Target pricing: Demand-side versus supply-side approaches

Hongmin Li*, Yimin Wang, Rui Yin, Thomas J. Kull, Thomas Y. Choi

W.P. Carey School of Business, Arizona State University, Tempe, AZ 85287, United States

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ABSTRACT

The practice of target pricing has been a key factor in the success of Japanese manufacturers. In the more commonly known demand-side approach, the target price for the supplier equals the manufacturer's market price less a percent margin for the manufacturer but no cost-improvement expenses are shared. In the supply-side approach, cost-improvement expenses are shared and the target price equals the supplier's cost plus a percent margin for the supplier. Using a general oligopoly and Cournot duopoly models, we characterize the equilibrium and optimal policy for each approach under various conditions. We find that sharing cost-reduction expenses allows the manufacturer using the supply-side approach to attain competitive advantage in the form of increased market share and higher profit, particularly in industrial conditions where margins are thin and price sensitivities are high.

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1. Introduction

Many manufactures have downsized supply base and have instituted long-term contracts with their suppliers. In this setting, the practice of target pricing rather than competitive pricing takes the center stage (Ellram, 2006; Omar, 1997; Cusumano and Takeishi, 1991), with manufacturers specifying prices to suppliers rather than suppliers submitting prices to manufacturers. Although the target pricing practice is often observed in many different industries, its implementation often varies across manufacturers (Asanuma, 1985; Helper and Sako, 1995; Liker et al., 1996). We identify two archetypes, terming one a demand-side (DS) approach and the other a supply-side (SS) approach. In the DS approach, manufacturers take the projected market price and work backwards to ascertain required prices for subassemblies and individual parts. They then submit these target prices to their suppliers. In the SS approach, manufacturers consider the supplier's cost structure and apply a reasonable supplier profit margin to determine the target price. Honda Motor Company, for example, follows the SS approach by first learning extensively about a supplier's cost structure and then, based on this knowledge, specifying a target price to the supplier that combines both the supplier's cost and a percent margin (Liker and Choi, 2004). Manufacturers may be forced to practice the DS approach because they lack cost information about their suppliers. As a result, they resort to the market price of their own product to determine what is a reasonable target price for the components from the suppliers.

In this study, we examine how these two archetypes of target pricing can bring benefits or detriments to manufacturers and suppliers. The DS approach uses demand-side information and is based on the market price of a manufacturer's product less the manufacturer's desired margin. Manufacturers using this approach allow suppliers to independently make cost reductions. They generally do not share in the supplier's cost-reduction expenses as they are not actively involved in the production process of the suppliers and without such investment, it is difficult to gain accurate knowledge of the supplier's cost structure. For example, a Honda supplier may present the "real" bill of material (BOM) cost only after it truly believes Honda is there to help; before that, only a "guest" version of the cost book may be shown. Hence, the DS approach can follow from manufacturers choosing not to invest in supplier development, rather than favoring one approach over the other.

The advantage of the DS approach is that it assures manufacturer profit margins while lowering relationship costs (albeit often at the expense of lower supplier margins). On the other hand, the SS approach focuses on supplier costs, with both parties seeking desired margins through joint cost-reduction efforts (Handfield et al., 2004). The SS approach aims to lower material costs at the expense of higher management costs and potentially lower manufacturer margins, yet can result in overall supply chain benefits (Cooper and Yoshikawa, 1994). Although both approaches have context specific advantages, no previous studies have analytically examined how the manufacturer–supplier joint improvement activities influence the relative attractiveness of these two policies.

According to Ellram (2006), many Japanese manufacturers actually use both approaches when determining a target price. They look to the market and establish the target price, while

* Corresponding author. Tel.: +1 480 965 2232; fax: +1 480 965 8629.
E-mail addresses: hongmin.li@asu.edu (H. Li), yimin_wang@asu.edu (Y. Wang), rui.yin@asu.edu (R. Yin), thomas.kull@asu.edu (T.J. Kull), thomas.choi@asu.edu (T.Y. Choi).

comparing this target price against the cost breakdowns from the supplier side. However, many US-based manufacturers that are new to target pricing tend to take the market side information and apply it as a target price to the supplier without considering supply-side information. This is not surprising because much effort is required to gather information from the supplier. In fact, the advantage of the DS approach is that it does not require heavy investment in supplier development; marketing can determine the market price and finance can work backwards to determine purchase prices. This approach is expedient and requires less administrative cost. In effect, the DS approach is driven more by marketing and finance, whereas the SS approach is driven more by operations and supply management.

For instance, to practice the SS approach, Honda sent a representative to a potential parts supplier, Atlantic Tool and Die, to work on its production lines while learning about this supplier's capability and capacity (Liker and Choi, 2004). Honda took about one year to learn what was possible at Atlantic. Honda's final submitted target price was such that Atlantic would have a small amount of profit and only through cost improvements could Atlantic earn more profit. Honda in return was fully willing to assist Atlantic in improvement efforts through Honda's supplier development programs. In general, Honda will devote over 10 weeks of assistance at a supplier's plant; an improvement effort that obviously requires a high amount of Honda's resources. Are such efforts worth the expense? Moreover, research shows that manufacturers often turn to target pricing as competition intensifies (Ax et al., 2008). Is this a good strategy?

Using an oligopoly model of multiple manufacturers each with a sole-source supplier and each adopting one of the two target pricing approaches, we characterize the equilibrium and the optimal policy for each supply chain. We then focus on a duopoly situation in which we contrast a DS model and a SS model in a Cournot competition. In addition, we also examine the duopoly between two DS models, as well the duopoly between two SS models. The Cournot competition model is common in the operations management literature when competing supply chain structures are studied (e.g., Li, 2002; Wu and Chen, 2003; Gilbert et al., 2006; Majumder and Srinivasan, 2008; Ha and Tong, 2008). In particular, the Cournot competition model has often been used in a retail setting where retailers (or manufacturers) compete for market share. Recent studies in this stream of literature have focused on the role of information sharing (e.g., Li, 1985, 2002; Zhang, 2002; Ha and Tong, 2008; Yao et al., 2008) and channel coordination (e.g., Gupta and Loulou, 1998; Wu and Chen, 2003; Narayanan et al., 2005).

Three recent papers are closely related to our research. Gilbert et al. (2006) consider two manufacturers sourcing from a common supplier. They find that outsourcing helps dampen the competition between the manufacturers and reduces the over-investment for cost reduction. In addition, they consider the case when each manufacturer outsources to a sole-source supplier and the suppliers do not directly compete. A supplier makes an investment in cost reduction, announces the price, and then the manufacturer determines whether to make or buy. Note that our focus is quite different from that of Gilbert et al. (2006): Although we also study the role of cost-reduction efforts between two competing supply chains, we focus on cost-improvement investment sharing between supply chain members, while they focus on the interaction between outsourcing and cost-reductions. Our study also complements Majumder and Srinivasan (2008), who study a duopoly between two supply chains with different structures. They incorporate scale economy to study the impact of competition on wholesale prices and quantities. Ha and Tong (2008) study a similar duopoly structure as this paper, but focus on the decision of information sharing between the two members

in each supply chain and consider the impact of contract types on the equilibrium outcome. We build on this stream of literature and examine a duopoly between two supply chains with the same sole-sourcing structure, but each with fundamentally different supplier development strategies. This is reflected in the target pricing policies, as well as the manufacturer's behavior toward cost-reduction investment sharing. Recently, interest has grown in the literature regarding the manufacturer's role in helping suppliers (e.g., Zhu et al., 2007; Babich, 2010; Wang et al., 2010), and our paper adds to that literature stream.

This paper contributes to the target pricing literature by contrasting the demand-side approach and the supply-side approach; these two supply chain practices compete against each other. In our model, we investigate the impact of joint manufacturer–supplier improvement efforts on the equilibrium outcome. We find that, when the manufacturer in the SS supply chain increases its share of cost-improvement expenses, it increases the SS supplier's incentive for cost improvement, but decreases the DS supplier's cost-improvement effort. By offering to engage in the supplier's cost-improvement activity and share the cost, the SS manufacturer increases its equilibrium market share. In addition, both the equilibrium market price and the equilibrium transfer price in both supply chains (the price that each manufacturer pays to its supplier) decrease monotonically with the SS manufacturer's cost share. For the SS supplier, this is offset by much-lowered cost. However, the DS supplier may experience profit deterioration as a result of lower transfer price. Lastly, we explore the optimal expense-sharing for the centralized supply chain and show that the manufacturer shares more in the centralized solution than the decentralized solution.

To the best of our knowledge, this study is the first to systematize the anecdotal evidence pertaining to target pricing and supplier improvement efforts.

The rest of the paper is organized as follows. In Section 2 we introduce an oligopoly model of multiple DS and multiple SS supply chains, and we fully characterize the manufacturer and the supplier's optimal decision in Section 3. We then specialize to three types of duopolies: two DS supply chain, two SS supply chains, and one DS and one SS supply chain. In Section 4, we focus our analysis on the duopoly of one DS and one SS supply chain to explore the competitive implications of these two different target-pricing approaches. In Section 5 we study the managerial implications of the joint supplier improvement effort. In Section 6, we explore how various parameters affect the equilibrium solution using sensitivity analysis. We conclude in Section 7. All proofs are contained in the Appendix.

2. The model

We consider a single period oligopoly consisting of multiple supply chains. Each supply chain has two members: a manufacturer and a supplier. Following previous literature and what is observable in practice (Agndal and Nilsson, 2008; Lovejoy, 2010), the manufacturer sole-sources a product from the supplier and then sells it to the end market. The manufacturers engage in an oligopoly competition—the market price is identical for all manufacturers, but the quantities sold by the manufacturers may differ due to the difference in costs. Within each supply chain, the supplier and manufacturer play a sequential game. First, they form an agreement on the transfer price scheme and the target price. Second, the supplier decides the per-unit amount of cost-reduction. The supplier's decision to invest in cost reduction affects the production cost of the product, and, depending on which target price scheme is used, the decision may affect the cost to the manufacturer. Third, the manufacturers then sell the

product to the same end market and form an oligopoly. The outcome is an oligopoly equilibrium in which the manufacturer with the lower cost obtains a larger market share. Note that each supplier sells to its respective manufacturer only and there is no direct competition between the suppliers. Often there are suppliers in the same market but they do not compete for the same contract. For example, in the automotive industry, Bridgestone may supply tires for one car model while Michelin supplies tires for another car model—for each model they are sole-sourced and these two companies are not in direct competition (see Richardson, 1993 for a general description). Therefore, for our purpose, it is reasonable to assume no direct competition between the suppliers for the component or service under consideration.

Let there be a total of n manufacturers, among which J manufacturers adopt the SS approach for determining the transfer price and K manufacturers adopt the DS approach. Let the set $\mathcal{S}$ be the set of SS manufacturers (or suppliers) and let the set $\overline{\mathcal{S}}$ be the set of DS manufacturers.

Let q_i denote the quantity supplied by manufacturer i ($i = 1, 2, \ldots, n$) to the end market. The total quantity of the product to the end market is therefore $q = \sum_{i=1}^{n} q_i$. The market price is linear in the quantity supplied:

$$p = a - b \sum_{i=1}^{n} q_i, \tag{2.1}$$

where p is the market price, a represents the maximal willingness to pay, and b is the slope of the (inverse) demand function. Manufacturers simultaneously determine their selling quantities to the end market and each manufacturer receives a revenue of $p \cdot q_i$. Because our model is a multi-stage sequential game, as described earlier, the improvement expenses are sunk when the manufacturers make the decision on procurement quantities. Therefore, the equilibrium quantities depend on the cost improvement only through the transfer prices. That is, whether a manufacturer shares any of the expense for its supplier's cost-reduction initiative is irrelevant at this stage of decision making.

Within each supply chain i; where $i = 1, 2, \ldots, n$; manufacturer i pays a linear, per-unit target price w_i to the supplier. As discussed in the Introduction, we consider two alternative approaches for setting the target price w_i between a manufacturer and its supplier. In the SS approach, the manufacturer pays the supplier according to a transfer price $w_j = c_j^e(1 + m_j), j \in \mathcal{S}$ where c_j^e is the supplier j's unit production cost and m_j is a fixed percent margin for the supplier. We do not consider the detailed negotiations of m and simply regard m as exogenous. In the DS approach, the manufacturer pays the supplier a transfer price $w_k = p(1 - r_k)$, $k \in \overline{\mathcal{S}}$ where p is the Cournot equilibrium market price and r_k is the desired margin for the manufacturer.[1]

Suppliers may have incentives to reduce their production cost to maximize profit. Hence, each supplier may decide, at its own discretion, the per-unit cost reduction amount (defined as e_i, for supplier i, $i = 1, 2, \ldots, n$). We assume that supplier i will be able to achieve the desired reduction in the per unit production cost of the supplier by e_i.

$$c_i^e = c_i - e_i.$$

where c_i is the initial unit production cost and c_i^e is the realized production cost for supplier i after the cost reduction. The expense required to achieve the cost improvement is $(1/2)\mu_i e_i^2$, which is convex increasing in e_i. The exact functional form of $(1/2)\mu_i e_i^2$ is motivated by the fact that the improvement effort has

declining marginal returns. That is, it becomes increasingly difficult to achieve further cost reductions (Bernstein and Kök, 2009). Such a quadratic functional form is commonly used in the economics and management literature for analytical tractability (see, for example, Perotti, 1995; Porteus and Whang, 1991). The cost-improvement expense is assumed to be independent of the quantities produced as we focus on process improvements in manufacturing. Note that we only consider the benefit in the form of cost reduction. In addition, to focus on the difference between the two supply chains and for simplicity, we do not consider the case where improvement effort may result in a stochastic cost-reduction outcome, and we assume $\mu_i = \mu, \forall i = 1, 2, \ldots, n$.

Consistent with industry practice (see Liker and Choi, 2004; Hartley and Choi, 1996), we assume that the manufacturer in the SS supply chain shares a portion θ_j ($0 \le \theta_j \le 1, j \in \mathcal{S}$) of the cost-improvement expenses incurred by the supplier. In contrast, we scale $\theta_k = 0, k \in \overline{\mathcal{S}}$ for the DS supply chain, i.e., the manufacturer in the DS supply chain does not share the improvement expenses incurred by the supplier. Although some DS manufacturers engage in supplier development (e.g., short-term oriented kaizen blitz), the expense they incur compared to the SS approach is much less and is assumed to be negligible for our comparative study. Hereafter we refer to θ_i as the *joint improvement share*.

2.1. Problem formulation

For notational clarity, we assume that the DS and SS chains are symmetric except for the target pricing policies discussed above. In our model, the Cournot competition takes place between the DS and SS supply chains, and performance comparisons are made at the supply chain level. We have done additional analysis of the Cournot competition between two same supply chains (i.e., two DS supply chains or two SS supply chains) and the details are available upon request.

To formulate the problem, we describe the sequence of events.[2] We assume that each supply chain will determine its margins through negotiation (m_j for the SS supply chain and r_k for the DS supply chain respectively). This agreement then forms a blanket contract for future dealings. This is consistent with industry practice where companies usually negotiate a master contract that provides guidelines and sometimes an exact number for transfer margins. These blanket contracts cover a long period of time, e.g., 5 years. Each year, or quarter, there is a cost reduction target and suppliers decide how much effort to invest. In modeling the sequential oligopoly game, we treat m_j and r_k as exogenously given. At the start of the game, the suppliers decide the amount of cost-reduction e_i, recognizing that their effort will affect the manufacturers's decision on production (procurement) quantities. Then the production cost c_i^e is realized. Next, the manufacturers simultaneously choose the optimal production quantity $\mathbf{q} = (q_1, q_2, \ldots, q_n)$ to maximize their own profit based on the transfer prices. Note that we do not distinguish the procurement quantity from the production or sales quantity because the market price is endogenous to the quantity sold to the market.

We now describe the manufacturers' and the suppliers' objectives. The profit function for manufacturer i is given by

$$\Pi_i^M(q_i) = (p - w_i)q_i - \tfrac{1}{2}\mu\theta_i e_i^2, \tag{2.2}$$

where the reader will recall that $p = a - b\sum_{i=1}^{n} q_i$, $\theta_k = 0, k \in \overline{\mathcal{S}}$ and $\theta_j \ge 0, j \in \mathcal{S}$. The profit function for supplier i can be expressed as

$$\Pi_i^S(e_i) = (w_i - c_i^e)q_i - \tfrac{1}{2}\mu(1 - \theta_i)e_i^2. \tag{2.3}$$

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[1] To be precise, the target price w_i would also depend on the fraction of the component cost (procured from the supplier) relative to the total cost of the final product. This can be easily incorporated in the model by introducing a scaling parameter and will not affect any of the subsequent analysis.

[2] Although we consider a single period simultaneous game, the sequence of events does matter in characterizing optimal solutions.

In (2.3), the first term is the supplier's net profit before the cost reduction and c_i^e is the supplier's unit production cost after the cost reduction. The second term is the expense of making such cost reductions.

In summary, the DS and SS supply chains differ in two aspects. First, in the DS supply chain the supplier assumes the entire expense of the cost reduction effort $\frac{1}{2}\mu e_k^2, k \in \overline{S}$, whereas in the SS supply chain the manufacturer shares a fraction θ of the supplier's expenses. Second, the target pricing policy differs between the two types of supply chains. As discussed before, the DS supply chain adopts a demand-side policy, with $w_k = p(1-r_k)$, whereas the SS supply chain adopts a supply-side policy, with $w_j = c_j^e(1+m_j)$. We emphasize that these two aspects are closely tied: The manufacturer in the DS chain is not actively involved in supplier development and thus does not have good cost information about its supplier. Consequently, it is forced to use the DS policy because a SS policy is not possible without first hand information of supplier cost.

3. Characterization of oligopoly equilibrium

In this section, we analyze the optimal decision for each member in the supply chain. We also examine the impact of the joint improvement expense sharing on each supplier's cost-reduction efforts and each supply chain's profit.

In what follows, we solve the manufacturers' oligopoly competition problem and derive the equilibrium market price. The solution to this oligopoly equilibrium will facilitate the characterization of the suppliers' cost improvement problem. Substituting (2.1) into (2.2), we have

$$\Pi_i^M(q_i) = \left(a - b\sum_{i=1}^n q_i - w_i\right)q_i - \frac{1}{2}\mu\theta_i e_i^2, \quad i = 1, 2, \ldots, n. \tag{3.1}$$

Note again here the decisions on quantities (i.e., q_i) and effort sharing (θ_i) are decoupled due to the sequential game assumption. It is straightforward to verify that (3.1) is jointly concave in $q_i, i = 1, 2, \ldots, n$ and their optimal quantities are given by

$$q_i^* = \frac{a + \sum_{\ell=1}^n w_\ell - (n+1)w_i}{(n+1)b}, \quad i = 1, 2, \ldots, n. \tag{3.2}$$

Substituting (3.2) into (2.1), we obtain the market equilibrium price

$$p^* = \frac{a + \sum_{\ell=1}^n w_\ell}{n+1}. \tag{3.3}$$

Note that both the optimal production quantities $\mathbf{q}^*$ and the market equilibrium price p^* implicitly depend on the suppliers' improvement effort.[3] Substituting p^* into (3.1), we can simplify the manufacturers' profit functions as

$$\Pi_i^M = \frac{[a + \sum_{\ell=1}^n w_\ell - (n+1)w_i]^2}{(n+1)^2 b} - \frac{1}{2}\theta_i\mu e_i^2. \tag{3.4}$$

Similarly, we simplify the suppliers' profit functions by substituting p^* into (2.3):

$$\Pi_i^S = (w_i - c + e_i)\frac{a + \sum_{\ell=1}^n w_\ell - (n+1)w_i}{(n+1)b} - \frac{1}{2}(1-\theta_i)\mu e_i^2, \tag{3.5}$$

where we assume $c_i = c, i = 1, 2, \ldots, n$, i.e., the suppliers' unit production costs in both supply chains are identical before the improvement efforts.

3.1. Optimal supplier improvement

In this section, we analyze the suppliers' optimal improvement efforts. Intuitively, the suppliers' improvement efforts will depend on the manufacturers' procurement quantities as well as whether the manufacturer will share a fraction of the improvement costs. Hence, the optimal amount of per-unit cost improvement for each supplier will be different between the DS and SS supply chains. Each supplier will determine its optimal cost improvement, taking into account the manufacturer's optimal reaction in terms of the procurement quantity. Our solution approach formalizes the above reasoning.

Proposition 1. *In a quantity-competition oligopoly, the equilibrium market price is given by*

$$p^* = \frac{a + \mu bc\sum_{j \in S}G_j(1-\theta_j)/m_j}{n+1-K+\sum_{k \in \overline{S}}r_k - \sum_{j \in S}G_j},$$

where

$$G_j \equiv 1 \Big/ \left(2 - \frac{1}{n+1-K+\sum_{k \in \overline{S}}r_k} + H_j\right) \quad and \quad H_j \equiv \frac{\mu b(1-\theta_j)}{m_j(1+m_j)},$$

(3.6)

and the equilibrium improvement efforts are given by

$$e_j^* = \left[c\left(2 - \frac{1}{n+1-K+\sum_{k \in \overline{S}}r_k}\right) - \frac{p^*}{1+m_j}\right]G_j, \quad j \in S, \tag{3.7}$$

$$e_k^* = \frac{r_k p^*}{\mu b(1-\theta_k)}, \quad k \in \overline{S}. \tag{3.8}$$

Proof. All proofs are given in the Appendix.

Proposition 1 provides the solution for a general case with multiple SS and DS supply chains and thus makes our method applicable to almost any combinatorially different scenario regarding the number of DS and SS supply chains in the market. Next, we consider three special cases: (i) the duopoly with two DS supply chains; (ii) the duopoly with two SS supply chains; and (iii) the duopoly with one DS and one SS supply chains. For notational simplicity, we drop the supplier and manufacturer parameter indices when there is no ambiguity.

Corollary 1. *If the market consists of only two symmetric DS supply chains with margin $r_k = r$ and $\theta_k = \theta = 0$, the equilibrium market price and improvement efforts are*

$$p^* = \frac{a}{1+2r}, \tag{3.9}$$

$$e^* = \frac{ra}{\mu b(1+2r)}. \tag{3.10}$$

Corollary 2. *If the market consists of only two symmetric SS supply chains with margin $m_j = m$ and $\theta_j = \theta$, the equilibrium market price and improvement efforts are*

$$p^* = \frac{a(H+5/3) + 2c(1+m)H}{3(1+H)}, \tag{3.11}$$

$$e^* = \frac{1}{1+H}\left[c - \frac{a}{3(1+m)}\right], \tag{3.12}$$

where

$$H \equiv \frac{\mu b(1-\theta)}{m(1+m)}.$$

Corollary 3. *Consider a case where the market consists of one SS supply chain with margin m and manufacturer cost share θ, and one DS supply chain with margin r. We use subscript 1 to denote the DS*

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[3] In (3.2) and (3.3) we only focused on the most interesting case where q_i^* and p^* are all interior (positive) solutions. For clarity, we omit the details of boundary conditions.

supply chain, and subscript 2 to denote the SS supply chain. The optimal market equilibrium price and the optimal production quantities are given by

$$p^* = \frac{[a+c(1+m)]H+a(2r+3)/(r+2)}{(r+2)H+2(1+r)},$$

$$q_1^* = \frac{r}{b}p^*, \quad q_2^* = \frac{a}{b}-\frac{r+1}{b}p^*.$$

The equilibrium improvement efforts are given by[4]

$$e_1^* = \frac{r}{\mu b}p^*, \quad e_2^* = c-\frac{(r+2)p^*-a}{1+m}.$$

While cases (i) and (ii) exemplify competition among homogenous supply chains, we emphasize case (iii) as the focal case to illustrate the dynamics of competing DS and SS supply chains. For the rest of the paper, we focus our analysis on case (iii).

4. Duopoly of one DS and one SS supply chain

Corollary 3 indicates that each supplier's cost-improvement amount is not only influenced by its own target pricing policy parameters, but also by the competing supply chain's target pricing policy parameters. This can be seen by the fact that e_1^* and e_2^* depend on both policy parameters m and r. Therefore, either supplier may exert more improvement effort, depending on the different combinations of the policy parameters m and r. A less apparent, yet more interesting question is how does Manufacturer 2's willingness to share in the improvement expense influence the suppliers' efforts? Empirical evidence indicates that manufacturers often are willing to help suppliers improve their performance (Li et al., 2007; Liker and Choi, 2004). The joint improvement share θ (by Manufacturer 2) can be viewed as a proxy for the manufacturer's willingness to help the suppliers, i.e., commitment for joint supplier development.

It is easy to check the following results hold:

Corollary 4.

(1) $\partial e_1^*/\partial\theta \le 0, \partial e_2^*/\partial\theta \ge 0$;
(2) $\partial q_1^*/\partial\theta \le 0, \partial q_2^*/\partial\theta \ge 0$; and
(3) $\partial p^*/\partial\theta \le 0, \partial w_1^*/\partial\theta \le 0, \partial w_2^*/\partial\theta \le 0$.

Recall that only Manufacturer 2 in the SS supply chain shares the supplier's improvement cost, i.e., $\theta_1 = 0$ and $\theta_2 = \theta$ where $0 \le \theta \le 1$. Nevertheless, because the two manufacturers compete in the same product market, the joint improvement share θ influences both DS and SS supply chains. The first statement in Corollary 4 implies that, if θ increases, i.e., Manufacturer 2 in the SS supply chain shares a higher proportion of the supplier's improvement expense, then Supplier 2's cost improvement e_2 increases while Supplier 1's improvement e_1 decreases.

The fact that Supplier 2's cost-improvement effort increases when Manufacturer 2 is willing to share the cost is fairly intuitive, because the cost burden for the supplier lessens. However, the impact of θ on Supplier 1's improvement effort is not as intuitive. We provide the following explanation: When Manufacturer 2's share of the improvement expense in the SS supply chain becomes larger (θ increases), the DS supply chain becomes less

competitive (sells less) and therefore Supplier 1 has less incentive to invest in expensive improvement efforts.

To formalize the above intuition, we examine the optimal production quantities given in Corollary 3. According to the second statement in Corollary 4, by sharing the expense of the supplier's improvement effort, Manufacturer 2 can gain a competitive advantage (in market share) over Manufacturer 1. Finally, the third statement in Corollary 4 indicates that when θ increases, the equilibrium market price decreases, reflecting a higher degree of market competition. Therefore, expense-sharing between the SS manufacturer and supplier also benefits the consumers. Subsequently, the target prices decrease for suppliers in both DS and SS supply chains. In the next session, we investigate how joint supplier improvement influences the suppliers profit.

5. Implications of joint supplier improvement

A question with practical importance is how the joint improvement share θ influences the relative profitability of the suppliers and manufacturers in *both* supply chains. Intuition suggests that θ in the SS supply chain affects manufacturer 2's profitability in two ways. First, profitability is negatively impacted from the manufacturer sharing the expense of supplier improvement activities. Second, profitability is positively impacted, as demonstrated by the second statement in Corollary 4, by the manufacturer benefiting from supplier improvement through increases in the manufacturer's competitiveness and market share. Therefore, the total effect of the joint improvement on the manufacturer's profit can be either negative or positive.

However, it is less obvious how the joint improvement share will affect manufacturer 1's profitability in the DS supply chain because the impact of θ occurs through the Cournot competition. That is, θ directly affects the cost of Manufacturer 2, which influences the equilibrium market price and, in turn, affects Manufacturer 1's profit.

Our subsequent analysis shows that we can characterize the effect of joint improvement effort on both manufacturers' profitability in a fairly succinct way.

Proposition 2.

(1) Π_1^{M*} is decreasing in θ.
(2) Π_2^{M*} is increasing in θ for $\theta \le \hat{\theta}$ and decreasing in θ for $\theta > \hat{\theta}$, where

$$\hat{\theta} = 1-\frac{(r+2)m(2gc-a)[mg+\mu b(r+2)]-2g^2am}{\mu b(r+2)[2g(a-gc)+\frac{1}{2}(r+2)m(2gc-a)]},$$

and $g = (1+r)(1+m)$.

Proposition 2 indicates that the effect of θ on Manufacturer 2's profitability is of a threshold type: if the improvement effort shared by the manufacturer is below a threshold $\hat{\theta}$, then it benefits Manufacturer 2 to increase its share of the joint improvement effort; but if the improvement share is above this threshold, it *hurts* Manufacturer 2. In contrast, a higher θ always hurts Manufacturer 1's profitability! At a casual glance, it may seem that if one's competitor spends relatively more on its supplier, then that would work to one's advantage. However, when the supplier in the SS supply chain receives assistance from its manufacturer, the supplier will be motivated to invest more in cost reduction, thus reducing both the target price and the overall SS supply chain costs. Not surprisingly, this would always hurt Manufacturer 1, who is in a Cournot duopoly with Manufacturer 2. Combining Proposition 2 and statement (2) in Corollary 4, we find that the joint improvement effort by Manufacturer 2 hurts

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[4] Notice $e_1^* \ge 0$, $p^* \ge 0$ and $q_1^* \ge 0$. To guarantee $e_2^* \ge 0$, a necessary and sufficient condition is $a \le 2(1+r)(1+m)c$; and a sufficient condition for $q_2^* \ge 0$ is $a \ge c(1+r)(1+m)$. In what follows, we assume these two conditions hold. For the cases when $e_2^* < 0$ or $q_2^* < 0$, we simply set them as 0.

the competitor's market share as well as its profit. While the joint improvement effort always increases Manufacturer 2's market share, too much joint improvement effort shouldered by the manufacturer may actually hurt its profitability.

A natural question arises then as to how the suppliers are affected by the joint improvement effort. The following proposition characterizes the influence of θ on both suppliers' profitability.

Proposition 3.

(1) Π_2^{S*} is increasing in θ.
(2) Π_1^{S*} is decreasing in θ if and only if $\theta \leq \overline{\theta}$, where $\overline{\theta}$ satisfies

$$p^*|_{\theta = \overline{\theta}} = \frac{c\mu b}{2\mu b(1-r)+r}, \tag{5.1}$$

where p^* is as defined in Corollary 3.

In contrast to the impact on Manufacturer 2, an increase in the joint improvement share θ always benefits Supplier 2. This is as expected because, all else being equal, the supplier bears a smaller fraction of the improvement cost. Because the manufacturers engage in a duopoly competition, the joint improvement share in the SS supply chain also affects Supplier 1's profit. The effect of θ on Supplier 1's profit is more nuanced, however. Proposition 3 states that Supplier 1's profit may decrease when θ increases, but only if θ is sufficiently small, i.e., $\theta \leq \overline{\theta}$.

In the above analysis, we have focused on the suppliers and the manufacturers' individual profits. We now turn attention to the effect of θ on the *supply chains*'s performance. In particular, we are interested in how Π_i^* changes as the joint improvement effort θ changes. The reader will recall that $\Pi_i^* = \Pi_i^{M*} + \Pi_i^{S*}$.

Proposition 4.

(1) Assuming $\Pi_1^{S*} \geq 0$, then Π_1^* is decreasing in θ.
(2) Π_2^* is increasing in θ for $\theta \leq \tilde{\theta}$, and decreasing in θ for $\theta > \tilde{\theta}$, where

$$\tilde{\theta} = 1 - \frac{\mu b m(r+2)^2(2gc-a)-2g^2am}{\mu b m(r+2)^2(2gc-a)+2\mu b(r+2)g(a-gc)}.$$

(3) $\tilde{\theta} \geq \hat{\theta}$.

Statement (1) of the above proposition is immediate from Propositions 2 and 3, because (under appropriate technical conditions) both Π_1^{S*} and Π_1^{M*} are decreasing in θ. Statement (2) says that, under some reasonable conditions, there exists an optimal $\tilde{\theta}$ such that the SS supply chain's total profit is maximized at $\tilde{\theta}$. In other words, Manufacturer 2 should neither share all of the supplier's improvement cost nor completely ignore the supplier's improvement cost. It therefore benefits the DS supply chain for Manufacturer 2 to help its supplier in its improvement efforts, albeit only to a certain degree (i.e., not to exceed $\tilde{\theta}$).

Statement (3) of Proposition 4 tells us that the optimal θ that maximizes the whole supply chain's profit does not coincide with what maximizes Manufacturer 2's own profit: Manufacturer 2 will prefer a joint improvement share θ that is lower than what is best for the whole supply chain. This result can be partially explained by observing that Manufacturer 2 benefits from helping the supplier in two ways: first, the manufacturer directly benefits from a lowered transfer price which lowers the manufacturer's production cost; second, the manufacturer also indirectly benefits from the increased market share because of its lower production cost. While both the manufacturer and the supplier benefit from the increased market share, the supplier can be hurt by the lower transfer price, which may not be offset by the increased

procurement quantities. When deciding its share of the supplier's improvement cost, however, the manufacturer ignores the negative impact of the lowered supplier profit margin, resulting in a joint improvement share level that is not necessarily best for the whole supply chain.

The above analysis indicates that the manufacturer and the supplier may prefer a different level of manufacturer involvement in the improvement efforts.[5] It is of interest to understand how competitive characteristics, such as the margins m and r, affect the supplier and manufacturer's preferred cost sharing levels. Toward this end, we designed a numerical study to investigate this question.

6. Numerical study

6.1. Design

In the numerical study, we focus on the duopoly of one DS and one SS supply chain. The purpose of the numerical study is threefold. First, we are interested in how various system parameters, such as transfer price margins m and r, as well as the price sensitivity of the market b, influence each supplier's cost-improvement effort and ultimately the two supply chains' performance. We characterize the performance using both total profit and relative market share of each supply chain. In a duopoly, the market share of each supply chain directly reflects how competitive it is against the other. Second, we are interested in how important it is for Manufacturer 2 to share improvement cost with its supplier. Third, we are also interested in the magnitude of the profit impact when Manufacturer 2 chooses an optimal θ to maximize the total supply chain's profit. In other words, Proposition 4 tells us that a manufacturer will choose a $\hat{\theta}$ that deviates from the supply chain optimizing $\tilde{\theta}$. It is of interest to understand how bad the supply chain's performance is when θ deviates from the optimal $\tilde{\theta}$. The answer to this question will aid decision makers to determine whether it is worthwhile to design a coordinating contract, in which $\hat{\theta}$ equals $\tilde{\theta}$. Table 1 describes the setup of our numerical study. Note that we choose these parameter values to roughly reflect a typical automobile industry setting.

For the (inverse) demand function, we fixed a at 30,000, but allowed the slope parameter b to vary from 0.1 to 10 with five intervals. We set the base case value for b to 1 and, for symmetry, the range of values chosen for b was 0.1, 0.5, 1, 2, and 10. We note that, consistent with the existing literature, we adopted the standard inverse demand function. Therefore, with an inverse linear demand function, a higher b is associated with a lower price sensitivity and vice versa.

In terms of the suppliers' production cost, we assumed that both suppliers have identical initial production cost c, which varies (in lock step) from 5000 to 25,000 with a step size of 5000. Therefore we had in total five different values for the suppliers' initial production cost. The improvement parameter μ was fixed at 100.

For the transfer price policy parameters m and r, we varied both m and r from 0.1 to 0.5 with a step size of 0.1. This results in a factorial combination of 25 observations. We then carried out a factorial combination of all the system parameters described above and repeated the calculation for the optimal $\tilde{\theta}$, $\hat{\theta}$, as well as performance metrics such as the manufacturers' and suppliers' profits. Note that while the factorial combination described above

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[5] Because the focus of this research is not in contract design, we do not further explore the set of contracts that will coordinate the supply chain. We refer the interested reader to Cachon (2004) for further details about coordinating contracts.

Table 1
Numeric study setup (Number in bracket indicates number of scenarios).

Parameter	a	b	c	μ	m	r
Base case	30,000	1	15,000	100	0.1	0.1
Range	30,000 (1)	0.1–10 (5)	5,000–25,000 (5)	100 (1)	0.1–0.5 (5)	0.1–0.5 (5)
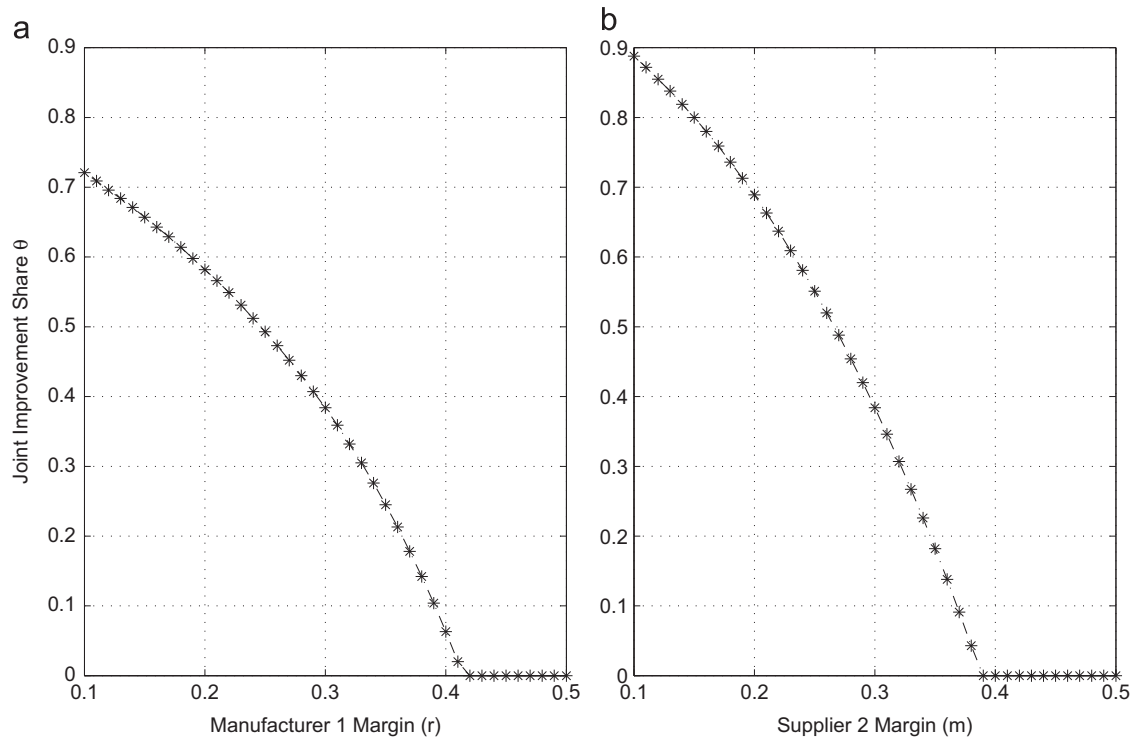
Fig. 1. Effect of m and r on Manufacturer 2's optimal joint improvement share $\hat{\theta}$. (a) Effect of Manufacturer 1 margin (r) on optimal improvement share θ. (b) Effect of Supplier 2 margin (m) on optimal improvement share θ.

would in theory yield a total of $5^4 = 625$ unique observations for each performance metric, we removed those corner solutions not satisfying the condition $gc \leq a \leq 2gc$ to ensure that the demand is nonnegative (see the footnote of Corollary 3 where g is defined in Proposition 2), thus leaving 236 observations.

6.2. Optimal joint improvement share $\hat{\theta}$

Proposition 2 characterizes the optimal $\hat{\theta}$ that maximizes the manufacturer's profit. Our numerical study indicates that $\hat{\theta}$ decreases in both m and r.

Fig. 1 indicates that the supplier margin m and the improvement cost sharing θ (by Manufacturer 2) can be regarded as substitutes. When Manufacturer 2 sets a smaller (larger) margin m for the supplier, then it is necessary and advantageous for it to share a larger (smaller) fraction of its supplier's improvement cost.

The fact that $\hat{\theta}$ also decreases in r is interesting. Fig. 1 indicates that when r increases (i.e., Manufacturer 1 pays a lower transfer price to its supplier), Manufacturer 2 would share a smaller fraction of its supplier's improvement cost: by paying a lower transfer price $p(1-r)$, Manufacturer 1 becomes more competitive in the market (at the expense of Supplier 1). Manufacturer 2 therefore sells less to the market and this dampens its incentive to help its supplier on cost improvement.

Furthermore, our numerical results also show that $\hat{\theta}$ on average decreases in the suppliers' initial unit production cost c. This is somewhat counter-intuitive, because it suggests that if the suppliers are not very efficient initially, then Manufacturer 2 will

have less incentive to help that supplier. Instead, Manufacturer 2 should be more willing to help a supplier that are initially more efficient. Our interpretation is that the unit cost c influences a manufacturer's revenue potential: the higher the initial cost, the less revenue potential for both manufacturers (or supply chains), and thus less incentive for improvement (improvement expenses increase in the square of the cost reduction amount). This observation has an important practical implications for suppliers: it is better to improve production efficiencies to a reasonable level first before expecting the manufacturer to help share the cost improvement expense.

6.3. Effect of supplier margin (m) and manufacturer margin (r) on system performance

In our base model, we assume that Supplier 2's margin m and Manufacturer 1's margin r are exogenous. In practice, however, both margins are subject to negotiations between the manufacturer and the supplier. In what follows, we explore the effect of these margins on the performance of the SS and DS supply chains.

First we focus on Supplier 2's margin m. Fig. 2 illustrates the effect of m on both suppliers' cost reduction effort, as well as the resulting market share of the two supply chains.

Notice that increasing Supplier 2's margin m is *not* an attractive move for Manufacture 2: It reduces the supplier's cost reduction effort (Fig. 2(a)) and it leads to a reduced market share for the SS supply chain (Fig. 2(b)). The intuition is that with a
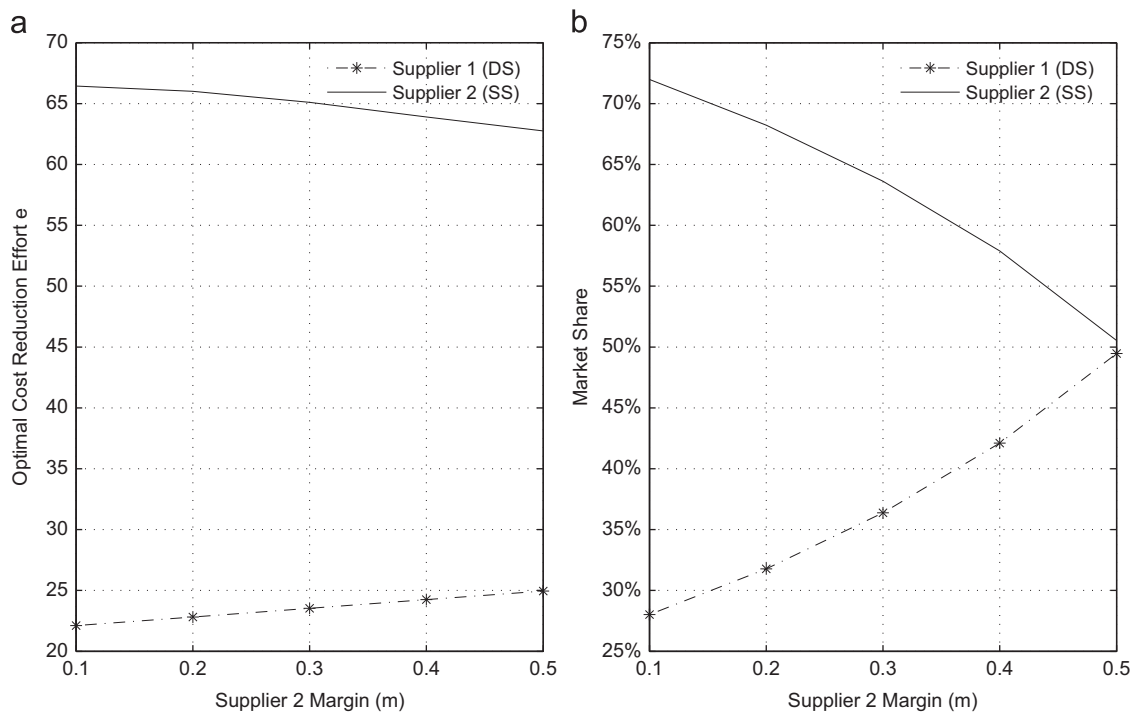
Fig. 2. Effect of Supplier 2's margin on operational performance. (a) Effect of Supplier 2 margin (m) on optimal improvement effort. (b) Effect of supplier 2 margin (m) on optimal market share.
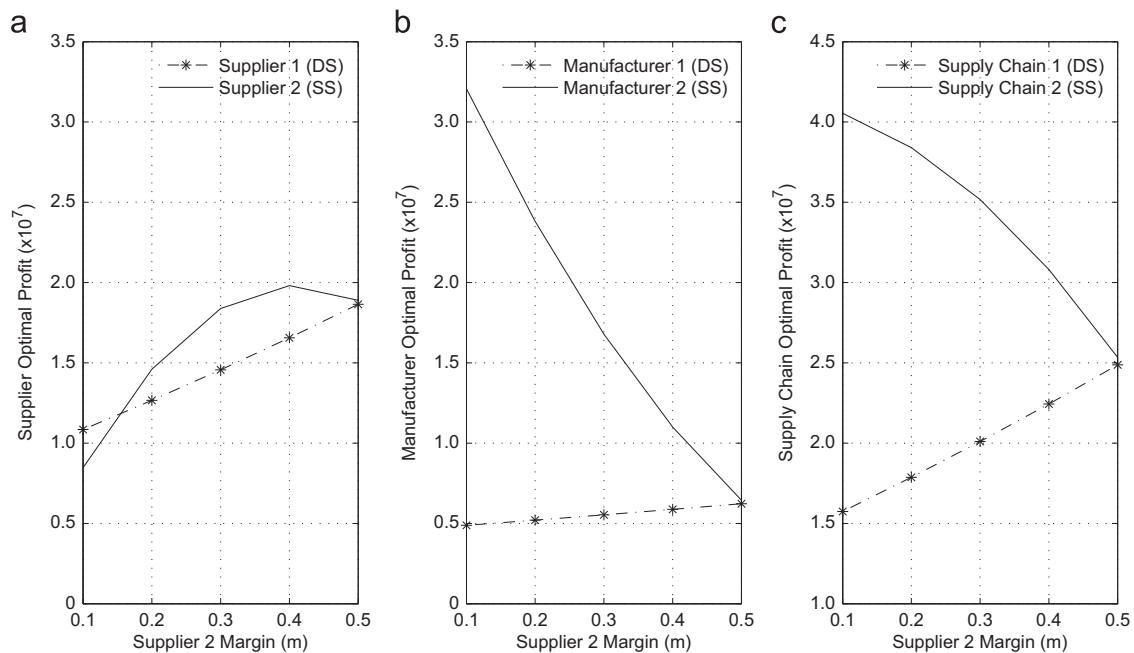
Fig. 3. Effect of Supplier 2's margin on financial performance. (a) Effective of Supplier 2 margin (m) on supplier optimal profit. (b) Effect of Supplier 2 margin (m) on manufacturer optimal profit. (c) Effect of Supplier 2 margin (m) on supply chain profit.

higher profit margin m, Manufacturer 2's cost increases and its market share is hurt. Therefore the optimal improvement effort share $\hat{\theta}$ decreases, causing Supplier 2 to lose incentive for cost reduction.

Fig. 3 illustrates the profit impacts of increasing m.

Interestingly, even Supplier 2 could suffer from a very high margin m, as indicated in Fig. 3(a). This is again due to a decreased market share caused by a less competitive supply chain as m increases. Overall, the SS supply chain suffers significantly from an increased margin m (Fig. 3(c)).

Therefore, we conclude that for the SS approach to be successful, it is imperative for the manufacturer not to set a "fat" margin for the supplier. Instead, the manufacturer should carefully balance the supplier's margin m so that it is neither too small (such that the supplier incurs losses) nor too high (such that the whole supply chain suffers). This observation coincides with the examples discussed in the Introduction that a successful implementation of the SS approach requires a manufacturer to understand the supplier's cost structure precisely in order to set a reasonable margin for the supplier.
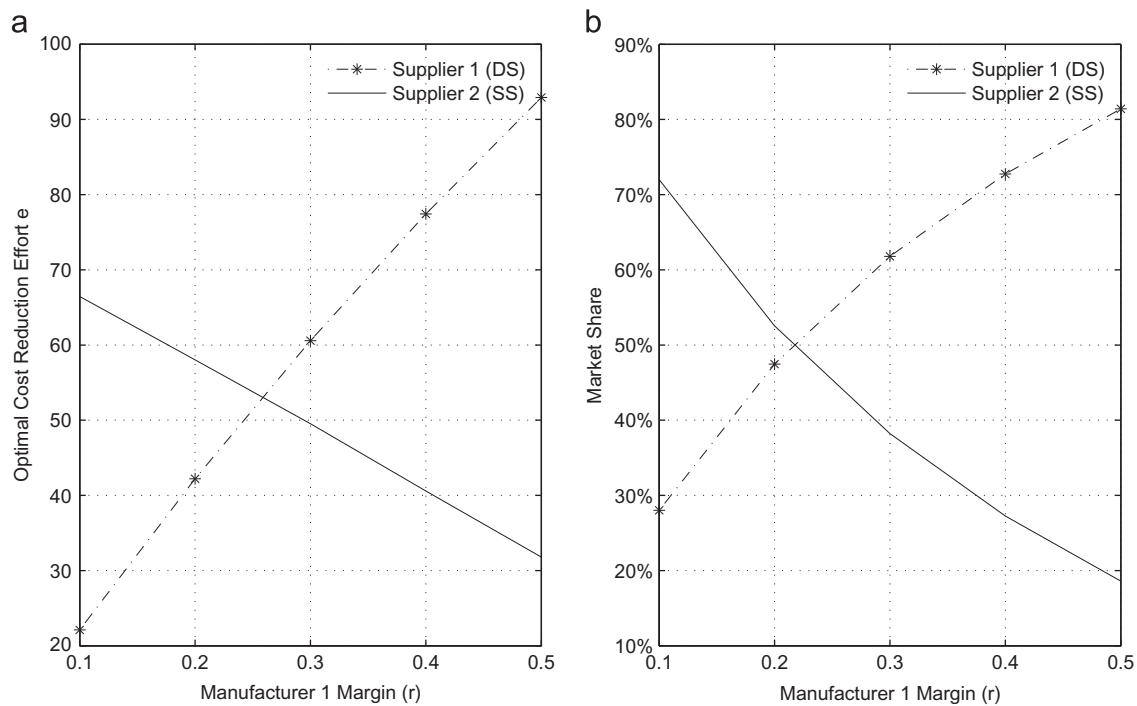
Fig. 4. Effect of Manufacturer 1's margin on operational performance. (a) Effective of Manufacturer 1 margin (r) on optimal improvement effort. (b) Effect of Manufacturer 1 margin (r) on optimal market share.
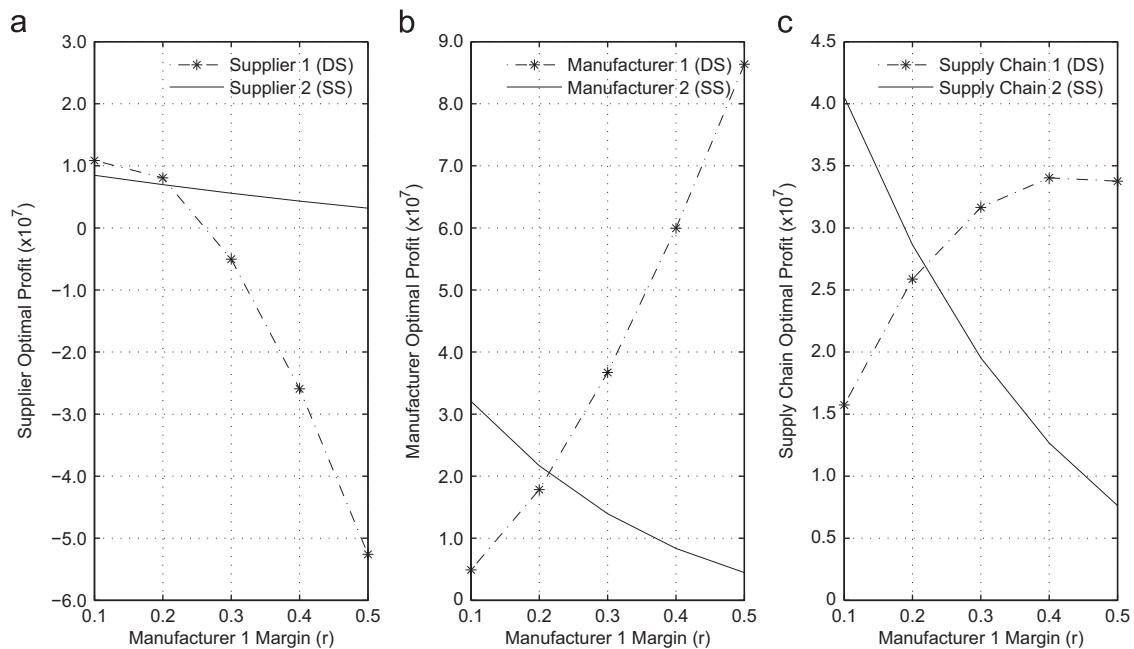
Fig. 5. Effect of Manufacturer 1's margin on financial performance. (a) Effect of Manufacturer 1 margin (r) on supplier optimal profit. (b) Effect of Manufacturer 1 margin (r) on manufacturer optimal profit. (c) Effect of Manufacturer 1 margin (r) on supply chain profit.

Next we examine Manufacturer 1's margin r. Fig. 4 illustrates the effect of r on both suppliers' cost-reduction effort and the resulting market shares of the two supply chains.

Notice that increasing Manufacturer 1's margin r (i.e., decreasing Supplier 1's margin) is *quite* effective for motivating Supplier 1 to exert higher cost-reduction effort (Fig. 4(a)), which leads to a larger market share for the DS approach (Fig. 4(b)). This suggests that, in a DS supply chain, "squeezing" the supplier benefits the manufacturer, which is consistent with our earlier discussion of industry examples where manufacturers adopting the DS

approach often choose to "squeeze" suppliers. In this case, with a higher manufacturer margin r and hence a lower transfer price, the DS manufacturer becomes more competitive in the duopoly and obtains a higher market share. Therefore, the supplier becomes more motivated to reduce cost. The DS approach therefore improves the whole supply chain's performance at the expense of the supplier.

Fig. 5 illustrates the profit impact of an increasing r.

Consistent with our above discussions, Fig. 5(a) suggests that the profit of the DS supplier decreases with r. Fig. 5(b) indicates
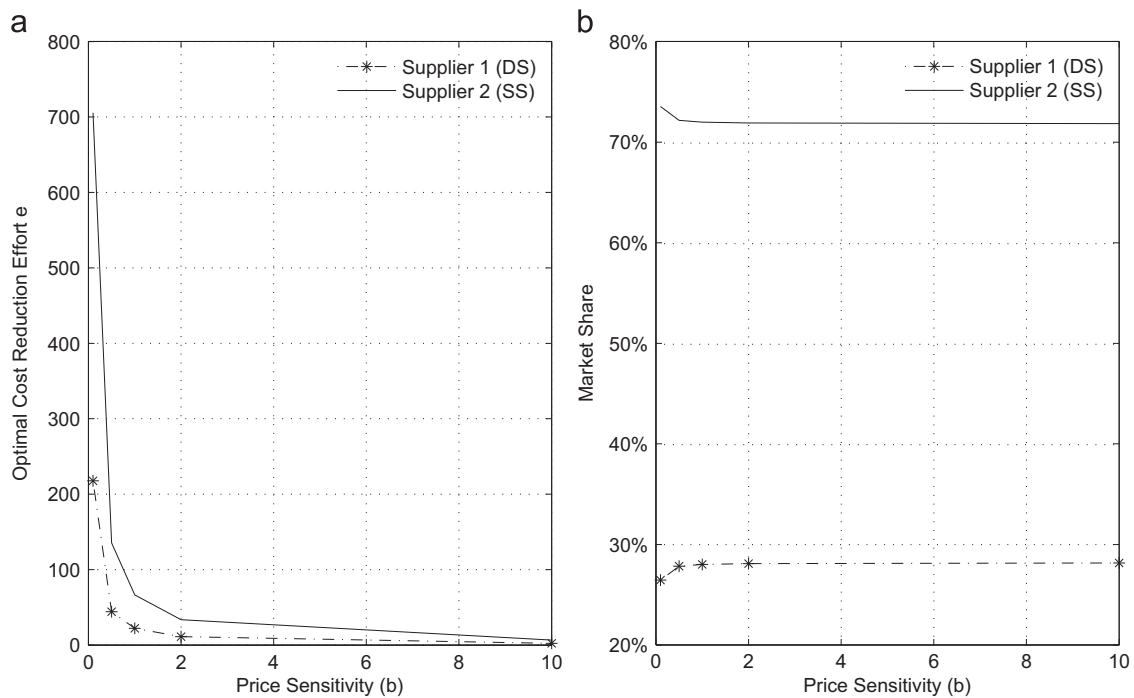
Fig. 6. Effect of price sensitivity on operational performance. (a) Effect of price sensitivity (b) on optimal improvement effort. (b) Effect of price sensitivity (b) on optimal market share.

that any benefit of a higher r predominantly accrues to the DS manufacturer. At excessively higher margins, the whole DS supply chain's performance suffers (Fig. 5(c)) as the DS supplier incurs even steeper losses. Thus, for the DS approach to be successful, the manufacturer should not set the margin too "thin" for the supplier. We conjecture that many supply chains that practice the DS approach fail to compete effectively with the SS approach due, in part, to the manufacturers' inability to resist the temptation of raising their own profit margin at the expense of the entire supply chain.

In summary, our numerical results suggest that a higher supplier margin m in the SS approach reduces the supplier's incentive to improve cost, whereas a higher manufacturer margin r in the DS approach increases the supplier's incentive for cost improvement. Therefore, from the perspective of supply chain efficiency, the SS manufacturer should refrain from setting a supplier margin that is too fat, whereas the DS manufacturer should refrain from setting a supplier margin that is too thin.

6.4. Effect of price sensitivity (b) on system performance

One of the important market characteristics is price sensitivity; that is, how market price responds to total market supply. Recall that we use parameter b in the demand function to capture the effect of price sensitivity: a higher b value implies that market price responds more drastically to market supply. In the following analysis, we explore how price sensitivity b affects performance in the DS and SS supply chains.

Fig. 6 illustrates the effect of price sensitivity on both suppliers' cost reduction efforts as well as the resulting market shares of the two supply chains.

Notice that, as the market price becomes more sensitive to the total supply (increasing b), the supplier's cost reduction effort in both the DS and SS approaches declines rapidly (Fig. 6(a)). However, market shares are much less sensitive to changes in b

(Fig. 6(b)).[6] When price is more sensitive to total market supply, both supply chains' sales decline. Therefore, both Suppliers 1 and 2 have reduced incentive for cost improvement as lower sales dampens the gain from such cost improvement. Managerially, in industries that exhibit high price sensitivity, it is difficult to motivate the suppliers to engage in process improvement regardless of the target-pricing approach that is chosen. This may be one explanation for the difficulty of implementing the SS target-pricing approach in these industries. In addition, we find that the optimal effort sharing $\hat{\theta}$ on average decreases in b, which further dampens the incentive of the SS supplier. The analysis of changes in financial performance as price sensitivity b changes reflects similar insights (see Fig. 7).

6.5. Impact of sharing improvement effort

Helping the supplier to improve the production efficiency is a practice observed in some settings but not others. It is therefore interesting to investigate whether helping a supplier on cost-improvement expense has any significant financial impact for the manufacturer. We compare Manufacturer 2's profit in two cases: the case of an optimal $\hat{\theta}$ and the case where the manufacturer does not share any of the supplier's improvement cost, i.e., $\theta = 0$. We find that, by sharing a fraction of the supplier's improvement cost, Manufacturer 2 improved its profit by an average of 1.7% and a maximum of 12.1%, which is quite significant. Furthermore, when a manufacturer shares the improvement cost, the supplier obtains an average increase of 1.2% in profit and a maximum increase of 7.9% in profit.

6.6. Profit impact of $\hat{\theta}$ versus $\tilde{\theta}$

Proposition 4 tells us that the manufacturer will select an optimal $\hat{\theta}$ that deviates from $\tilde{\theta}$. At the same time, we know that $\tilde{\theta}$

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[6] Note that in Fig. 6(b) the market share for the SS supply chain is much higher than that for the DS supply chain; this is not due to inherent superiority of the SS approach: it is merely a reflection of the base line values specified in Table 1.
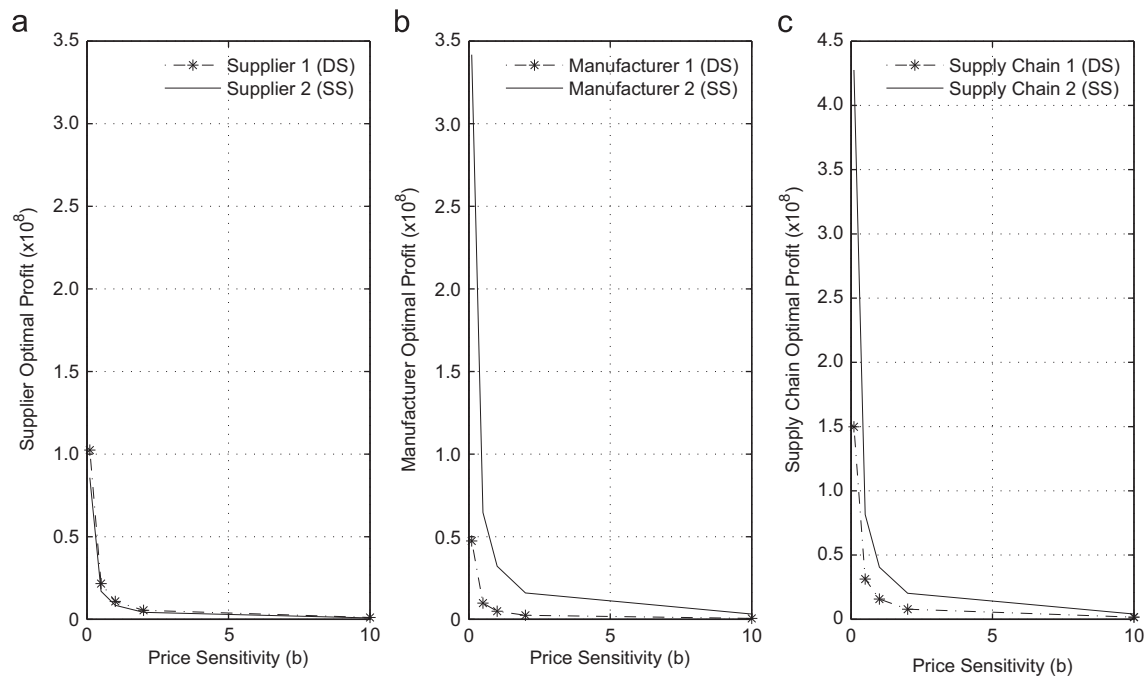
Fig. 7. Effect of price sensitivity on financial performance. (a) Effective of price sensitivity (*b*) on supplier optimal profit. (b) Effect of price sensitivity (*b*) on manufacturer optimal profit. (c) Effect of price sensitivity (*b*) on supply chain profit.

maximizes the SS supply chain's profit. If such a deviation has a large impact on the SS supply chain's performance, then it may be worthwhile to design a more complex, coordinating contract that maximizes the SS supply chain's profit. However, if the profit loss is small, then the implementation cost of a coordinating contract may not be offset by the potential profit gain for the supply chain.

We find that the SS supply chain's total profit loss through the manufacturer's selection of $\hat{\theta}$ is on average only 0.1%, with a maximum profit loss of 2.59%. We also find that the supply chain's profit loss is more pronounced when the demand slope parameter b is small and when m and r are higher. Table 2 illustrates the profit loss when $b = 0.1$ and $c = 15,000$.

We can see from Table 2 that the SS supply chain profit loss is higher when Manufacturer 2 sets a higher supplier margin m, or when Manufacturer 1 sets a higher manufacturer margin r (i.e., Manufacturer 1 pays less to Supplier 1). This suggests that it might be worthwhile to implement coordinating contracts when Supplier 2 enjoys a higher profit margin (m), or when the competitor (Manufacturer 1) leverages its suppliers. In contrast, we find that the SS supply chain profit loss diminishes when b becomes larger, suggesting that it is not worthwhile to implement coordinating contracts in industries where price sensitivities are low.

In summary, we find that helping suppliers to improve their production efficiencies is quite important for the SS supply chain's performance. In particular, it is more important for Manufacturer 2 to help its supplier when the market exhibits high price sensitivities. Helping suppliers by sharing their improvement costs is not entirely an altruistic action: it helps to improve not only the supplier's bottom line, but also the manufacturer's profit. In addition, it weakens the competition that uses a demand-side transfer price policy. On average, the manufacturer enjoys a larger share of the benefits from a supplier's cost improvement effort. In general, the manufacturer's optimal selection of $\hat{\theta}$ does not seriously degrade the SS supply chain's performance, compared to the optimal sharing $\tilde{\theta}$ under a centralized supply chain. Therefore, a simple linear transfer price contract is sufficient to guarantee that the whole SS supply chain's performance is close to optimality.

Table 2
Average SS supply chain profit loss in percentages (dash '–' indicates corner solutions).

m	r				
	0.1	0.2	0.3	0.4	0.5
0.1	0.00	0.01	0.02	0.04	0.10
0.2	0.03	0.07	0.16	0.35	0.87
0.3	0.12	0.28	0.65	1.68	1.79
0.4	0.37	0.89	2.34	1.81	–
0.5	0.98	2.59	2.02	–	–

7. Conclusions

In this research, we contrast two often observed practices in target pricing; namely, the supply-side approach and the demand-side approach. We derive a general oligopoly equilibrium solution for the market price, the market share for each supply chain, and the suppliers' improvement efforts. Using a Cournot duopoly model, we fully characterize the optimal policy when the two types of supply chains compete. We show that sharing the cost-improvement expenses with its supplier proves to be a competitive advantage for the SS supplier in the form of increased market share and higher profit. The competition of the two supplier chains intensifies as a result of such sharing, leading to a decrease in the equilibrium market price and equilibrium transfer prices. In addition, the results indicate that the optimal level of the manufacturer's involvement in the supplier's improvement effort is influenced by a number of system characteristics. Through our numerical study, we suggest that the manufacturer should help the suppliers more in industries where the transfer price parameters m and r are lower, and where the price sensitivities are higher. We show that a higher supplier margin m in the SS approach reduces the supplier's incentive to improve cost, whereas a higher manufacturer margin r in the DS approach increases the supplier's incentive for cost improvement. Therefore, to improve the supply chain's efficiency, the SS manufacturer

should refrain from setting a supplier margin that is too fat, whereas the DS manufacturer should refrain from setting a supplier margin that is too thin. Our results also indicate that in industries with very high price sensitivity, it is difficult to induce cost improvement efforts regardless of the target-pricing approach. In addition, we point out that a manufacturer's deviation from the supply chain's optimal improvement cost sharing does not cause significant profit loss.

There are a number of immediate extensions to this research. One potential extension is to consider the scenario where the two manufacturers share a same supplier. In this case, the benefit of one manufacturer's joint improvement effort may spill over to the other manufacturer because they share the same supplier.

In this paper, we examine single-period oligopoly and duopoly models. In practice, cost reduction occurs over time. One may also consider a multi-period model to study the time effect of the target pricing policies. Intuitively, the time consideration will increase the attractiveness of the supply-side policy as the manufacturer will be able to accumulate the benefits of helping its suppliers. In each period, the starting cost c is a result of the cost reduction from the previous time period, and thus retains the impact from the improvement effort of the previous period. Therefore, the effect of high improvement effort (as well as the effort sharing by the manufacturer) propagates through future time periods. As a result, we expect the competition to be much fiercer and that both the suppliers and the manufacturers will be more aggressive in choosing the improvement effort and the sharing of cost-improvement expenses. Finally, one may study the incentive issues in setting the transfer price margins m and r. We hope future studies by the authors and others will provide further insights into the practice of target pricing.

Acknowledgment

Appendix A. Proofs

Proof of Proposition 1. First, we obtain $e_j^* = (c(1+m_j)Z-p)/((1+m_j)Z+\mu b(1-\theta_j)/m_j)$, $j \in \mathcal{S}$ where $Z \equiv 2-1/(n+1-K+\sum_{k \in \overline{\mathcal{S}}} r_k)$, and $e_k^* = r_k p/\mu b(1-\theta_k)$, $k \in \overline{\mathcal{S}}$ by optimizing the suppliers' profits in Eq. (3.5) and taking into consideration the facts that $w_k = p(1-r_k)$, $k \in \overline{\mathcal{S}}$ and $w_j = (c-e_j)(1+m_j)$, $j \in \mathcal{S}$. Then using $p = (a+\sum_\ell w_\ell)/(n+1)$, and $\sum_{\ell=1}^n w_\ell = (a(K-\sum_{k \in \overline{\mathcal{S}}} r_k) + (n+1)\sum_{j \in \mathcal{S}} (c-e_j)(1+m_j))/(n+1-K+\sum_{k \in \overline{\mathcal{S}}} r_k)$, and substituting e_k^* and e_j^*, we obtain a linear equation for p and thus solve for the equilibrium market price p^*. Next, substitute p^* into the expressions for e_j^* and e_k^* to obtain the equilibrium investment effort. We omit the details here. □

Proof of Corollary 1. With two symmetric DS supply chains, $K = n = 2$ and $J=0$. Thus, $\sum_{k \in \overline{\mathcal{S}}} r_k = 2r$ and $G=0$. The results follow immediately after substituting these into Proposition 1. □

Proof of Corollary 2. With two symmetric SS supply chains, $J = n = 2$ and $K=0$. Thus, $\sum_{k \in \overline{\mathcal{S}}} r_k = 0$ and $\sum_{j \in \mathcal{S}} G_j = 2/(5/3 + \mu b(1-\theta)/[m(1+m)])$. The equilibrium price and investment effort

follow after substituting the above into Proposition 1 and applying algebraic transformation. □

Proof of Corollary 3. With one DS and one SS supply chain, $J = K = 1$ and $n=2$. Thus, $\sum_{k \in \overline{\mathcal{S}}} r_k = r$ and $\sum_{j \in \mathcal{S}} G_j = 1/(2-1/(r+2) + \mu b(1-\theta)/[m(1+m)])$. The equilibrium price and investment effort follow after substituting the above into Proposition 1 and applying algebraic transformation. □

Proof of Corollary 4. Assuming the condition $a \leq 2gc$ holds. Define

$$A = \frac{(1-\theta)\mu b(r+2)[a+c(1+m)]+(2r+3)am(1+m)}{(1-\theta)\mu b(r+2)+2(1+r)m(1+m)}.$$

We can check that $\partial A/\partial \theta = -\mu b(r+2)m(1+m)[2gc-a]/[(1-\theta) \mu b(r+2)+2gm]^2 \leq 0$. Therefore statement (1) in Corollary 4 follows from Corollary 3 and the fact that $p^* = (1/(r+2))A$. Statement (2) follows from the expressions of q_1^* and q_2^* in Corollary 3 and the fact that $\partial A/\partial \theta \leq 0$ under the condition $a \leq 2gc$. Finally, statement (3) follows from Corollary 3 and the fact that $\partial A/\partial \theta \leq 0$. □

Proof of Proposition 2. Statement (1) follows from the facts that $\Pi_1^{M*} = (r^2/b(r+2)^2)A^2$, and A is decreasing in θ under the condition $a \leq 2gc$.

To prove statement (2), we can show that $\partial \Pi_2^{M*}/\partial \theta = m\mu[2gc_0 - a]/(r+2)[(1-\theta)\mu b(r+2)+2gm]^3 \cdot [B(1-\theta)-D]$, where $B = \mu b(r+2) [2g(a-gc)+\frac{1}{2}(r+2)m(2gc-a)]$ and $D = (r+2)m(2gc-a)[mg+\mu b(r+2)]-2g^2 am$. Assuming $0 \leq \theta \leq 1$ and under the condition $gc \leq a \leq 2gc$, we have $m\mu[2gc_0-a]/(r+2)[(1-\theta)\mu b(r+2)+2gm]^3 \geq 0$ and $B \geq 0$. Therefore it follows that $\partial \Pi_2^{M*}/\partial \theta \geq 0$ if $B(1-\theta)-D \geq 0$, or equivalently, $\theta \leq 1-D/B = \hat{\theta}$; and $\partial \Pi_2^{M*}/\partial \theta \leq 0$ otherwise. This completes the proof. □

Proof of Proposition 3. Statement (1) follows from the fact that $\partial \Pi_2^{S*}/\partial \theta = \frac{1}{2}\mu(c-(A-a)/(1+m))^2 \geq 0$. To show statement (2), as $\Pi_1^{S*} = ((2\mu br(1-r)+r^2)/2\mu b^2(r+2)^2)A^2-(cr/b(r+2))A$ (details omitted), we have $\partial \Pi_1^{S*}/\partial \theta = [((2\mu br(1-r)+r^2)/\mu b^2(r+2)^2)A - cr/b(r+2)] \cdot \partial A/\partial \theta$. Therefore $\partial \Pi_1^{S*}/\partial \theta \leq 0$ iff $((2\mu br(1-r)+r^2)/\mu b^2(r+2)^2)A-cr/b(r+2) \geq 0$ (recall $\partial A/\partial \theta \leq 0$); or equivalently, iff $A \geq c\mu b(r+2)/(2\mu b(1-r)+r)$, which is equivalent to $\theta \leq \overline{\theta}$, where $\overline{\theta}$ satisfies equation (5.1). This completes the proof. □

Proof of Proposition 4. Using the fact that $\partial A/\partial \theta \leq 0$ under the condition $a \leq 2gc$, it is easy to show that $\Pi_1^{S*} \geq 0$ is equivalent to $\theta \leq \overline{\overline{\theta}}$, where $\overline{\overline{\theta}}$ satisfies $A|_{\theta = \overline{\overline{\theta}}} = 2c\mu b(r+2)/(2\mu b(1-r)+r)$. Comparing $\overline{\overline{\theta}}$ with $\overline{\theta}$ defined in (5.1), we have $\overline{\overline{\theta}} < \overline{\theta}$. Therefore $\Pi_1^{S*} \geq 0$ implies $\theta \leq \overline{\overline{\theta}} < \overline{\theta}$. Statement (1) follows from Propositions 2 and 3. To show statement (2), we have $\partial \Pi_2^*/\partial \theta = (\partial A/\partial \theta) \cdot (1/(1+m)b(r+2)^2[(1-\theta)\mu b(r+2)+2gm]) \cdot [E-F(1-\theta)]$, where $E = \mu b(r+2)^2 m(2gc-a)-2g^2 am$, and $F = \mu bm(r+2)^2(2gc-a)+2\mu b(r+2)g(a-gc)$. As $\partial A/\partial \theta \leq 0$, $1/(1+m)b(r+2)^2[(1-\theta)\mu b(r+2)+2gm] \geq 0$ (assuming $0 \leq \theta \leq 1$), we know immediately that $\partial \Pi_2^*/\partial \theta \geq 0$ if $E-F(1-\theta) \leq 0$, or equivalently, if $\theta \leq 1-E/F = \tilde{\theta}$ (notice $F \geq 0$ under the condition $gc \leq a \leq 2gc$); and $\partial \Pi_2^*/\partial \theta < 0$ if $\theta > \tilde{\theta}$. Finally, statement (3) follows from the facts that $E \leq D$ and $F \geq B$, where B and D are defined in the proof of Proposition 2. This completes the proof. □

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