Bundling in maintenance contracts

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Abstract

This paper investigates the owner’s choices about whether to procure the maintenance service from single or separate providers for the different stages when the spillover effect between stages, the OEM’s learning-by-doing effect, and asymmetry of competition in different markets co-exist. We find that when the competition in the post-warranty market is weak and the effect of learning-by-doing is strong, the owner prefers a bundling contract; otherwise, the owner prefers un-bundling contracts. In addition, un-bundling contracts lead to the “make a mess for others” phenomenon that is the OEM intentionally makes a less reliable machine to increase the maintenance costs of other providers.

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1 Introduction

For a machine that needs a lot of maintenance in several related stages, the owner’s choices about whether to procure the maintenance service from single or separate providers for the different stages represent an important part of the operation strategy. For instance, in the wind turbine industry, during the warranty period, the owner of a turbine often gets free maintenance from its original equipment manufacture (OEM). In the post-warranty period, the owner has to decide whether to continue contracting with the OEM for the maintenance service or turn to a third-party service provider. Similarly, the owners of airplanes, medical equipment, etc. face the same choice when the warranty expires.

The owner’s decisions about whether to continue contracting with the OEM influence the OEM’s allocation of effort between different tasks in the warranty period. To reach a performance level required by the owner, the OEM can choose between two substitute tasks: either making a more reliable machine or putting more maintenance effort. The more reliable the machine is, the less maintenance it needs. The OEM’s choice of reliability influences not only its cost of obtaining the required performance during the warranty period but also the cost in the post-warranty period because the machine’s reliability cannot be changed in the post-warranty period. This spillover effect is similar to the task dependence in multitasking (Holmstrom and Milgrom 1991) literature and the effort externality in public-private partnership (e.g. Laffont and Tirole 1988; Martimort and Pouyet 2008; Bennett and Iossa 2006; Chen and Chiu 2010, etc.) literature.

Besides the spillover effect between tasks, there are two noticeable features in the maintenance industry. The first one is when the OEM maintains the machine during the warranty period it enjoys a learning-by-doing effect that improves its maintenance efficiency in the post-warranty period. The second one is there is much more competition in the post-warranty maintenance market than the equipment market. These two features create
a trade-off for the owner when it decides whether to procure the maintenance service from the OEM only.

Maintenance contracts are often based on the machine’s performance rather than its reliability and maintenance effort, because for owners the performance is easier to measure than the factors behind it. Due to the information asymmetry, owners in practice use auctions to select providers to reduce the providers’ information rents (see McAfee and McMillan 1986; Laffont and Tirole 1987).

This paper investigates whether owners of machines should bundle the procurement of maintenance service in two periods in an environment where, to meet certain performance requirements, OEMs choose the reliability of machines and the maintenance effort in the warranty period, and maintenance providers choose maintenance effort in the post-warranty period. Learning-by-doing effect and internalization of the spillover between periods favor owners to bundle the procurement, however, more competition in the post-warranty market favors owners to un-bundle.

We find that under bundling the OEM prefers making a more reliable machine because it has a relatively high maintenance efficiency due to learning-by-doing and also because it internalizes the spillover effect of the choice of reliability on the maintenance cost in the post-warranty period. In contrast, under un-bundling, the OEM prefers making the machine less reliable than when there is no spillover effect, which we call “make a mess for others” phenomenon. The reason behind the phenomenon is that the OEM is more efficient to clean the mess than other competitors due to learning-by-doing effect. However, if the number of competitors in the post-warranty market is big enough, the owner may still benefit to un-bundle the procurement because the competition could bring a much more efficient maintenance provider.

This paper belongs to the strand of literature that investigates either optimal contracts in the public-private partnership (e.g. Hart 2003; Martimort and Pouyet 2008; Iossa and
Martimort 2015; Li et al. 2015; Hoppe and Schmitz 2010, etc.) or incentive scheme auction (e.g. McAfee and McMillan 1986; Laffont and Tirole 1987; Anton and Yao 1987, etc.). Our paper brings the learning-by-doing effect, the spillover effect and competition effect together and the result sheds light on how to design an optimal procurement in the complicated situation.

The rest of this paper is organized as follows. Section 2 introduces the basic model. Section 3 analyzes how bundling and un-bundling affects the OEM’s choice and the owner’s procurement cost. Section 4 compares reliability choices and procurement costs under different bundling schemes. Section 5 concludes.

2 The model

The owner of a machine cares about machine’s performance index: availability \( A \) that is a percentage of time during which the machine is available to work. There are two factors influencing machine’s availability: machine’s reliability \( \mu \) and maintenance effort \( s \). The machine’s availability increases in its reliability and the maintenance effort.

\[
A(\mu, s) = \frac{MTBF}{MTBF + MDT} = \frac{\mu}{\mu + \frac{1}{s}}
\]

where MTBF is the abbreviation for Mean-Time-Between-Failure and MDT for Mean-Delay-Time. The more reliable the machine is, the longer the mean time between failures is. When the machine is broken, the more maintenance effort the provider puts, the shorter the mean delay time is.

The owner procures the machine from its original equipment manufacture (OEM) with a warranty under which the OEM provides maintenance for free. Denote the warranty period by \( t = 1 \). When the warranty expires, the owner can either continue contracting with the OEM for the maintenance service or turn to a third-party provider. Denote the post-warranty period by \( t = 2 \).
It is easy for the owner to observe the machine’s availability but impossible to observe the two factors influencing it. Hence the owner only sets a minimum requirement for the machine’s availability \( (A) \) while purchasing the machine and maintenance service. To meet the availability requirement, at \( t = 1 \), the OEM is free to choose a combination of reliability and maintenance effort. However, at \( t = 2 \), no matter who is the maintenance service provider, it can only influence availability via maintenance effort because the machine’s availability cannot be changed anymore once the machine is designed and manufactured.

The owner uses second-price auctions to purchase the machine with warranty at \( t = 1 \) and the post-warranty maintenance at \( t = 2 \). A total of \( M \) OEMs can design and manufacture machines and each OEM can only maintain the machine made by itself. During the post-warranty period, including the OEM, a total of \( N \) firms can provide the post-warranty maintenance. Assume \( M < N \), which reflects the maintenance market is more competitive than the equipment market.

At \( t = 1 \), a chosen OEM is responsible for designing and making, and maintaining the machines to meet the owner’s availability requirement. The cost includes two parts: the reliability cost \( (\mu) \); the maintenance cost \( (\beta_1 s_1) \). The total cost is \( C_1 = \mu + \beta_1 s_1 \) where \( \beta_1 \) reflects the OEM’s maintenance efficiency.

At \( t = 2 \), the maintenance provider can only change its maintenance effort to impact the machine’s availability. The maintenance cost is \( C_2 = \beta_2 s_2 \) where \( \beta_2 \) reflects the provider’s maintenance efficiency. At \( t = 2 \), if the OEM continues maintaining the machine, \( \beta_2^{OEM} = \delta \beta_1 \) with \( \delta \in (0, 1) \), where \( \delta \) represents the learning-by-doing effect.

Assume the maintenance efficiency \( \beta_1 \) and \( \beta_2 \) independently follow a distribution over \([\beta_\bar{\beta}]\) with a cumulative distribution function \( F(\cdot) \). At the beginning of the first period, a random draw of maintenance efficiency \( \beta_1^i \) is only revealed to the OEM \( i \). At the beginning of the second period, a random draw of maintenance efficiency \( \beta_2^i \) is only revealed to the new maintenance provider \( i \). And all new maintenance providers know the existing OEM’s
degree of learning-by-doing effect that is $\delta$.

Denote the payment to the maintenance provider in period $t$ by $P_t(A)$. Assume the discount factor is 1 between periods.

## 3 The bundling decisions

The owner of a machine considers how the decision of bundling affects the OEM’s choice of reliability and the overall cost for obtaining a certain performance.

### 3.1 The bundling contract

If the owner uses a bundling contract to purchase the machines with warranty at $t = 1$ and the maintenance service at $t = 2$, each OEM solves the following problem

$$\min_{\mu, s_1, s_2} \mu + \beta_1 s_1 + \delta \beta_1 s_2$$

s.t. \[
\frac{\mu}{\mu + \frac{1}{s_1}} \geq A \\
\frac{\mu}{\mu + \frac{1}{s_2}} \geq A
\]

We have $\mu^*_b = \sqrt{(1 + \delta)\beta_1 A_1 - A}$ and $s^*_1 = s^*_2 = \sqrt{\frac{1}{(1 + \delta)\beta_1 A_1 - A}}$. Hence, the minimum overall cost to achieve the performance requirement is $TC_b = \sqrt{4(1 + \delta)\beta_1 A_1 - A}$.

### Auction

In the second price auction, submitting its true cost is a weakly dominant strategy for each bidder. Hence each OEM bids $b^i = \sqrt{4(1 + \delta)\beta^i_1 A_1 - A}$. Let $Y^r(M)$ denote the $r^{th}$ minimum $\beta^i_1$ among the $M$ bidders. The density of $Y^r(M)$ is $g^r(M)(y) = M f(y)\left(\frac{M - 1}{M - r - 1}\right)(1 - F(y))^{r-1}$. Then the owner’s expected payment to the winning bidder is

$$E(P(A)) = \int_{\hat{\beta}} \sqrt{4(1 + \delta)y\frac{A}{1 - A}} g^r_2(M)(y)dy$$

where $g^r_2(M)(y) = M(M - 1)F(y)(1 - F(y))^{M-2}f(y)$. 
Lemma 1. With a bundling contract, the owner pays a total cost $TC_b = E(P(A))$ to achieve an availability level $A$ for two periods.

3.2 The un-bundling contracts

At $t = 1$, each OEM decides a bidding strategy and an optimal reliability $\mu$ accordingly. Since the maintenance cost of each bidder at $t = 2$ is influenced by the winning OEM’s choice of reliability $\mu$ at $t = 1$, we figure out each OEM’s optimal bidding strategy and choice of reliability by backward induction.

3.2.1 The provider’s optimization at $t = 2$

Assume the winning OEM chooses the optimal reliability $\mu$ at $t = 1$. If each OEM has a unique optimal bidding strategy and choice of reliability, all other bidders at $t = 2$ can perfectly infer $\mu$ from what the winning OEM bid at $t = 1$. Given the winning OEM’s choice of reliability at $t = 1$ and the owner’s performance requirement, each provider at $t = 2$ will choose $s^*_2 = \frac{A}{\mu}$. Hence we can rewrite each provider’s cost function as $C_2 = \beta_2 \frac{A}{\mu}$. For the OEM, its maintenance efficiency is $\beta_{OEM}^2 = \delta \beta_1$.

Auction

In the second price auction, each provider bids its true cost $\frac{\beta_2 A}{\mu}$. And the OEM bids $\frac{\delta \beta_1 A}{\mu}$. The OEM wins the auction if its bid is the smallest, i.e. $\delta \beta_1 < Y_{1}^{(N-1)}$ where $Y_{1}^{(N-1)}$ is the minimum $\beta^i_2$ among the other $N - 1$ providers. The expected profit by the
OEM with efficiency parameter $\beta_1$ can be written as

$$m_2^{OEM}(\beta_1) = \text{Prob}[\text{Win}] \times E((2\text{nd lowest bid} - \text{OEM's cost})|\delta \beta_1 \text{is the smallest})$$

$$= \text{Prob}[\text{Win}] \times (E(2\text{nd lowest bid}|\delta \beta_1 \text{is the smallest}) - \text{OEM's cost})$$

$$= (1 - G_1^{(N-1)}(\delta \beta_1)) \times \left( \int_{\delta \beta_1}^{\bar{\beta}} \frac{y}{\mu(1-A)} \frac{g_1^{(N-1)}(y)}{1 - G_1^{(N-1)}(\delta \beta_1)} dy - \frac{\delta \beta_1}{\mu} \frac{A}{1-A} \right)$$

$$= (1 - G_1^{(N-1)}(\delta \beta_1)) \times \frac{A}{\mu(1-A)} \left( \int_{\delta \beta_1}^{\bar{\beta}} \frac{g_1^{(N-1)}(y)}{1 - G_1^{(N-1)}(\delta \beta_1)} dy - \delta \beta_1 \right)$$

**Lemma 2.** In the un-bundling auction, the winning OEM’s expected profit at $t = 2$ decreases in its reliability choice $\mu$ at $t = 1$.

**Proof.** Since $(1 - G_1^{(N-1)}(\delta \beta_1)) > 0$, $1 - A > 0$, and $\int_{\delta \beta_1}^{\bar{\beta}} \frac{g_1^{(N-1)}(y)}{1 - G_1^{(N-1)}(\delta \beta_1)} dy - \delta \beta_1 > 0$, we have $\left( \frac{\partial m_2^{OEM}(\beta_1)}{\partial \mu} \right) < 0$.

### 3.2.2 The OEM’s optimization at $t = 1$

Given the owner’s performance requirement, each OEM will choose $s_1^* = \frac{1}{\mu} \frac{A}{1-A}$. Hence we can rewrite the OEM’s cost function at $t = 1$ as $C_1 = \mu + \frac{\beta_1}{\mu} \frac{A}{1-A}$.

**Auction**

In the second-price auction, each OEM bids its true cost. As we know, the choice of $\mu$ is a function of $\beta_1^i$. Hence each OEM bids $b_1^i = \mu(\beta_1^i) + \frac{\beta_1^i}{\mu(\beta_1^i)} \frac{A}{1-A}$. Assume that the bidding function $b_1^i$ increases in $\beta_1^i$. The OEM $i$ wins the auction if its bid is the smallest, i.e. $\beta_1^i$ is the smallest among $M$ OEMs. The expected profit by the OEM with efficiency parameter $\beta_1$ can be written as
$m_1^{OEM}(\beta_1) = \text{Prob}[\text{Win}] \times E(\text{(2nd lowest bid} - \text{OEM's cost)}|\beta_1 \text{ is the smallest})$

$= \text{Prob}[\text{Win}] \times (E(\text{2nd lowest bid}|\beta_1 \text{ is the smallest}) - \text{OEM's cost})$

$= \text{Prob}[b_i^1 < b_1^i] \times (E(\text{2nd lowest bid}|\beta_1 \text{ is the smallest}) - \text{OEM's cost})$

$= (1 - G_1^{(M-1)}(\beta_1)) \times \left( \int_{\beta_1}^{\beta} (\mu(y) + \frac{y}{\mu(y)(1 - \Lambda)} A) g_1^{(M-1)}(y) dy - (\mu(\beta_1) + \frac{\beta_1 A}{\mu(\beta_1)(1 - \Lambda)}) \right)$

**Lemma 3.** In the unbundling auction, at $t = 1$ the OEM’s expected profit increases in its reliability choice $\mu$ when $0 < \mu < \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$ and decreases in $\mu$ when $\mu > \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$.

**Proof.** Since $(1 - G_1^{(N-1)}(\delta \beta_1)) > 0$, and $\mu(\beta_1) + \frac{\beta_1 A}{\mu(\beta_1)(1 - \Lambda)}$ decreases in $\mu$ when $0 < \mu < \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$ and increases in $\mu$ when $\mu > \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$, we have $\frac{\partial m_1^{OEM}(\beta_1)}{\partial \mu} > 0$ when $0 < \mu < \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$, and $\frac{\partial m_1^{OEM}(\beta_1)}{\partial \mu} < 0$ when $\mu > \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$. \hfill \Box

**Lemma 4.** At $t = 1$, no OEM chooses $\mu > \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$.

**Proof.** Assume that an OEM chooses a $\mu > \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$. We can always find a $\mu' < \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$ such that $b_1(\mu, \beta - 1) = b_1(\mu', \beta_1)$. By choosing $\mu'$, the OEM doesn’t change its expected profit at $t = 1$ but increases its expected profit at $t = 2$ according to Lemma 2. Hence no OEM chooses $\mu > \sqrt{\beta_1 \frac{A}{1 - \Lambda}}$. \hfill \Box

The OEM’s expected profit over two periods is

$m^{OEM}(\beta_1) = m_1^{OEM}(\beta_1) + \text{Prob}[\text{Win the first auction}] \times m_2^{OEM}(\beta_1)$

$= m_1^{OEM}(\beta_1) + (1 - G_1^{(M-1)}(\beta_1)) \times m_2^{OEM}(\beta_1)$
Optimal choice of reliability

We know that the OEM’s expected profit at \( t = 2 \) decreases in its reliability choice. Hence, OEM tends to choose a low level of reliability. However, a low level of reliability decreases its expected profit at \( t = 1 \). The OEM chooses a level of reliability to maximize its overall expected profit.

**Lemma 5.** The optimal choice of reliability for each OEM is the one that maximizes its overall expected profit, i.e. \( \mu^*_u = \sqrt{\frac{A}{1-A} \beta_1 - (1 - G_1^{(N-1)}(\beta_1)) \left( \int_{\delta_\beta_1}^\beta y \frac{g_1^{(N-1)}(y)}{1-G_1^{(N-1)}(\delta_\beta_1)} dy - \delta_\beta_1 \right)} \).

**Proof.** Since \( \mu^*_u \in \max_\mu m^{OEM}(\mu, \beta_1) \), we know \( \frac{\partial m^{OEM}(\mu^*_u, \beta_1)}{\partial \mu^*_u} = 0 \). This condition implies

\[
(1 - G_1^{(M-1)}(\beta_1))[-(1 - \frac{\beta_1}{(\mu^*_u)^2} \frac{A}{1-A}) - (1 - G_1^{(N-1)}(\delta_\beta_1)) \frac{A}{(\mu^*_u)^2(1-A)} \times \left( \int_{\delta_\beta_1}^\beta y \frac{g_1^{(N-1)}(y)}{1-G_1^{(N-1)}(\delta_\beta_1)} dy - \delta_\beta_1 \right)] = 0
\]

Hence we have \( \mu^*_u = \sqrt{\frac{A}{1-A} \beta_1 - (1 - G_1^{(N-1)}(\beta_1)) \left( \int_{\delta_\beta_1}^\beta y \frac{g_1^{(N-1)}(y)}{1-G_1^{(N-1)}(\delta_\beta_1)} dy - \delta_\beta_1 \right)} \). \( \square \)

### 3.2.3 The owner’s expected payment

By plugging the optimal choice of reliability \( \mu^*_u \) into the bidding function, we can calculate the owner’s expected payment for getting the required performance. As we know, the owner will pay the second lowest bid to the winning bidder in the second price auction.

In the first auction, each OEM bids \( b_1^i = \mu^*_u + \frac{\beta_1}{\mu^*_u} \frac{A}{1-A} \). The owner’s expected payment to the winning bidder is

\[
E(P_1(A)) = \int_{\beta}^\beta (\mu^*_u(y) + \frac{y}{\mu^*_u(y)} \frac{A}{1-A}) g_2^{(M)}(y) dy
\]

where \( g_2^{(M)}(y) = M(M-1)F(y)(1-F(y))^{M-2}f(y) \).

In the second auction, each provider bids \( b_2^i = \frac{\beta_2}{\mu_2^*} \frac{A}{1-A} \). For the OEM, its maintenance efficiency is \( \beta_2^{OEM} = \delta_\beta_1 \). According to the ranking of the provider’s maintenance efficiency,
we have three scenarios: $\delta \beta_1$ is the smallest; it is the second-smallest; it is the third-smallest. Hence the owner’s expected payment to the winning bidder is $E(P_2(A)) = E(E(P_2(A)|\beta_1)) = \int_{\bar{\beta}}^{\beta} E(P_2(A)|\beta_1) g_1^M(\beta_1) d\beta_1$. We know

\[
E(P_2(A)|\beta_1) = \text{Prob}(\delta \beta_1 < Y_1^{(N-1)}) \times E(\frac{Y_1^{(N-1)}}{\mu^*_u} \frac{A}{1-A}|\delta \beta_1 < Y_1^{(N-1)}) \\
+ \text{Prob}(Y_1^{(N-1)} < \delta \beta_1 < Y_2^{(N-1)}) \times \frac{\delta \beta_1 A}{\mu^*_u 1-A} \\
+ \text{Prob}(Y_2^{(N-1)} < \delta \beta_1) \times E(\frac{Y_2^{(N-1)}}{\mu^*_u} \frac{A}{1-A}|Y_2^{(N-1)} < \delta \beta_1)
\]

\[
= \int_{\delta \beta_1}^{\bar{\beta}} \frac{y}{\mu^*_u 1-A} g_1^{(N-1)}(y)dy \\
+ \int_{\beta}^{\delta \beta_1} g_1^{(N-1)}(y)dy \int_{\delta \beta_1}^{\bar{\beta}} g_2^{(N-1)}(y)dy \times \frac{\delta \beta_1 A}{\mu^*_u 1-A} \\
+ \int_{\beta}^{\delta \beta_1} \frac{y}{\mu^*_u 1-A} g_2^{(N-1)}(y)dy
\]

\[
= \frac{1}{\mu^*_u 1-A} \times (\bar{\beta} - \int_{\delta \beta_1}^{\bar{\beta}} G_1^{(N-1)}(y)dy - \int_{\beta}^{\delta \beta_1} G_2^{(N-1)}(y)dy \\
+ \delta \beta_1 G_2^{(N-1)}(\delta \beta_1)(1 - G_1^{(N-1)}(\delta \beta_1))
\]

where $g_1^{(N-1)}(y) = (N-1)(1-F(y))^{N-2}f(y)$ and $g_2^{(N-1)}(y) = (N-1)(N-2)F(y)(1-F(y))^{N-3}f(y)$.

**Lemma 6.** With un-bundling contracts, the owner pays a total cost $TC_{ub} = E(P_1(A)) + E(P_2(A))$ to achieve an availability level $A$.

**4 Comparison**

The owner of a machine cares about whether bundling leads to a lower cost to obtain a certain performance. Before coming to this point, we study how bundling affects the OEM’s choice of reliability and how the learning-by-doing effect influences the choice of reliability.
4.1 Reliability

If the OEM ignores the spillover effect of reliability on the maintenance cost at \( t = 2 \), i.e., it only minimizes its cost at \( t = 1 \), it will choose \( \mu^*_1 = \sqrt{\beta_1 \frac{A}{1-A}} \). We can draw the cost function of reliability at \( t = 1 \) given the performance requirement.

Proposition 1. An un-bundling contract leads to a lower level of reliability than a bundling contract. [Make a mess for others.]

Proof. Recall \( \mu^*_b = \sqrt{(1+\delta)\beta_1 \frac{A}{1-A}} \), \( \mu_1 = \sqrt{\beta_1 \frac{A}{1-A}} \) and

\[
\mu^*_u = \sqrt{\frac{A}{1-A} \left[ \beta_1 - (1 - G_1^{(N-1)}(\delta\beta_1)) \left( \int_{\delta\beta_1}^{\beta} y \frac{g_1^{(N-1)}(y)}{1 - G_1^{(N-1)}(\delta\beta_1)} dy - \delta\beta_1 \right) \right]}.
\]

Since \((1+\delta)\beta_1 > \beta_1 > \beta_1 - (1 - G_1^{(N-1)}(\delta\beta_1)) \left( \int_{\delta\beta_1}^{\beta} y \frac{g_1^{(N-1)}(y)}{1 - G_1^{(N-1)}(\delta\beta_1)} dy - \delta\beta_1 \right)\), we have \( \mu^*_b > \mu^*_1 > \mu^*_u \).

The intuition behind this result is as follows. With an un-bundling contract the winning OEM has to compete with other maintenance providers in the second auction. Due to the learning-by-doing effect, the winning OEM has an advantage in maintenance efficiency at \( t = 2 \), which increases its chance to win the second auction. If the OEM wins the second
auction, the payment it receives is the cost of the second efficient provider. Hence the OEM has an incentive to increase the second efficient provider’s cost, which implies the OEM makes a less reliable machine in the first place.

4.2 The impact of learning-by-doing

![Graph showing the relationship between reliability and cost]

Proposition 2. The higher degree the learning-by-doing effect is (a smaller \( \delta \)), the lower level of reliability the OEM chooses.

Proof. It is clear that \( \frac{\partial \mu^*}{\partial \delta} > 0 \). Since \( \frac{\partial (1-G_1^{N-1}(\delta \beta_1))}{\partial \delta} < 0 \) and \( \frac{\partial ((1-G_1^{N-1}(\delta \beta_1))(\int_0^{\bar{y}} \frac{g_1^{(N-1)}(y)}{1-G_1^{N-1}(\delta \beta_1)} dy - \delta \beta_1))}{\partial \delta} < 0 \), we can show \( \frac{\partial \mu^*}{\partial \delta} > 0 \).

This result comes from the fact that a higher degree of learning-by-doing effect brings down the OEM’s maintenance cost at \( t = 2 \). The OEM internalizes this impact by making a less reliable machine at \( t = 1 \).

4.3 Procurement payment

The owner cares about whether a bundling contract leads to a smaller procurement payment for a certain performance. Due to the complexity of the expected payment under
un-bundling, it is not easy to calculate directly. However, the trade-off between a bundling contract and un-bundling contracts is clear. If there is much more competition in the post-warranty market than the equipment market, it is more likely to have a third-party maintenance provider whose efficiency is much higher than the current OEM in the post-warranty period. Then the cost saving from contracting with the more efficient maintenance provider at $t = 2$ is higher than the cost saving from contracting with the OEM for two periods, especially when the OEM’s learning-by-doing effect is weak.

\[ C_1 = \mu + \frac{\beta_1}{\mu} \frac{A}{1 - A} \]

\[ C_2 = \frac{\beta_2}{\mu} \frac{A}{1 - A} \]

**Proposition 3.** When the competition in the post-warranty market is weak and the effect of learning-by-doing is strong, the owner prefers a bundling contract; otherwise, the owner prefers un-bundling contracts.

Since it is difficult to compare $TC_b$ with $TC_{ub}$ for a general distribution $F(\cdot)$, we consider a special case. Assume that $\beta_1$ and $\beta_2$ follow the uniform distribution over $[0, 1]$. Suppose there are two OEMs at $t = 1$, i.e. $M = 2$, and $N$ providers including the winning OEM at $t = 2$.

The following simulated graphs illustrate how the procurement costs under bundling or un-bundling contracts change with the degree of competition in the post-warranty market and the degree of learning-by-doing effect.
5 Conclusion

Our paper shows that when an OEM’s choice of reliability poses an externality on the post-warranty maintenance cost, a bundling maintenance contract could internalize this externality. In addition, the learning-by-doing effect gives another advantage to the bundling contract. However, committed to a bundling contract, the owner may miss a more efficient third-party maintenance provider. The un-bundling contracts lead to “make a mess for others” phenomenon that is the OEM intentionally makes a less reliable machine so that the third-party providers have high costs to maintain the machine. Hence, it may be a good idea for the owner to announce at the beginning that the OEM is not allowed to participate in the post-warranty maintenance auction if the owner believes there is a more efficient third-party maintenance provider.
References


