Supplement to"Supplier Competition and Cost Reduction with Endogenous Information Asymmetry"

Cuihong Li

School of Business, University of Connecticut, Storrs, Connecticut, 06269, USA

cuihong.li@uconn.edu

A All-or-nothing Cost Improvement

We consider the all-or-nothing uncertainty in the improvement effort. The effort may fail when disruption happens that derails the project, resulting in zero improvement (e.g., Babich et al. 2007, Chaturvedi and Martınez-de-Albeniz 2011, Gümüs et al. 2012). Specifically, a cost reduction effort e has a probability η $(1-\eta)$ that it will succeed (fail). If it succeeds, the final production cost is $c_0 - e$; if it fails, the production cost will remain at c_0. We denote by Υ_i supplier i's final production cost. Then Υ_i has a probability mass at the value c_0: $\Pr(\Upsilon_i = c_0) = 1 - \eta(1 - F_i(0))$. For $\gamma \le c_0$, we have $\Pr(\Upsilon_i < \gamma) = \eta(1 - F_i(c_0 - \gamma))$. Define $H_i(\gamma)$ as supplier i's virtual production cost with an actual production cost $\gamma \le c_0$. Then

$$H_i(c_0) = c_0 + \frac{\Pr(\Upsilon_i < c_0)}{\Pr(\Upsilon_i = c_0)} = c_0 + \frac{\eta(1 - F_i(0))}{1 - \eta(1 - F_i(0))},$$

and for $\gamma < c_0$,

$$H_i(\gamma) = \gamma + \frac{1 - F_i(c_0 - \gamma)}{f_i(c_0 - \gamma)} = c_0 - J_i(c_0 - \gamma),$$

where $J_i(e) = e - \frac{F_i(e)}{f_i(e)}$. $H_i(\gamma)$ is decreasing in $\gamma \le c_0$ if $J_i(e)$ is increasing in $e \ge 0$ and $\frac{\eta(1-F_i(0))}{1-\eta(1-F_i(0))} \ge \frac{1-F_i(0)}{f_i(0)}$.

We assume $H_i(c_0) > r$, i.e., $\eta(1 - F_i(0)) > \frac{r-c_0}{1+r-c_0}$. Under this assumption, the buyer will never purchase from a supplier with final production cost c_0. Therefore, a supplier will not receive any quantity if the cost-reduction effort fails. That also means the expected quantity of a supplier must not be higher than η.

Define e_u^* as the system-efficient effort level for a single supplier; that is, e_u^* maximizes $\eta e - \varphi(e)$, giving $\varphi'(e_u^*) = \eta$. Proposition A.1 shows that the structural results based on the main model (as in Proposition 2 of the paper) continue to hold.

Proposition A.1 *Assume* $\eta > \frac{r-c_0}{1+r-c_0}$. *There exists a unique symmetric mixed strategy equilibrium in which:*

(i) a supplier's strategy has $\underline{e} = 0$ *and* $\overline{e} = e_u^*$, *with*

$$F(e) = \begin{cases} F^l(e) \equiv 1 - \frac{r-c_0}{r-c_0+e} & \text{if } e \in [\underline{e}, \widehat{e}] \\ F^h(e) \equiv 1 - \frac{1}{\eta}\left(1 - \left(\frac{\varphi'(e)}{\eta}\right)^{\frac{1}{n-1}}\right) & \text{if } e \in (\widehat{e}, \overline{e}] \end{cases}, \tag{1}$$

for which $\widehat{e} = e_u^*$ *if* $n = 1$, *and otherwise* $\widehat{e}$ *is uniquely defined by* $J^h(\widehat{e}) = c_0 - r$ *and decreases in* n, *for* $J^h(e) \equiv e - \frac{1-F^h(e)}{f^h(e)}$;

(ii) the buyer's strategy is such that $\widetilde{\overline{q}}_i(\gamma) = \varphi'(c_0-\gamma)/\eta$ *and* $\widetilde{\overline{t}}_i(\gamma) = \gamma\widetilde{\overline{q}}_i(\gamma) + \varphi(c_0-\gamma)/\eta$, $\gamma \in [c_0 - e_u^*, 0]$, *for all* $i \in S$, *with* $\widetilde{q}_i(\gamma) = 1$ *if* $\gamma_i < \min\{\gamma_{-i}, c_0 - \widehat{e}\}$ *and* $\widetilde{q}_i(\gamma) = 0$ *if* $\min\{\gamma_i, c_0 - \widehat{e}\} > \min\{\gamma_{-i}\}$.

The above analysis suggests that all structural results and insights can be extended to the case when the success of the investment is uncertain, i.e., $\eta < 1$, as long as the probability of success is not too small.

Next, we analyze the suppliers' and buyer's profits with respect to the supply base size (number of suppliers). Again, Proposition A.2 maintains the same insights as in Proposition 5 of the main model, that the buyer always benefits from supplier competition (compared to sole sourcing), and the desired supply base size (beyond two supplier) is negatively related with the product margin.

Proposition A.2 *(i) A supplier's expected profit is zero. (ii) The buyer's profit with* $n = 1$ *is* $\eta(r-c_0)$, *and the profit with* $n \geq 2$ *is strictly greater than* $\eta(r-c_0)$. *(iii) When* $r \to \infty$, *the buyer's profit monotonically decreases with* $n \geq 2$.

B Asymmetric Suppliers

We consider suppliers with different ex ante capabilities that are reflected in the cost reduction achieved with the same investment. For analytical tractability, we assume a binary effort decision and limit our consideration to two suppliers. Consider two asymmetric suppliers, L and H (with Low and High capabilities). Each supplier L (H) can choose to exert effort e_L (e_H) or not, with $e_L < e_H$, at the same effort disutility φ. Let the probability of exerting effort be p_{L1} (p_{H1}), and hence the probability of not exerting effort $p_{L0} = 1 - p_{L1}$ ($p_{H0} = 1 - p_{H1}$). Let the expected quantity received by a supplier $i = L, H$, be $q_i\left(x_L, x_H\right)$, for given efforts x_L and $x_H \in \{0, 1\}$. Define $\mathbf{q} \equiv (q_L, q_H)$.

As a benchmark, we first analyze the case with a single supplier that can choose whether to exert effort e with disutility φ. Let p_0 and $p_1 = 1 - p_0$ be the probability that the supplier does not and does exert effort. Let the supplier's quantity be q_0 and q_1 without and with effort. To avoid trivial cases, we assume $\varphi/e \leq 1$, i.e., the disutility of effort is less than the benefit of cost reduction.

Proposition B.1 *(i) The equilibrium with one supplier is characterized by* $q_0 = \varphi/e$, $q_1 = 1$, $p_0 = \frac{e}{r-c+e}$ *and* $p_1 = \frac{r-c}{r-c+e}$.

(ii) The buyer's profit with one supplier is equal to $r - c$.

With a binary effort choice, it remains true that a mixed-strategy equilibrium emerges in which the supplier chooses to exert effort with a certain probability, and the buyer does not benefit from the supplier's effort.

Now consider two suppliers, L and H. Again, we assume $\varphi\left(e_L^{-1} - e_H^{-1}\right) \leq 1$ to avoid trivial situations. The equilibrium result is characterized in Proposition B.2.

Proposition B.2 *(i) The equilibrium with two suppliers is characterized by:* $\mathbf{q}(1,1) = \mathbf{q}(0,1) = (0,1)$, $\mathbf{q}(1,0) = (1,0)$, *and, (i-1) if* $e_L e_H < \varphi\left((e_H + e_L) + 2(r - c)\right)$, *then*

$$\mathbf{q}(0,0) = (\frac{1}{2} + \frac{\varphi\left(e_H - e_L\right)}{2e_L e_H}, \frac{1}{2} - \frac{\varphi\left(e_H - e_L\right)}{2e_L e_H}),$$

$$p_{L1} = \frac{e_L e_H - \varphi\left(e_H + e_L\right)}{e_L e_H - \varphi\left(e_H - e_L\right)},\ p_{H1} = \frac{e_L e_H - \varphi\left(e_L + e_H\right)}{e_L e_H + \varphi\left(e_H - e_L\right)},$$

with $p_{L1} > p_{H1}$, *and (i-2) otherwise,*

$$\mathbf{q}(0,0) = (\frac{\varphi\left(e_H + r - c\right)}{e_L e_H}, \frac{\varphi\left(e_L + r - c\right)}{e_L e_H}),$$

$$p_{L1} = \frac{r-c}{e_L + r - c},\ p_{H1} = \frac{r-c}{e_H + r - c},$$

with $p_{L1} > p_{H1}$*.*

(ii) The buyer's profit with two suppliers is equal to $r - c + p_{H1}e_H$*, which is greater than the profit with a single supplier.*

The result based on symmetric suppliers, that supplier competition benefits the buyer, continues to hold with asymmetric suppliers, as shown in part (ii). Part (i) characterizes the equilibrium decisions in two cases, based on the buyer's revenue r. In both cases, all quantity goes to the supplier that exerts effort, and if both suppliers exert effort, all quantity is allocated to the more capable supplier H. In these cases, there is no trade inefficiency since the total purchasing quantity is equal to one. If neither supplier exerts effort, however, then quantity allocation differs between the two cases based on the revenue. Specifically, when the buyer's revenue is sufficiently large (case i-1), again there is no trade inefficiency, as the total quantity $q_L + q_H$ is always equal to one. When the revenue is relatively small (case i-2), the buyer may not purchase from either supplier, with $q_L + q_H < 1$. In both cases, the less capable supplier L has a higher chance to exert effort than the more capable supplier H ($p_{L1} > p_{H1}$), and meanwhile the former receives more quantity on expectation than the latter ($q_L > q_H$) when they both choose zero efforts, despite the fact that supplier L is less capable than supplier H ($e_L < e_H$). This result is consistent with Amaldoss and Jain (2002), who study the asymmetric mixed-strategy equilibrium in a patent race. They show that, counter-intuitively, the firm that values the patent less is more likely to invest more aggressively and also win the patent.

The impact of supplier asymmetry is further illustrated in Figure 1. The plots vary the supplier capability asymmetry level $e_H - e_L$ on the horizontal axis while keeping the average capability $e_L + e_H$. The top left plot draws the quantities received by the two suppliers when they both exert zero efforts, and top right is for the expected quantities considering all possible effort profiles. The lower left plot illustrates the suppliers' probabilities of efforts, while the lower right plot is for the buyer's expected profit. The vertical dashed line in the plots represents the threshold where the transit from case (i-ii) to case (i-1) happens.

As we can see in the top left plot, when both exert zero efforts, the less-capable supplier's quantity increases while the more-capable supplier's decreases when their capability discrepancy increases. As a result, the less-capable supplier receives more quantity on expectation than the more-capable supplier when their asymmetry is sufficiently large, as shown in the top right plot. Furthermore, the less-capable supplier is more aggressive at cost reduction, more likely to exert effort, than the more-capable supplier, as shown in the bottom left plot. In the result, when the supplier asymmetry is not too large, more asymmetry increases the trade efficiency by improving the total quantity (by increasing the quantity for the less-capable supplier while decreasing, by a less amount, the one for the more-capable supplier), thereby enhancing the buyer's profit; as shown in the bottom right plot, the buyer's profit first increases and then decreases as supplier asymmetry widens. In other words, the buyer benefits from supplier asymmetry up to a certain level, for more asymmetry motivates the less-capable supplier to invest more in cost reduction, increasing the chance of a trade.

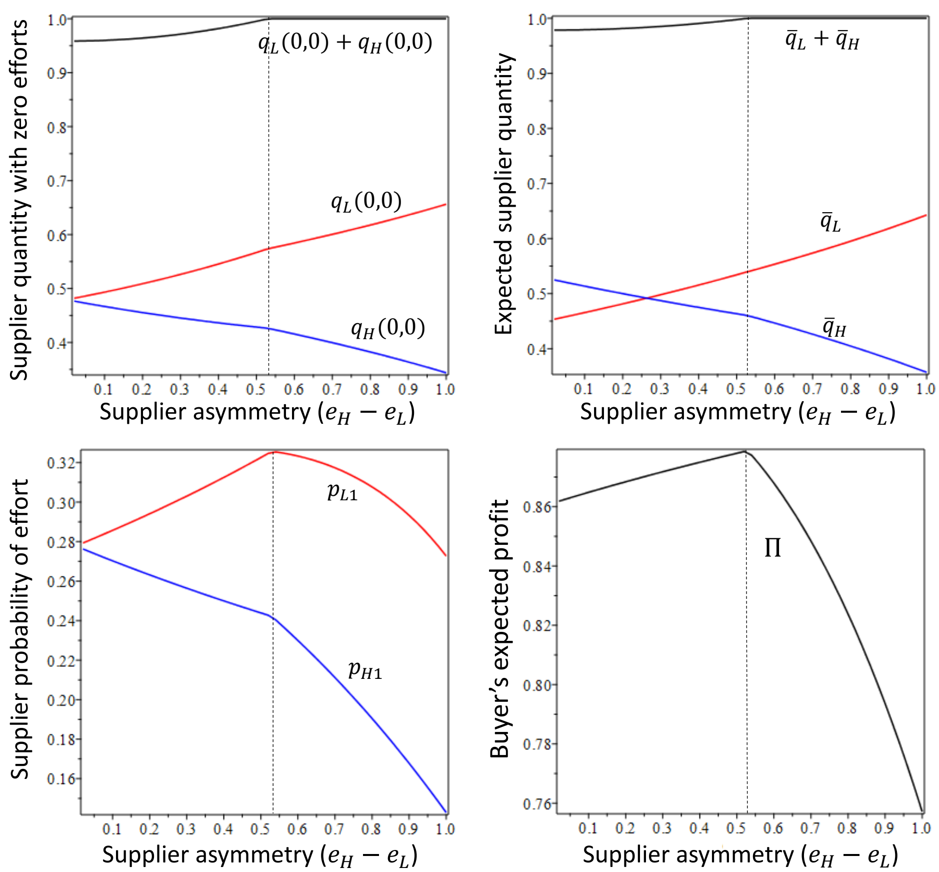

Figure 1: Equilibrium results with varying supplier asymmetry. $r = 2.5$, $\varphi = 0.45$, $e_H + e_L = 2.6$.

In summary, with asymmetric suppliers, the buyer still benefits from supplier competition, better off with two suppliers than with a single supplier. Interestingly, it is the less capable supplier that is more likely to invest in cost reduction. Due to this motivation effect, more supplier asymmetry benefits the buyer, up to a certain point.

C Contract Commitment

In our main model, the parties cannot commit to a contract prior to suppliers' cost reduction investment. Such a lack of contract commitment causes the hold-up problem. If a contract commitment is possible, then the buyer will offer a contract to a single supplier. The contract will grant the supplier the full quantity, inducing the first-best effort, and pays the supplier a fixed fee that covers the production cost and effort disutility. In other words, a contract commitment achieves the first-best result and allows the buyer to extract all profits in the supply chain. The result with a contract commitment is formalized in Proposition C.1.

Proposition C.1 *With a contract commitment, the buyer offers a contract to a single supplier that specifies a quantity* $q = 1$ *and payment* $t = c_0 - e^* + \varphi(e^*)$ *for* e^* *defined by* $\varphi'(e^*) = 1$*, and the supplier chooses the first-best effort* e^**, receiving zero profit.*

Figure 2 plots the buyer's profit with a contract commitment, in contrast to the case without a commitment, using the same parameters as for Figure 2 in the paper.

A contract commitment allows the buyer to achieve both the effort efficiency (with supplier effort equal to e^*) and trade efficiency (with trade quantity equal to one) with a *single* supplier. A lack of commitment undermines both efficiencies, as shown in the main paper. Nevertheless, our result of supply base design (Section 5 in the paper) suggests that the buyer can compensate for the efficiency loss with supplier competition: although it is sufficient to have a single supplier in the presence of a contract commitment, it is beneficial to have multiple suppliers in the absence of it. In fact, Proposition C.2 shows that, when the product margin r is very large, supplier competition achieves almost the first-best profit for the buyer. This result occurs because, with r large, the effort inefficiency is negligible (compared to r), and trade inefficiency is reduced close to zero with supplier competition (as

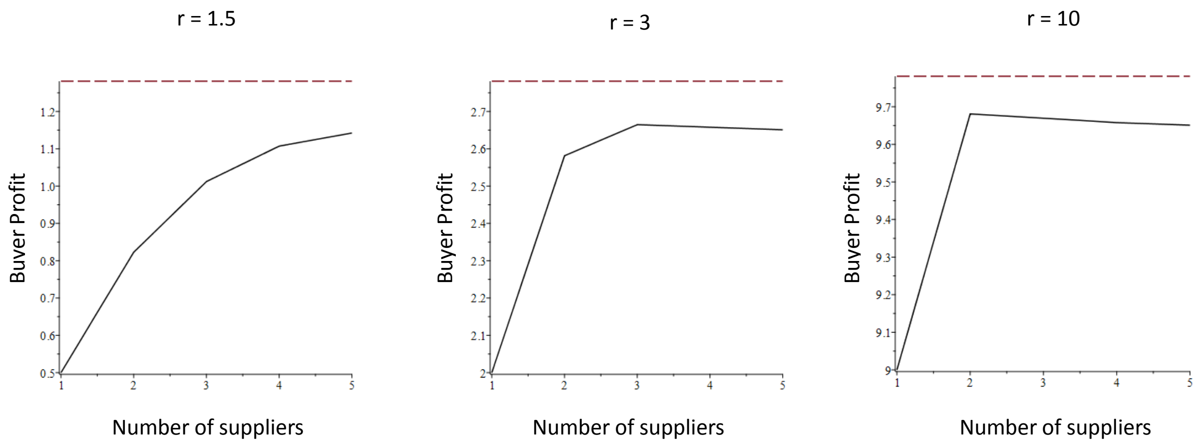

Figure 2: Buyer's expected profit based on the number of suppliers with different product revenue r, with (dashed line) and without (solid line) a contract commitment. $\varphi(e) = 1.1e^5$, $c_0 = 1$.

$\widehat{e} \to 0$ and hence the buyer will almost always purchase the full quantity from a supplier). Therefore, with a high product margin, simply adding a supplier to introduce competition is sufficient to make up for the buyer's loss for the lack of commitment power.

Proposition C.2 *In the presence of multiple suppliers, we have* $\lim_{r\to\infty} \Pi/\Pi^* = 1$, *where* Π *and* Π^* *are the buyer's profits without and with a contract commitment, respectively.*

References

Amaldoss, W., S. Jain, (2002) David vs. Goliath: An Analysis of Asymmetric Mixed-Strategy Games and Experimental Evidence. *Management Science* 48(8) 972–991.

Babich, V., A. N. Burnetas, P. H. Ritchken. 2007. Competition and diversification effects in supply chains with supplier default risk. *Manufacturing & Service Operations Management* 9(2) 123–146.

Chaturvedi, A. and V. Martínez-de-Albéniz. 2011. Optimal procurement design in the presence of supply risk. *Manufacturing & Service Operations Management* 13(2) 145-280.

Gümüs, M., S. Ray, and H. Gurnani. 2012. Risks, Guarantees, Competition, and Information Asymmetry. *Management Science* 58(9) 1694–1714.