e.g., Arora & Alam, 2005; Dekker, 2016; Hui, Klasa, & Yeung, 2012; Raman & Sharur, 2008; Sedatole, Vrettos, & Widener, 2012).

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<sup>23</sup>See, for example, Bertomeu, Magee, and Schneider (2019) where accounting standards are modeled as partitions. The underlying information, however, is continuous in their model.

The common view in the accounting and economics literature is that the owner benefits from involving a better-informed manager in decisions but that the manager has an incentive to mis-report private information. Eliciting truthful information, the owner has to pay an information rent which makes the manager's participation costly. Depending on the owner's value of perfect information and the size of the manager's information rent, the owner prefers to rely on ex-ante information or to install an information system and let the manager report the observed costs. This paper offers a novel perspective on the optimal design of a firm's information system since it highlights the important interaction between the choice of information system and the firm's supply side. We show that there is a crucial interdependence between the design of the firm's information system and the pricing behavior of the firm's supplier. In particular, if the owner asks the manager for a cost report, the associated information rent reduces the firm's expected production. This causes the supplier to reduce the input price. This positive input price effect has to be traded off against the other two, more well-known effects.

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No potential conflict of interest was reported by the authors.

### ORCID

Georg Schneider  <http://orcid.org/0000-0001-7301-556X>

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## Appendix. Proofs

*Proof of Lemma 4.2* To prove the lemma, we make use of the following lemma: ■

**LEMMA A.1** *The locally optimal input price of the supplier is given by (i) if  $0 < w \leq a - C/(1 - \phi)$ , we have  $w = (a - C)/2$  for  $C \leq a(1 - \phi)/(1 + \phi)$  and  $w = a - C/(1 - \phi)$  for  $C > a(1 - \phi)/(1 + \phi)$ ; (ii) if  $a - \frac{C}{(1-\phi)} < w \leq a$ , we have  $w = a/2$  for  $C > a(1 - \phi)/2$  and  $w = a - C/(1 - \phi)$  for  $C \leq a(1 - \phi)/2$ .*

*Proof of Lemma A.1* We first derive the supplier's locally optimal input price in region 1 (i.e.,  $w \leq a - C/(1 - \phi)$ ). The objective function is given by the first line in (3), which can be rewritten as  $\frac{1}{2}(a - C - w)w$ . The first-order condition yields the input price  $w = (a - C)/2$  as long as this value is in region 1, i.e., as long as  $w = (a - C)/2 \leq a - C/(1 - \phi)$ . This latter condition translates into the requirement that  $C \leq a(1 - \phi)/(1 + \phi)$ . Since the objective function in region 1 is concave, this is the locally optimal value in region 1 as long as  $w$  is in region 1. If this is not the case, then the locally optimal input price in region 1 is attained at the upper bound of the region ( $w = a - C/\phi$ ). The result for region 2 can be obtained similarly. ■

We can now prove Lemma 4.2. First, note that  $a(1 - \phi)/(1 + \phi) > a(1 - \phi)/2$ . Therefore, for  $C \leq a(1 - \phi)/2$  the local maximum in region 1 is the global maximum. This is because the objective function decreases in  $w$  if  $w$  exceeds  $(a - C)/2$  in region 1 and because the objective function is continuous in  $w$  and must decrease in region 2 (because the local maximum in region 2 is attained at the lower bound of region 2). Similarly, one can show that

for  $C \geq a(1 - \phi)/(1 + \phi)$  the local maximum in region 2 is the global maximum. Finally, for  $a(1 - \phi)/(1 + \phi) > C > a(1 - \phi)/2$  the maximal value in region 1 is  $\frac{1}{8}(a - C)^2$  and in region 2 it is  $\phi(a^2/8)$ . For  $C = a(1 - \phi)/2$ , we have  $\frac{1}{8}(a - C)^2 > \phi(a^2/8)$  and for  $C = a(1 - \phi)/(1 + \phi)$  we have  $\frac{1}{8}(a - C)^2 < \phi(a^2/8)$ . Also,  $\frac{1}{8}(a - C)^2$  is strictly decreasing in  $C$  while  $\phi(a^2/8)$  is constant in  $C$ . Therefore, there exists a unique value  $\widehat{C}$  such that  $\frac{1}{8}(a - \widehat{C})^2 = \phi(a^2/8)$ . Solving this equation yields  $\widehat{C} = a(1 - \sqrt{\phi})$ .

*Proof of Proposition 4.4* It remains to be shown that  $\overline{C} = a/(1 + \sqrt{\phi}) < C_{\max} = a(1 - \phi)$  if and only if  $\phi < (3 - \sqrt{5})/2$ . It is not difficult to show that  $1/(1 + \sqrt{\phi}) = 1 - \phi$  if and only if  $\phi = 0$  or  $\phi = (3 - \sqrt{5})/2$ . Substituting  $\phi = Q^2$  yields  $1 - (1 - \phi)(1 + \sqrt{\phi}) = Q(Q^2 + Q - 1)$ . This polynomial is strictly positive for  $Q = 1$  and its derivative  $\frac{\partial}{\partial Q}Q(Q^2 + Q - 1) = -1 + Q + Q^2 + Q(1 + 2Q)$  is negative for  $Q = 0$ . Therefore  $\frac{1}{1 + \sqrt{\phi}} < 1 - \phi$  if and only if  $0 < \phi < \frac{3 - \sqrt{5}}{2}$ . This finishes the proof. ■

*Proof of Lemma 4.5* The proof follows along the lines of the proof of Lemma 4.2. The value  $\widehat{C}^*$  is the unique solution of the equation  $\frac{1}{8}(a - C(1 - \phi))^2 = \phi(a^2/8)$  that satisfies  $a - C(1 - \phi) > 0$ . We have  $\widehat{C} = a(1 - \sqrt{\phi}) < \widehat{C}^* = \frac{a}{1 + \sqrt{\phi}}$  if and only if  $a(1 - \phi) < a$  which is satisfied for all  $\phi \neq 0$ . ■

*Proof of Proposition 4.6* For  $C \leq \widehat{C}^*$  we can calculate  $\Pi_i^* - \Pi_i = C\phi(2a(\phi - 1) + C(-3\phi^2 + 5\phi + 2))/16(\phi - 1)$ . This difference is strictly negative if and only if  $C > \widetilde{C} := 2a(1 - \phi)/(2 - \phi)(1 + 3\phi)$ . It remains to compare the threshold value  $\widetilde{C}$  with  $\underline{C}$  and  $\widehat{C}$ . Recall that  $\underline{C} = 2a(1 - \phi)/(6 - (3 - \phi)\phi)$  and  $\widehat{C} = a(1 - \sqrt{\phi})$ . Comparing the first two values, we get  $\widetilde{C} - \underline{C} = 8(1 - \phi)^3/(2 - \phi)(1 + 3\phi)(6 - (3 - \phi)\phi) \geq 0$ . For the second comparison, we have  $\widetilde{C} - \widehat{C} = (2a(1 - \phi)/(2 - \phi)(1 + 3\phi)) - a(1 - \sqrt{\phi})$ . This difference equals 0 if and only if  $2(\phi - 1) - (1 - \sqrt{\phi})(3\phi^2 - 5\phi - 2) = 0$ . It is not difficult to show that the above polynomial has exactly three zeros,  $\phi = 1$ ,  $\phi = 0$ , and  $\phi = \frac{1}{6}(7 - \sqrt{33})$ , and that the derivative of  $\widetilde{C} - \widehat{C}$  is  $\infty$  for  $\phi = 0$ . Also, substituting  $\phi = Q^2$  in this polynomial yields (as is easily checked) the expression  $(Q - 1)^2Q(3Q^2 + 3Q - 2)$ . Since this expression has a single root at  $\frac{1}{6}(\sqrt{33} - 3)$ , the derivative cannot be zero at  $\frac{1}{6}(\sqrt{33} - 3)$ . Therefore, it must be strictly increasing or strictly decreasing at  $Q = \frac{1}{6}(\sqrt{33} - 3)$  and (since a polynomial is continuously differentiable) this also holds in a neighborhood of  $Q = \frac{1}{6}(\sqrt{33} - 3)$ . Since it is strictly positive for  $Q < \frac{1}{6}(\sqrt{33} - 3)$  it must be decreasing and therefore for  $Q > \frac{1}{6}(\sqrt{33} - 3)$  the polynomial is negative. This translates directly to the difference  $\widetilde{C} - \widehat{C}$ . Therefore,  $\widetilde{C} - \widehat{C}$  is negative for  $\phi > \frac{7 - \sqrt{33}}{6}$ . ■