Supplier-buyer Models for the Bargaining Process over a Long-term Replenishment Contract

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ABSTRACT
This paper presents supplier-buyer models to describe the bargaining process between a supplier and a buyer over a long-term replenishment contract in a supply chain system. We develop two different models, one for the situation where the supplier has a superior bargaining power over the buyer and the other for the reverse situation.

Analysis based on a game theoretic approach is done to derive the methods for finding the optimal strategies for each agent. We verify that the solutions derived are Nash Equilibriums. The system costs resulting from the strategies are compared with each other to find out the economic implications of the strategies.

KEYWORDS: supplier-buyer model, game theory, replenishment contract

1. Introduction
Long-term contracts between the supplier and buyer can lead to more effective control of the logistics and production processes securing competitive advantages for both agents. Among the numerous forms of the contracts in a supply chain, we focus on a replenishment contract lasting over a longer period of time, typically more than a year. Some examples of this type of contract include a replenishment contract on consumer goods between a large retailer and a supplier.

When the replenishment contract is made, they agree on the parameters specifying various terms. They may contain the stipulation of decision rights, pricing structure such as quantity discount, inventory control policy, and the length of the contract. The logistic system we consider is that the retailer’s inventory is continuously monitored and replenished by the supplier in vendor-managed-inventory (VMI) environment. For the system, we consider a problem where the two agents negotiate the terms of the contract including the length of the contract, order size, and reorder point.

During the bargaining process, they first determine who decides which terms. These decisions are usually made based on the relative economic power of each agent. We construct two different models for the situation. The first model, the supplier driven model, assumes that the supplier has a power to determine the time length and order size. On the other hand, in the second model, the supplier has less economic power so that the buyer decides the whole terms. The latter kind of relationship is commonly maintained by the big retailers having hundreds of chain stores. In order to express the

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sequential nature of the bargaining process in the models, we make use of Stackelberg game model.

The previous work on the supply contract dates back, in some sense, to the classical inventory literature. The most relevant among them are the research for the two different contracts called minimum commitment (MC) and quantity flexibility (QF) respectively. The minimum commitment contract is investigated by Bassok and Anupindi (1997). Barnes-Schuster et al. (2002) later study the effects of an option for additional purchase. Chen and Krass (2001) analyze the contract with two different pricing schemes.

Research on the QF is initiated by Tsay (1995) who investigates the contracts in automobile industry and classifies them as quantity flexibility type contracts. Tsay (1999), Tsay and Lovejoy (1999) further analyze the performance of the QF under various conditions. The majority of the research though focuses on a single period problem and has limitation in real-world applications. Other interesting works, especially in supplier-buyer relationships, include the works by Li (1996) and Ertek and Griffin (2002).

In view of the long-term contract, Kim et al. (2003) is the closest to the current work. They explicitly model the multi-period contracting to find out the suitable terms of the contract. However, the work is confined to the buyer’s perspective and is deficient in describing the interactions between the two agents. Current study further extends the previous work by investigating the processes occurring between the buyer and the supplier during the bargaining for the contract.

2. Problem description
We make the following assumptions:
(1) We consider a single type of item.
(2) Demand is generated from an ARIMA process.
(3) Price is an exogenous variable, i.e., we assume a perfect competition market.
(4) Demand is lost when no stock is available and shortage cost depends on the size of the shortage and not on the length of its duration.
(5) Buyer’s inventory is controlled by VMI based \( (s,Q) \) policy by a supplier.

We assume that the demand data is generated from an ARIMA process because of its ability to represent many real-world demand data very well. However, the approach in this paper is not based on any specific stochastic process. Thus, the current methodology will be fully functional regardless of the demand process type.

Under a continuously reviewed policy such as \( (s,Q) \), replenishment timing is not regular. So, in the system we are concerned, it is natural that they agree on the number of replenishment to specify the length of the contract rather than on the usual time length. We refer to this number as contract length.

2.1 Cost function of the buyer
There exist several methods to decide the reorder point of the system controlled by \( (s,Q) \) policy
(Silver, Pyke, & Peterson, 1998). They can be divided into two groups. One group is based on minimizing cost and the other on customer service measure. All the methods in the groups though decide the reorder point in the same fashion, i.e., sum of the mean of the lead time demand and the safety stock. Based on this observation, we suggest to decide the reorder point of \( t + \tau \) period, when the confirmed contract length is \( n \), as

\[
s(\tau, n) = \text{lead time demand forecast of period } (t + \tau) + \text{ safety stock}
\]

\[= \hat{\delta}_{t+\tau} + \text{safety factor} \times \text{standard deviation of the error of the forecast}
\]

\[= \hat{\delta}_{t+\tau} + \kappa \xi_{t+\tau}.
\] (1)

When the data is not stationary, a constant mean of the number of cycles in a year does not exist. Therefore, the conventional approach of calculating the average cost in a cycle and multiplying it by the average number of cycles in a year to find the average yearly cost can not be used in our problem. Instead, we find out that the length of a cycle is the time to consume \( Q \) and, therefore, we can express the expected length of a cycle as \( (Q / \text{forecast of the average demand rate during a cycle}) \).

Thus the relative length of \( t + \tau \) period is expressed as \( Q / \hat{d}_{t+\tau} \). The contract consists of \( n \) such cycles and the length of the contract, denoted by \( m \), is the sum of the length of each cycle.

\[m = \sum_{\tau=1}^{n} (Q / \hat{d}_{t+\tau}) = Q \sum_{\tau=1}^{n} (1 / \hat{d}_{t+\tau}) = Q \hat{d}_{n}^{-1}.
\] (2)

\( \hat{d}_{n}^{-1} \) denotes \( \sum_{\tau=1}^{n} (1 / \hat{d}_{t+\tau}) \).

We now derive the expected holding, shortage, and purchase costs per year below.

\[
H(n, Q) = \text{expected holding cost per year when the contract length is } n
\]

\[= \left\{ \frac{Q}{2} + \kappa \left( \sum_{\tau=1}^{n} \xi_{t+\tau} / n \right) \right\} h.
\] (3)

\[
G(n, Q) = \text{expected shortage cost}
\]

\[= \text{expected number of shortage during a contract period} \times \text{shortage cost per unit value}
\]

\[\times (1 / \text{expected length of a contract})
\]

\[= \sum_{\tau=1}^{n} \sum_{e_{t+\tau} \in \left\lfloor \xi_{t+\tau} \right\rfloor} (e_{t+\tau} - \kappa \xi_{t+\tau}) \hat{P}(e_{t+\tau}) (b / m),
\] (4)

where \( \left\lfloor x \right\rfloor \) returns the least integer greater than or equal to \( x \). \( \hat{P}(e_{t+\tau}) \) is an empirical discrete distribution approximating the theoretical error distribution of \( t + \tau \) period ahead forecast.

\[
R(n, Q) = \text{expected purchase cost per year} = \psi n Q / m.
\] (5)

Using the derived equations, we complete the expected total cost of buyer per year:
\[ \Re(n,Q) = R(n,Q) + H(n,Q) + G(n,Q) \]
\[ = n\psi / \tilde{d}_n^{-1} + hQ / 2 + h\kappa \left( \sum_{\tau=1}^{n} \tilde{e}_\tau \right) / n + b\Xi / Q\tilde{d}_n^{-1}. \]

We denote \( \sum_{\tau=1}^{n} \sum_{e_{\tau-i} \leq \tilde{e}_\tau} \left( e_{\tau+i} - \kappa\tilde{e}_\tau \right) \tilde{P}(e_{\tau+i}) \) by \( \Xi \).

**Property 1.** For a given \( n \), the cost function of the buyer is convex for \( Q > 0 \).

**Property 2.** For a given \( n \), \( \bar{Q}_b(n) \) in (7) minimizes \( \Re(n,Q) \).

\[ \bar{Q}_b(n) = \frac{2h\Xi}{hd_n^{-1}}. \]  

(7)

Proofs of the properties are in Appendix.

### 2. 2 Cost function of the supplier

The cost incurred to the supplier during the contract period is the sum of the order processing and holding costs subtracted by the production cost reduction realized by the long-term relationship. We assume that the regular production cost \( \psi_p \) reduces to \( \psi_p e^{-\beta n} \) when the contract length is \( n \). In this case, the cost reduction per unit production amounts to \( \psi_p - \psi_p e^{-\beta n} \). Therefore, the expected cost of supplier during the contract period is

\[ -(\psi_p - \psi_p e^{-\beta n})nQ + n\sigma_s + h_s Qm / 2. \]

(8)

Note that the cost function is based on those appeared in Lal and Staelin (1984). Dividing (8) by the expected length of the contract period, we obtain the expected cost per unit time:

\[ \phi(n,Q) = \frac{-n(\psi_p - \psi_p e^{-\beta n})}{\bar{d}_n^{-1}} + \frac{n\sigma_s}{Q\bar{d}_n^{-1}} + \frac{h_s Q}{2}. \]

(9)

**Property 3.** For a given \( n \), \( \bar{Q}_s(n) \) in (10) minimizes \( \phi(n,Q) \).

\[ \bar{Q}_s(n) = \frac{2n\sigma_s}{h_s \bar{d}_n^{-1}}. \]

(10)

See Appendix for a proof.

### 3. Supplier-buyer models

In this section, we present two different algorithms to decide the terms of the contract for the models.

#### 3.1 Supplier driven model
In this model, the supplier has some power over the buyer. Therefore it is assumed that the supplier determines the order size and the buyer decides the contract length and reorder point. The algorithm for the model is as follows.

**Step 1:** (Search the optimal order size and contract length based on the supplier’s cost function)

Calculate the supplier’s optimal order size for each \( n \) by (10), i.e.,
\[
Q_s^*(n) = \sqrt{\frac{2n\sigma^2}{h_n d_n^{-1}}}.
\]
Calculate \( n_s^* = \arg \min_n \varphi(n, Q_s^*(n)) \), i.e., \( n_s^* \) is the supplier’s optimal contract length based on his optimal order size.

**Step 2:** (Find the buyer’s optimal contract length based on her cost function)

\[
n_b^*(Q_s^*(n^*_s)) = \arg \min_n \mathfrak{R}(n, Q_s^*(n^*_s)).
\]

**Step 3:** (Calculate each party’s cost change to be realized when they agree on \((n, Q_s(n))\))

For \( n = 1 \) to \( \tilde{n} \), calculate \( \mathfrak{R}(n, Q_s(n)) - \mathfrak{R}(n_b^*(Q_s^*(n^*_s)), Q_s^*(n^*_s)) = \Delta \mathfrak{R}(n) \) and \( \varphi(n, Q_s(n)) - \varphi(n_b^*(Q_s^*(n^*_s)), Q_s^*(n^*_s)) = \Delta \varphi(n) \).

**Step 4:** (Find the solution and stop)

If \( \Delta \mathfrak{R}(n) + \Delta \varphi(n) \geq 0 \) for all \( n \), the solution is \( [Q_e, n_e] = [Q_s^*(n^*_s), n_b^*(Q_s^*(n^*_s))] \). Otherwise,

\[
[Q_e, n_e] = \left[ \sqrt{\frac{2n_e \sigma^2}{h_n d_n^{-1}}}, \arg \min_n (\Delta \varphi(n) + \Delta \mathfrak{R}(n)) \right].
\]

In Step 1, we determine the order quantity the supplier would choose to minimize his cost function. Since \( n_s^* \) is the replenishment size that corresponds to the minimum cost, \( Q_s^*(n_s^*) \) would be chosen for his preferred order size. In response, in Step 2, the buyer selects her preferred contract length which minimizes her cost function under the constraint of the fixed order size specified by the supplier, i.e., \( Q_s^*(n_s^*) \). Thus \( (n_b^*(Q_s^*(n^*_s)), Q_s^*(n^*_s)) \) is the term of the contract if there were no further bargaining.

In Steps 3 and 4, we search the total number of \( \tilde{n} \) points \( (n, Q_s(n)) \) for \( n = 1, \ldots, \tilde{n} \) to search for the point which gives the maximum cost reduction. \( \Delta \mathfrak{R}(n) \) and \( \Delta \varphi(n) \) in Step 3 represent cost changes of the buyer and the supplier respectively when they choose \( n \). Therefore, \( \Delta \varphi(n) + \Delta \mathfrak{R}(n) \) is the change in the sum of their cost functions. For example, if \( \Delta \varphi(n) = -120 \) and \( \Delta \mathfrak{R}(n) = 40 \), the supplier’s cost decreases by 120 and the buyer’s cost increases by 40.

We note that \( \Delta \mathfrak{R}(n) \) cannot be positive and therefore the buyer should bear increased cost when she agrees to change into the point the supplier prefers. Thus it is necessary to compensate the buyer with the cost increase to entice her to accept the new term. In the case we consider, at least 40 should
be given to the buyer among the total cost reduction of 120. Actually what portion of the newly created profit or cost reduction should be distributed among the two parties is the Nash bargaining problem. In this paper, we do not pursue the distribution problem further because it is not the main purpose of this paper.

We may also realize that it is no gain to move to a different point if  \( \Delta R(n) + \Delta \varphi(n) \geq 0 \) for all \( n \). Otherwise, we choose the point where net cost reduction is maximized. By agreeing on the solution, the buyer at least loses nothing and supplier can make a maximum profit of  \( \Delta \varphi(n) + \Delta R(n) \). It is important to note that the solution generated is the Nash Equilibrium because neither agent can be better off by deviating alone from the equilibrium while the other agent stays unchanged.

### 3.2 Buyer driven model

This model assumes the buyer has dominating power compared to the supplier. This kind of relationships are prevalent in retail industry, e.g., global retailer chain stores such as Wal-mart. It is appropriate in this case to assume that the buyer decides all the three terms: order size, contract length and reorder point. The algorithm for the model is as follows.

**Step 1**: (Search the optimal order size and contract length based on buyer’s cost function)

Calculate the buyer’s optimal order size for each \( n \) by (7), i.e.,  
\[
Q^*_b(n) = \sqrt{2b\Xi/h_d^{-1}}.
\]

Calculate \( n^*_b(Q^*_b) = \arg\min_n R\left(n, Q^*_b(n)\right) \), i.e., \( n^*_b(Q^*_b) \) is the optimal contract length based on the buyer’s optimal order size.

**Step 2**: (Calculate both agents’ cost changes for moving from from \( (n^*_b(Q^*_b), Q^*_b(n^*_b)) \))

For \( n = 1 \) to \( \bar{n} \), calculate  
\[
R(n, Q_s(n)) - R(n^*_b(Q^*_b), Q^*_b(n^*_b)) = \Delta R(n)
\]

\[
\varphi(n, Q_s(n)) - \varphi(n^*_b(Q^*_b), Q^*_b(n^*_b)) = \Delta \varphi(n).
\]

**Step 3**: (Find the solution and stop)

If  \( \Delta R(n) + \Delta \varphi(n) \geq 0 \) for all \( n \), the solution is  
\[
\left[Q_s, n_s\right] = \left[n^*_b(Q^*_b), Q^*_b(n^*_b)\right].
\]

Otherwise,  
\[
\left[Q_s, n_s\right] = \sqrt{\frac{2n_s\sigma_s}{h_d^{-1}d_{ns}}}, \arg\min_n \left(\Delta \varphi(n) + \Delta R(n)\right)
\]

We start from a point which usually is not identical to the starting point of the supplier driven model. In Steps 2, we search the total number of \( \bar{n} \) points \( (n, Q_s(n)) \) for \( n = 1, \ldots, \bar{n} \) to find out the one which gives the maximum cost reduction. Unless  \( \Delta R(n) + \Delta \varphi(n) \geq 0 \) for all \( n \), the algorithm leads to the same equilibrium as the algorithm of the previous model. However, the net cost reductions achieved by each model are usually different. Also, the percentage of the compensation
among the total cost reduction is not less than the one in the supplier driven model. This is due to the fact that the buyer in this model has more decision rights that should be rewarded more to relinquish.

4. Numerical experiment
We carry out experiments to verify the validity and to find out implications of the solutions. The input parameters for the experiment are:

\[ b = 8, \ h = 5, \ h_s = 3, \ \sigma_s = 200, \ \Xi = 2, \ \kappa = 1.65, \ \xi = 2, \ \psi = 10, \ \psi_p = 9, \ \beta = 0.01, \ \bar{n} = 40. \]

The input parameters are constructed so that they can represent the real systems well. The demand data chosen for the experiment is the monthly Australian sales of sweet white wine. The data shown in Figure 1 shows the typical characteristics of the real world demand data; non-stationarity with strong seasonal and trend factors. It is defined as the ARIMA process:

\[(1 - B)(1 - B^{12})d_e = \left(1 - 0.48198B\right)\left(1 - 0.64112B^{12}\right)e_t.\]

The test results of the supplier driven model are summerized in Table 1. Without our bargaining procedure, the terms of the contract would be determined as \( n = 3, \ Q = 119.58 \) with the total cost of 1,648.84 (= buyer’s cost (1,328.82) + supplier’s cost (320.02)). This is because the supplier selects the order size of 119.58, which minimizes his cost as 40.54. Then the buyer selects \( n = 3 \) as the contract length to achieve the minimum cost of 1,328.82 under the constraint of order size of 119.58. Note that the reorder point is decided by Equation (1) after the contract length is agreed.

In contrast, our algorithm found the solution of \( n = 36 \) and \( Q = 116.12 \) with the total cost of 1,405.16 (= buyer’s cost (1,331.96) + supplier’s cost (73.20)), i.e., 243.68 of cost reduction. By just conforming to the solution generated by the algorithm, the supplier can reduce his cost by 246.82 (= 320.02 - 73.20). On the other hand, the buyer’s cost increases by 188.97. After compensation, net reduction of the system cost amounts to 539.75 (= 1,944.91 - 1,405.16) or 27.75%

The result of the buyer driven model is similar. As summarized in Table 2, without bargaining procedure, the contract would be agreed on \( n = 3, \ Q = 25.30 \) with the total cost of 1,944.91 (= buyer’s cost (1142.99) + supplier’s cost (801.92)). However, applying our bargaining procedure, we can find the solution \( n = 36 \) and \( Q = 116.12 \) with the total cost of 1,405.16 (= 1,331.96 + 73.20). The supplier can reduce his cost by 728.72 (= 801.92 - 73.20). The buyer’s cost increases by 188.97. After compensation, net reduction of the system cost amounts to 539.75 (= 1,944.91 - 1,405.16) or 27.75%

The compensation for the buyer is more than the one of the previous case. This is natural phenomenon because the buyer waives the bargaining power, which is greater than the one in the supplier driven
model.

Additionally, we found out that the terms the two agents agree on in each model coincide with each other. In respect to the optimization of the problem, the solution we derived is the global minimum under the current model assumptions. In game theoretic point of view, the solution obtained is the Nash Equilibrium of the Stackelberg games. Neither player can make a profit by unilaterally moving from the agreed solution. Finally it is worthwhile to mention that the derived term is not a Nash bargaining solution because the problem we solved is not the Nash bargaining problem. When it comes to how to divide the additional profit to each party, it becomes a Nash bargaining problem, which has multiple forms of solutions such as the Nash bargaining solution or Kalai-Smordinsky solution.

5. Conclusion
In this paper, we have studied the supplier-buyer models describing the bargaining procedures over a long-term replenishment contract. We have developed two different models, a supplier driven model and a buyer driven model, and proposed algorithms for each model. The algorithms are based on the Stackelberg game and can find the Nash Equilibrium of the contract game models.

By agreeing on the terms generated by the algorithm, both agents can be better off than when they choose other strategies. The cost reductions amount to 14.78 and 27.75% for the system we have tested during computational experiment. Further research area includes the extension of how we should divide the additional profit to each agent. Another interesting problem is to consider a repeated bargaining situation where each agent starts negotiating from each player’s most desired position.
APPENDIX A

The following notations are used in our model:

- \( n \) : confirmed contract length,
- \( Q \) : order size,
- \( s(\tau, n) \) : reorder point of \( \tau \) time ahead period when the confirmed contract length \( n \),
- \( t \) : time period when the forecasting is made,
- \( \tau \) : distance in period from \( t \),
- \( \hat{\delta}_{t+\tau} \) : forecast of the lead time demand of \( t + \tau \) period when forecast origin is \( t \),
- \( \hat{\epsilon}_{t} \) : standard deviation of error of \( \hat{\delta}_{t+\tau} \),
- \( \hat{d}_{t+\tau} \) : forecast of the average demand rate during \( t + \tau \) period when forecast origin is \( t \),
- \( \kappa \) : safety factor,
- \( h \) : buyer’s per unit holding cost,
- \( b \) : buyer’s per unit shortage cost,
- \( \psi \) : buyer’s unit purchase cost,
- \( \psi_p \) : supplier’s normal per unit production cost,
- \( h_s \) : supplier’s per unit holding cost,
- \( \sigma_s \) : setup cost of supplier,
- \( \tilde{n} \) : maximum allowable number of replenishment specified in advance by the management,
- \( \Re(n, Q) \) : buyer’s cost function per unit value per year of buyer,
- \( \phi(n, Q) \) : supplier’s cost function per unit value per year of supplier.
APPENDIX B

Proof of Property 1.

\[ R(n,Q) = \gamma \ast \hat{d}^{-1} + hQ + \kappa \left( \sum_{i=1}^{n} \frac{x_i}{Q} \right) + b\Xi / Q \hat{d}^{-1}. \]

The first order partial derivative with respect to \( Q \) is

\[ \frac{\partial R(n,Q)}{\partial Q} = h - \frac{b\Xi}{Q^2 \hat{d}^{-1}}. \]

The second order partial derivative is

\[ \frac{\partial^2 R(n,Q)}{\partial Q^2} = -\frac{2b\Xi}{Q^3 \hat{d}^{-1}}. \]

Since \( \frac{\partial^2 R(n,Q)}{\partial Q^2} > 0 \) for \( Q > 0 \), \( R(n,Q) \) is convex with respect to \( Q > 0 \) for a given \( n \).

Proof of Property 2.

\[ \frac{\partial R(n,Q)}{\partial Q} = h - \frac{b\Xi}{Q^2 \hat{d}^{-1}}. \]

\[ \frac{\partial R(n,Q)}{\partial Q} = 0 \text{ gives } \frac{h}{2} - \frac{b\Xi}{Q^2 \hat{d}^{-1}} = 0. \]

After arranging the equation, we have

\[ Q = \sqrt{\frac{2bn\Xi}{hd^{-1}}}. \]

Proof of Property 3.

\[ \frac{\partial \phi(n,Q)}{\partial Q} = \frac{h}{2} - \frac{n\sigma_s}{Q^2 \hat{d}^{-1}}. \]

\[ \frac{\partial \phi(n,Q)}{\partial Q} = 0 \text{ gives } \frac{h}{2} - \frac{n\sigma_s}{Q^2 \hat{d}^{-1}} = 0. \]

After arranging the equation, we have

\[ Q = \sqrt{\frac{2n\sigma_s}{h\hat{d}^{-1}}}. \]
REFERENCE
Figure 1. Monthly sales of sweet white wine in Australia
Table 1. The result of the supplier driven model

<table>
<thead>
<tr>
<th>n</th>
<th>$Q_s(n)$</th>
<th>$R(n,119.58)$</th>
<th>$\varphi(n,119.58)$</th>
<th>$R(n,Q_s(n))$</th>
<th>$\varphi(n,Q_s(n))$</th>
<th>$\Delta \varphi(n) + \Delta R(n)$ net cost change</th>
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<td>377.24</td>
<td>1604.74</td>
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<td>341.00</td>
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<td>898.87</td>
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</table>

35 126.64 | 1534.28 | 60.87 | 1551.04 | 60.24 | -37.57 |
36 116.12 | 1340.21 | 73.35 | 1331.96 | 73.20 | -243.68 |
37 117.06 | 1356.97 | 65.20 | 1350.98 | 65.12 | -239.88 |
38 117.02 | 1356.21 | 58.93 | 1350.12 | 58.85 | -221.31 |
39 118.39 | 1380.72 | 49.65 | 1377.89 | 49.64 | -206.13 |
40 119.58 | 1402.18 | 40.54 | 1402.18 | 40.54 | -206.13 |

a: initial cost of each agent, b: cost of each agent accepting the suggested solution.

Table 2. The result of the buyer driven model

<table>
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<tr>
<th>n</th>
<th>$Q_b(n)$</th>
<th>$Q_s(n)$</th>
<th>$R(n,Q_b(n))$</th>
<th>$\varphi(n,Q_b(n))$</th>
<th>$R(n,Q_s(n))$</th>
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a: initial cost of each agent, b: cost of each agent accepting the suggested solution.