Design of environmentally conscious incentive contracts for logistics services

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Abstract. There are two major hurdles, economy of scale and incentives for practice, in logistics service for environmentally friendly operations. This paper models and designs the incentive contracts between a company with environmental commitment and its logistics service provider. The company aims to encourage the logistic service provider to devote effort on environmental concerns. It is generally believed that such effort implies costly burden to the service provider but benefits the company. We consider different information structures in our models and show the corresponding contract forms. The research starts with investigating the contract form with symmetric information and known effort of the provider. Through single-period and multiple-period models, it is found that long run cooperation can benefit both parties. We then extend the model to a case where the effort of the provider is unobservable and unverifiable. It is found that with proper incentive compatible constraint, the provider will make the effort as expected. In addition, the optimal incentive contracts not only motivate the logistics service provider to make the expected effort on environmentally friendly operations, but it also acts as a risk sharing tool.

Keywords: logistics service, environment management, incentive contracts, information structure, risk sharing

1 Introduction

Along with rapid change of the world manufacturing and distribution scheme, the logistics service has emerged as a new industry area, growing with a dramatically fast speed. The logistics service, including the third party logistics service, applies various consolidation strategies to maximize the utilization of expensive logistics operations to simultaneously meet the service commitments and minimize the overall cost. On the other hand, the industry has widely accessed and accepted the concept of environmental management in recent years. Some popular environmental impact factors under consideration include the risk of environmental damage during the transportation, waste of inventory and packaging material, and extreme inefficiency in recycling process. However, without precisely quantitative and analytical investigation, the performance of environmental management in logistics operations has not yet been fully understood, and the benefit has not yet been properly perceived by the industry. It is thus frequently observed that in both service and manufacturing sections, environment management is adopted and implemented either as a “long term strategy” in which the cost has been counted as a “strategic investment”, or as a compromise tool to deal with the social pressures on the business environment, in which the cost is expected to be absorbed by the other activities in the business.

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the initial facility investment and learning cost involved in environmental operations, if cannot be digested in an anticipated time period, often blocks the logistics service provider to adopt the new operations strategy. In other words, if the economy of scale of environmental oriented operations cannot be perceived, the service provider will prefer to stay in the conventional business practice. Another critical factor involves operations incentives granted to the logistics service provider by the customer. Large manufacturing companies, particularly those brand named multi national companies, often request environmental concerns on the logistics service to enhance their community image and long term “green” operations strategy. It is obvious that such a practice cannot be sustainable or committed in long term without a rational and proper design of incentive agreement. In this research, we model and design incentive contracts between a manufacturing company with environmental commitment and its logistics service provider. We analyze the optimal contract by adding incentive compatible conditions to the logistic service provider.

The environmental impact on the logistics operations and management has attracted great attention from institutional researchers and practitioners in recent years. In the general supply chain management research area, Beamon (1999)\(^4\) discusses the development of a supply chain concerning environmental factors, and describes elemental differences between the extended and the traditional supply chain. It compares performance measures appropriate for the extended supply chain, including material recovery rate (Guide et al, 1997)\(^10\), core return rate (Krupp, 1992)\(^14\), waste ratio (Fiksel, 1996)\(^7\), eco-efficiency (Schmidheiny, 1992)\(^26\) etc., and develops a general procedure towards achieving and maintaining a green supply chain. Sarkis (1998)\(^24\) provides a model for environmental evaluation on business practice. Min and Galle (1997)\(^21\) discusses environmental factors that may reshape supplier selection decisions, and the role of “green” purchasing in reducing and eliminating waste. Through a case study of Xerox Ltd., McIntyre et al (1998)\(^19\) details how the environmental concern is developed and used in measuring environmental performance for the whole supply chain, and for different product delivery scenarios. Sarkis (2003)\(^25\) uses the AHP/ANP techniques to make strategic supply chain management.

For the specific logistics management research, Hoek (1999)\(^11\) conducts a research on green logistics system in practice, as a step to lowering the ecological footprint of logistics. Stilweel et al (1991)\(^28\) reports that some leading U.S. companies (e.g., DuPont, Heinz, Coca-Cola, PepsiCo, P&G, International Paper) have launched various forms of green packaging programs through the introduction of recyclable and reusable packages. Wu (1995)\(^29\) examines logistics issues relative to the natural environment and discusses measures that can be undertaken to achieve a more proactive environmental management focus. Environmentally responsible logistics is defined and related activities are explained. Green et al (1998)\(^9\) examines the green purchasing and supply activities of some UK firms and points out that some fundamental questions need a certain level of attention before “green supply” can be confirmed as an effective way of improving industry’s environmental performance. Barros (1998)\(^3\) reports a case study addressing the design of a logistics network for recycling sand resulting from the processing of construction waste. Louwers et al (1999)\(^18\) considers the design of a recycling network for carpet waste. Spengler et al (1997)\(^27\) examines recycling networks for industrial by-products in German steel industry. Jayaraman et al (1999)\(^12\) analyzes the logistics network of an electronic equipment remanufacturing company. In Yan et al (2001a\(^31\), 2001b\(^30\)), we discuss how to create a win-win business through information sharing and cooperation environmentally and economically. We identify fundamental factors in a green supply chain, and investigates the green production practice in a manufacturing company in China. In his book, Fleischmann (2001)\(^8\) presents some quantitative models in reverse logistics management and discusses the distribution issues and storage issues in reverse logistics, facility location decision, inventory systems with reverse logistics, inbound flows, and product recovery network.

It is clear that most of these researches are still at initial stages. They are either a single case analysis based or specific industry oriented. The general characteristics of environment concern related logistics management are yet clearly described. The trade-offs between time-cost efficiency and environmental management is not fully understood. In particular, some critical elements such as “incentive”, “motivation”, and “long term benefit” are not specifically defined and quantified, and therefore, the performance of a logistics service is still conventionally measured by cost, time and quality.

The incentive problem has been an important issue in the economics and management for a long period (Laffont and Tirole, 1993)\(^15\). It is noticed that most participants in economics and management have the

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“principal-agency” relationships, in which the principal party should motivate the agent party acting on the expected behalf. Since the agent usually has some private information which is not known to the principal, the information structure is a key factor in designing incentive contracts. The research on incentive contracts with information structure consideration is an interesting branch for many areas, such as hierarchical organization (Caillaud et al., 1996)[5], corporate finance (Cornell, 2004)[6], accounting (Lambert, 2001)[16], marketing (Jorgensen and Zaccour, 2003)[13] and other areas. Lee and Whang (1999)[17] reviews some original contributions of the incentive problems in economics. Ackoff (1967)[1] investigates the sequence of events when existing incentive and information problems in inventory. Riordan (1984)[23] considers a two-level system with asymmetric information on the demand at the retailer and private information on manufacturing costs at the supplier. Porteus and Whang (1991)[22] designs incentive compatible contracts in a two-stage serial supply chain with stationary stochastic demand and fixed transportation times, and van Mieghem (1999)[20] compares the effectiveness of three types of popular contracts. Lee and Whang (1999)[17] analyzes the cost conservation, information in the incentive models. They link the incentive aspect with the performance of the supply chain in their research and give a set of linear contracts for a similar production inventory multi-echelon system are also given. Agrell et al (2004)[2] extends the incentive models to a three-stage case with asymmetrical information and limited commitment. The relationship of risk sharing and the motivation mechanisms in supply chain is the key point of their research.

In this paper, we model and design the incentive contracts between a company (called “customer”) with environmental commitment and its logistics service provider (called “provider”). The customer aims to motivate the provider to devote effort on environmentally friendly practice. The effort of the provider is costly but will benefit the customer. We show different contract forms under different information structures. With some basic assumptions given in section 2, in section 3, we firstly investigate the form of the contract when information between them is symmetric and the effort of the provider can be revealed. Through single-period and multiple-period models, we find that long run cooperation between them will benefit both parties. Then in section 4, we extend our model to a case where the effort of the provider is unobserved by the customer and unverified. We show that by adding an incentive compatible constraint of the provider, it will make effort as the customer expects, although such incentive is costly for the customer. In section 5, we analyze and compare different incentive contract models, and find that these contracts not only motivate the provider to devote desirable effort on environmentally oriented operations, but also acts as a risk sharing tool. The last section concludes the research.

2 Basic model assumption

Consider a manufacturing company (hereafter referred to as “customer”), which outsources its logistics operations to a logistics service provider (hereafter referred to as “provider”). The customer aims to have an incentive contract with the provider for motivating the provider to devote effort on environmentally conscious logistics practices.

Assume that both the customer and the provider have neutral risk attitude and have rational expectation. The market interest rate is assumed to be zero, and the customer has a dominant power in the contracting process. Thus the provider is willing to cooperate with the customer if it can achieve its financial break-even point. For each contract period, there is a mutually agreed logistics service amount $Q$. $Q$ is fixed for the initial and the following periods in sections 3 and 4, but is adjustable by the customer in section 5.

Denote the effort of the provider as $e$, which may include acquiring initial facilities, or learning new operations, and is private information of the provider. The effort of the provider is specific but has sustaining power, which has the following two distinct meanings. First, when the provider makes such effort, the cost will be sunk and the effort can be further utilized in the future. The provider will not be paid for such effort further if it does not serve this particular customer any more. Thus, the contract gives incentive to the provider to have long time cooperation with the customer. The literature review shows that in most of industrial areas, the environmentally oriented operations is usually designed and implemented for a specific company. Second,
if the provider makes such effort in the first period, the effort will benefit the customer in the first period and any customers hereafter without any additional costs\(^3\).

It is clear that the effort is costly for the provider, but has benefit to the customer. Denote such benefit by \( R \), where \( R > 0 \). \( R \) is common information which can be observed and verified by the customer, the provider and any other third party such as the court. \( R \) depends on the provider’s effort \( e \), but may be further affected by a random variable \( t \) on \([t, \bar{t}]\) with density function \( f(\cdot) \). \( t \) is determined by some uncontrollable factors which cannot be foreseen by the time to sign the contract. Such factors may include unexpected innovations for environmental technology, or competitors’ greening strategies, or capability of employees in learning processes. The expected value of \( t \) is zero. \( t \) is referred to as “state of nature” in this research. Assume that \( R \) satisfies

\[
\frac{dR}{de} > 0; \quad \frac{d^2R}{de^2} < 0, \tag{1}
\]

which means that the customer benefit increase as the provider effort increase, but the marginal benefit from the effort decrease.

The cost function of the provider is denoted by \( S = S(e) \), satisfying

\[
\frac{dS(e)}{de} > 0; \quad \frac{d^2S(e)}{de^2} > 0, \tag{2}
\]

which means that both cost and marginal cost increase as the effort increase. The cost function is also open information. Since the environmentally friendly practice effort is costly for the provider, the customer commits to compensate for the cost. The compensation price is denoted by \( C \) per logistics unit, which is to be contracted.

In the following sections, we consider the information structure in contract models. As the effort \( e \) is the provider’s private information, whether \( e \) can be revealed and verified greatly affects the contract structure. There are two cases:

- \( R \) is not affected by the random variable \( t \). This indicates the case where the effort of the provider means to acquire initial facilities for environmentally friendly operations, and the benefit from such effort is less affected by other factors. Since \( R = r(e) \) is common information which can be observed and verified in public, effort \( e \) can also be revealed and verified. Therefore the customer and the provider can have a contract \( C \) based on the provider’s effort \( e \);

- \( R \) is affected by the random variable \( t \). That is, \( R = r(e) + t \). This indicates the case where the effort of the provider means to learn the environmentally conscious operations, and the benefit of the customer is clearly affected by the state of nature. In such a case, although the ex post benefit \( R \) can be observed and verified by the customer, the provider and any other third parties, \( e \) cannot be revealed. The contract will be based on the ex post observable and verifiable \( R \).

In the following, we will first consider the single period case, then extend the model to the multiple-period cases (a two-period model is used in this research) and the results are compared.

### 3 The optimal contract model with a verifiable effort

In this section, we consider a case where the benefit of the customer \( R = r(e) \) is not affected by the random shock \( t \). Since \( e \) can be revealed and verified, a contract \( C \) can be drawn up based on \( e \). Denote \( C := C(e) \), which means that the value of \( C \) is assigned by the value of \( e \) and the function form, or the contract form under discussion. Assume that the contract only lasts for one period. If the provider breaks the contract with effort \( e' \neq e \), the customer may ask for an ex post compensation which is denoted by \( B := B(e') \), which says that the value of \( B \) is assigned by the value of \( e' \) and the function form, or the contract form. We will later extend the model to a two period case.

\(^3\)The further operational cost in the following periods is ignored for it is easier to be compensated in the contract. Such ignorance will not change the main results of our models.
The utility of the customer \((U)\) and that of the provider \((V)\) can be represented respectively as following,

\[
U = R(e) - C(e)Q, \quad V = C(e)Q - S(e).
\]

(3) \hspace{1cm} (4)

The optimal contract for the customer can be represented as the following problem \((OC_1)\).

\[
\max_{e, C(e), B(e')} U = R(e) - C(e)Q, \quad \text{s.t.} \quad C(e)Q - S(e) \geq 0,
\]

(5) \hspace{1cm} (6)

\[
C(e)Q - S(e) \geq C(e)Q - S(e') - B(e'), \quad B(e') \geq 0,
\]

where (5) is the provider’s individual rationality constraint, or the participant constraint. For effort \(e\) is observable and verifiable, the customer can exert ex post punishment to the provider if the contract is broken. When the ex post punishment exceeds the advantage from its contract breaking as (6) indicates, the provider will prefer to obey the contract. We have the following theorem.

**Theorem 1.** The optimal solution \((e_1, C_1(e_1), B_1(e'))\) of problem \((OC_1)\) has the form

\[
e_1 \in \{e \mid R'(e) = S'(e)\},
\]

(7)

and

\[
C_1(e_1) = \frac{S(e_1)}{Q}, \quad B_1(e') \geq \max\{0, S(e_1) - S(e')\}.
\]

(8)

The necessary and sufficient condition for the customer to draw up such a contract with the provider is

\[
R(e_1) \geq S(e_1).
\]

(9)

**Proof:** Note that \(C(e)\) and \(B(e')\) not only depend on the values of \(e\) and \(e'\), they also depend on the individual contract forms respectively. Then, (5) in problem \((OC_1)\) must be tight, since otherwise we can further increase the objective value \(U\) by slightly decreasing \(C(e)\) and slightly increasing \(B(e')\) with proper contract forms. Therefore,

\[
C_1(e) = \frac{S(e)}{Q}
\]

is the optimal compensation to the provider. Then the objective function can be rewritten as

\[
U = R(e) - S(e).
\]

Denote \(e_1\) as the optimal effort for the customer to maximize its utility. The first order condition is \(R'(e_1) = S'(e_1)\). The second order condition \(R''(e_1) \leq S''(e_1)\) is satisfied as (1) and (2) indicate. The form of \(B(e')\) can be easily generated from (6).

As for the customer, only when the optimal value of \((OC_1)\) problem \(U_1 = R(e_1) - S(e_1) \geq 0\) will it participant in the contract ((9) is thus called customer’s participant constraint). This completes the proof. \(\square\)

Since \(C_1(e)\) is the compensation paid by the customer to the provider’s effort for improving the environmental practice, this theorem has a clear explanation. The provider’s cost \(S(e)\) will be eventually transferred to the customer in the logistics service because the effort is specific (as assumed before, it may be used but not paid by other customers.). When the benefit of the customer from the improvement of environmentally friendly procedure exceeds the transferred cost, the customer is willing to sign a contract with the provider and pay the cost.

When the contract lasts for two periods, the provider may still be confronted with the ex post penalty. The optimal contract now can be represented as the following problem \((OC_2)\) (it is similar to \((OC_1)\)),

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The optimal solution

\[
\max_{e,C(e),B(e')} \quad U = 2(R(e) - C(e))Q,
\]

s.t.
\[
\begin{align*}
2C(e)Q - S(e) & \geq 0, \\
2C(e)Q - S(e) & \geq 2C(e)Q - S(e') - B(e'), \\
B(e') & \geq 0,
\end{align*}
\]

We can then obtain the similar result as the following.

**Theorem 2.** The optimal solution \((e_2, C_2(e_2), B_2(e'))\) of problem \((OC_2)\) has the form,

\[
e_2 \in \{e \mid 2R'(e) = S'(e)\},
\]

and

\[
C_2(e_2) = \frac{S(e_2)}{2Q}, \quad B_2(e') \geq \max\{0, S(e_2) - S(e')\}.
\]

The necessary and sufficient condition for the customer to draw up such a contract with the provider is

\[
2R(e_2) \geq S(e_2).
\]

Therefore, a long term contract may increase the benefit of the customer. As explained above, the cost of the provider in the first period will be eventually transferred to the customer. By extending their cooperation period, the customer may compensate the provider with a lower price, but obtain the benefit from the provider’s effort for a longer period. Therefore, a long time partnership (or strategic partnership) with the provider will benefit the customer.

Although the customer can be further benefited from a long cooperation period, the provider does not achieve more than its break-even point because the customer has a complete contracting power. Considering that the longer cooperation will benefit the customer, the provider may negotiate with the customer for a price higher than \(\frac{S(e_2)}{2Q}\), and the customer is also willing to accept such a price if it is not so high as in the one period case. Such a negotiation process in fact indicates how the customer and the provider divide the additional benefit.

### 4 Multiple-period model with a unverifiable effort

In this section, we consider a case where the effort \(e\) of the provider cannot be revealed. In the discussions above, \(e\) is the provider’s private information, but it can be revealed and verified since the benefit function of the customer from its effort \(R(e) = r(e)\) is common information. However, when \(R\) is affected by a random variable \(t\), that is, \(R(e,t) = r(e) + t\), \(e\) cannot be revealed because the customer cannot differentiate the contribution of the provider’s effort from the effect of the random influence \(t\). Or it could be too expensive for the customer to obtain sufficient information about the effort of the provider.

When \(e\) is not revealed, the customer and the provider cannot have a contract based on \(e\), and the ex post punishments as in the above models are no longer implementable. We now consider a two-period model with a unverifiable effort. In the model, the customer and the provider sign a contract at the beginning of the first period, and at the end of the period, the customer will decide whether to cooperate with the provider in the next period according to the contractible value \(R\).

Denote \(R_1 = r(e) + t_1\) and \(R_2 = r(e) + t_2\) as the ex post benefits of the customer in the first and second period (if they cooperate in period two) from the provider’s first period effort \(e\), where \(t_1\) and \(t_2\) are i.i.d. with
density function $f(\cdot)$. The expected values of $R_1$ and $R_2$ satisfy $E(R_1) = E(R_2) = r(e)$. The customer is committed to compensate the provider with price $C(r(e))$. For any realized benefit of the customer $r(e) + t_1$ in the first period, the probability that the customer decides to cooperate with the provider in period two is $P(r(e) + t_1)$.

Then, the expected utility of the customer ($U$) and that of the provider ($V$) can be represented as

$$U = \int_{\tilde{t}}^{\tilde{t}} \int_{\tilde{t}}^{\tilde{t}} [R_1 - C(E(R_1))Q + P(R_1)(R_2 - C(E(R_1))Q)] f(t_1) f(t_2) dt_1 dt_2$$

$$= \int_{\tilde{t}}^{\tilde{t}} \int_{\tilde{t}}^{\tilde{t}} [r(e) + t_1 - C(r(e))Q + P(r(e) + t_1)(r(e) + t_2 - C(r(e))Q)] f(t_1) f(t_2) dt_1 dt_2$$

$$= r(e) - C(r(e))Q + \int_{\tilde{t}}^{\tilde{t}} \int_{\tilde{t}}^{\tilde{t}} P(r(e) + t_1)(r(e) + t_2 - C(r(e))Q) f(t_1) f(t_2) dt_1 dt_2,$$

$$V = \int_{\tilde{t}}^{\tilde{t}} [C(E(R_1))Q - S(e) + P(R_1)C(E(R_1))Q] f(t_1) dt_1$$

$$= \int_{\tilde{t}}^{\tilde{t}} [C(r(e))Q - S(e) + P(r(e) + t_1)C(r(e))Q] f(t_1) dt_1$$

$$= C(r(e))Q - S(e) + C(r(e))Q \int_{\tilde{t}}^{\tilde{t}} P(r(e) + t_1) f(t_1) dt_1.$$

The optimal contract of the customer can then be represented as the following problem (OC$_3$),

$$\max_{e, C(\cdot), P(\cdot)} \quad r(e) - C(r(e))Q + \int_{\tilde{t}}^{\tilde{t}} \int_{\tilde{t}}^{\tilde{t}} P(r(e) + t_1)(r(e) + t_2 - C(r(e))Q) f(t_1) f(t_2) dt_1 dt_2,$$

s.t.

$$C(r(e))Q - S(e) + C(r(e))Q \int_{\tilde{t}}^{\tilde{t}} P(r(e) + t_1) f(t_1) dt_1 \geq 0,$$

$$C(r(e))Q - S(e) + P(r(e) + t_1)C(r(e))Q \geq 0,$$

$$C(r(e))Q - S(e') + P(r(e') + t_1)C(r(e))Q, \forall e' \neq e, \forall t_1 \in [\tilde{t}, \tilde{t}],$$

$$P(r(e) + t_1) = 0, \forall t_1 \notin [\tilde{t}, \tilde{t}],$$

$$P(r(e) + t_1) > 0, \forall t_1 \in [\tilde{t}, \tilde{t}].$$

Constraint (15) is the provider’s individual rationality constraint, or so-called provider participant constraint. (16) and (17) are the incentive compatible constraints of the provider. (16) means that when the desirable effort is $e$, the provider will not make effort $e' \neq e$. (17) indicates that when the ex post profit after the first period $R_1 \notin [r(e) + t_1, r(e') + t_1]$, the effort of the provider is not $e$ and the customer will not cooperate with the provider in the next period. We have the following lemma.

**Lemma 1.** Constraints (16) and (17) are satisfied if and only if the cooperation probability $P(\cdot)$ is of the following form

$$P(r(e) + t_1) = \begin{cases} 
\frac{S'(e)}{C(r(e))Q r'(e)} (r(e) + t_1), & t_1 \in [\tilde{t}, \tilde{t}], \\
0, & t_1 \notin [\tilde{t}, \tilde{t}].
\end{cases}$$

**Proof:** Define $g(e, e')$ as

$$g(e, e') = C(r(e))Q - S(e') + P(r(e') + t_1)C(r(e))Q.$$

Then (16) is equivalent to that $e' = e$ maximizes $g(e, e')$. The first order condition is

$$\frac{\partial g(e, e')}{\partial e'} \bigg|_{e'=e} = -S'(e) + C(r(e))Q r'(e) P'(r(e) + t_1) = 0.$$
We have

\[ P'(r(e) + t_1) = \frac{S'(e)}{C(r(e))Qr'(e)}, \tag{21} \]

which holds for all \( t_1 \in [\underline{t}, \bar{t}] \). For a determinative effort \( e \), the right part of (21) is a constant. Together with (17), the cooperation probability \( P(\cdot) \) has the form as (19) indicated.

The second order condition is

\[
\left. \frac{\partial^2 g(e,e')}{\partial e^2} \right|_{e'=e} = -S''(e) + C(r(e))Q \left( (r'(e))^2 P''(r(e) + t_1) + r''(e)P'(r(e) + t_1) \right)
\]

\[
= -S''(e) + C(r(e))Q(r'(e))^2 P''(r(e) + t_1) + r''(e) \frac{S'(e)}{r'(e)} \leq 0.
\]

From (1), (2) and (19), the second order condition holds. This completes the proof. \( \square \)

The provider participant constraint (15) now can be rewritten as

\[ C(r(e))Q - S(e) + \frac{S'(e)r(e)}{r'(e)} \geq 0. \tag{22} \]

It should be tight, since otherwise the customer can further increase the objective value of problem (\( OC_3 \)) problem by slightly decreasing \( C(\cdot) \) with a certain contract form. Therefore,

\[ C(r(e))Q - S(e) + \frac{S'(e)r(e)}{r'(e)} = 0. \tag{23} \]

Denote

\[ \alpha(e) = \frac{r'(e)S(e)}{S'(e)r(e)} = \frac{\alpha_S}{\alpha_C}, \tag{24} \]

where \( \alpha_S = S'(e)/S(e) \) is the elasticity of the cost \( S(e) \) to the effort of the provider, \( \alpha_e = r'(e)/r(e) \) is the elasticity of the deterministic benefit of the customer \( r(e) \) to the effort of the provider. Therefore \( \alpha(e) \) can be interpreted as the ratio of elasticity of the provider cost and that of the customer benefit. From (23) and (19), \( C(r(e)) \) and \( P(\cdot) \) have the following forms:

\[
C(r(e)) = \frac{S(e)}{Q} \left( 1 - \frac{1}{\alpha(e)} \right), \tag{25}
\]

\[
P(r(e) + t_1) = \begin{cases} \frac{1}{\alpha(e)-1} \frac{r'(e)+t_1}{r(e)}, & t_1 \in [\underline{t}, \bar{t}], \\ 0, & t_1 \notin [\underline{t}, \bar{t}], \end{cases} \tag{26}
\]

The objective function of problem (\( OC_3 \)) is

\[ U = \frac{\alpha(e)}{\alpha(e) - 1} r(e) - s(e). \]

Up to this stage, the constraint (18) is still not included in the model. From (26), it is equivalent to that

\[ \frac{1}{\alpha(e) - 1} \frac{r(e) + t_1}{r(e)} \in [0,1], \]

for all \( t_1 \in [\underline{t}, \bar{t}] \). As \( R = r(e) + t > 0 \) for all \( t \in [\underline{t}, \bar{t}] \), we have

\[ \alpha(e) \geq 2 + \frac{\bar{t}}{r(e)}. \tag{27} \]

Therefore the optimal \( e \) in contract problem (\( OC_3 \)) can be solved from the following problem (\( OC_4 \)):
The above results can be summarized in the following theorem.

**Theorem 3.** When effort $e$ is private information of the provider, the optimal $e_3$ for the customer can be solved from the problem (OC4), and the optimal compensation price $C_3(\cdot)$ and $P_3(\cdot)$ have the following forms:

\[
C_3(r(e_3)) = \frac{S(e_3)}{Q} \left(1 - \frac{1}{\alpha(e_3)}\right),
\]

\[
P_3(r(e_3) + t_1) = \begin{cases} 
\frac{1}{\alpha(e_3) - 1} \frac{r(e_3) + t_1}{r(e_3)}, & t_1 \in [t, \bar{t}], \\
0, & t_1 \notin [t, \bar{t}],
\end{cases}
\]

where

\[
\alpha(e_3) = \frac{r'(e_3)S(e_3)}{S'(e_3)r(e_3)},
\]

and $r(e_3) + t_1$ is the customer’s realized benefit in the first period. The necessary and sufficient condition for the customer to draw up such a contract with the provider is

\[
\frac{\alpha(e_3)}{\alpha(e_3) - 1} r(e_3) - s(e_3) \geq 0
\]

□

The condition (30) is called “customer’s participant constraint”. In this contract, since there is an incentive compatible constraint of the provider, the provider will devote the desirable effort in the first period. Comparing the above results with the contracts in section 3, we can see that when the effort of the provider is unverifiable, the compensation price will be higher, and the expected benefit of the customer is lower than that in Theorem 2. This indicates that when information about the effort of the provider is asymmetrical, there is agent cost for the customer. Although the incentive compatible constraint is costly for the customer, it makes the provider devote desirable effort for environmentally friendly operations.

The probability that the customer decides to cooperate with the provider in period two has two effects. First, it acts as punishment power on the provider if the provider breaks the contract. Second, it acts as a risk sharing tool, which will be discussed in the next section. The punishment makes the provider to lose more expected compensation in the second period if it does not devote the desirable effort. In the next section, we consider another punishment strategy of the customer.

### 5 Further discussion on the contract with unverified effort

In this section, we modify the incentive contract by allowing the customer to change the logistics quantity in the second period. In addition, we analyze the risk sharing in the incentive contracts.

In the optimal incentive contract in section 4, the logistics service quantity is fixed for two periods, and the customer only decides whether to renew the contract for the next period. According to its ex post benefit in the first period, the customer may change the service quantity assigned to the provider due the following reasons. The customer may shift part of its workload to another service provider to protect its own market position. It may also adjust the quantity according to the change of its internal business strategy or external business conditions. In many situations, the customer simply uses the contract renewing as a tool to enforce the ex post punishment for the unsatisfied performance of the provider in the environmentally friendly operations.

In the following model, the customer decides the logistics service quantity in the second period.
Let $R_1, R_2, t_1, t_2$ and $C(r(e))$ be defined as in section 4. For any realized benefit of the customer $r(e) + t'$ in the first period, the customer decides the logistics service quantity $Q_2 = Q_2(r(e) + t')$, where $t'$ is a realized value of $t_1$.

The expected utility of the customer ($U$) and that of the provider ($V$) are respectively given as,

$$U = \int_{\bar{t}}^{t} \int_{\bar{t}}^{t} [R_1 - C(E(R_1))Q + R_2 - C(E(R_1))Q_2(R_1)]f(t_1)f(t_2)\, dt_1 dt_2,$$

$$V = \int_{\bar{t}}^{t} [C(E(R_1))Q - S(e) + C(E(R_1))Q_2(r(e) + t_1)] f(t_1)\, dt_1.$$

(31)

The optimal contract of customer can be represented as the following problem $(OC_5)$:

$$\max_{e,C(\cdot),Q_2(\cdot)} \quad 2r(e) - C(r(e))Q - C(r(e))\int_{\bar{t}}^{t} Q_2(r(e) + t_1)f(t_1)\, dt_1,$$

$$\text{s.t.} \quad C(r(e))Q - S(e) + C(r(e))\int_{\bar{t}}^{t} Q_2(r(e) + t_1)f(t_1)\, dt_1 \geq 0,$$

$$C(r(e))Q - S(e') + C(r(e))Q_2(r(e') + t_1) \geq C(r(e))Q - S(e) + C(r(e))Q_2(r(e) + t_1), \forall e' \neq e, \forall t_1 \in [\bar{t}, \bar{t}],$$

$$Q_2(r(e) + t_1) \geq 0, \forall t_1 \in [\bar{t}, \bar{t}].$$

(33)

(34)

Similar to the result in the last section, we have the following lemma.

**Lemma 2.** Constraints (34) is satisfied if and only if $Q_2(\cdot)$ has the following form

$$Q_2(r(e) + t_1) = \frac{S'(e)}{C(r(e))r'(e)}(r(e) + t_1).$$

\(\square\)

The optimal contract form can be thus summarized in the following theorem.

**Theorem 4.** When effort $e$ is private information of the provider, and the logistics service quantity in the second period $Q_2$ is contractible, the optimal value $e_4$ for the customer satisfies:

$$e_4 \in \arg\max_e \{2r(e) - S(e)\},$$

(35)

and the optimal compensation price $C_4(\cdot)$ and $Q_2^*(\cdot)$ have the following form:

$$C_4(r(e_4)) = \frac{S(e_4)}{Q} \left(1 - \frac{1}{\alpha(e_4)}\right),$$

$$Q_2^*(r(e_4) + t_1) = \frac{Q}{\alpha(e_4) - 1} \frac{r(e_4) + t_1}{r(e_4)}, \quad t_1 \in [\bar{t}, \bar{t}],$$

(36)

(37)

where

$$\alpha(e_4) = \frac{r'(e_4)S(e_4)}{S'(e_4)r(e_4)} > 1,$$

and $r(e_4) + t_1$ is the customer’s realized benefit of the first period. The necessary and sufficient condition for the customer to draw up such a contract with the provider is

$$2r(e_4) - s(e_4) \geq 0.$$

(38)
The state of nature is the risk in the environmental improvement process. After the contract with the form indicated in Theorem 3 is drawn up, the customer’s utility \( U \) and the provider’s utility \( V \) will be affected by the states of nature \( t_1 \) and \( t_2 \):

\[
U = r(e_3) + t_1 - C_3(r(e_3))Q + P_3(r(e_3) + t_1)(r(e_3) + t_2 - C_3(r(e_3))Q),
\]

\[
= A + \left( 1 + \frac{A}{\alpha(e_3) r(e_3)} \right) t_1 + \frac{1}{\alpha(e_3) - 1} t_2 + \frac{1}{\alpha(e_3) - 1} r(e_3) t_1 t_2
\]

\[
= A + \left( 1 + \frac{A}{\alpha(e_3) r(e_3)} \right) t_1 + P_3(r(e_3) + t_1) t_2
\]

\[
= A + \left( 1 + \frac{A}{\alpha(e_3) r(e_3)} \right) t_1 + P_3(r(e_3) + t_1) t_2
\]

\[
= A + \left( 1 + \frac{A}{\alpha(e_3) r(e_3)} \right) t_1 + P_3(r(e_3) + t_1) t_2
\]

\[
= \frac{S(e_3)}{\alpha(e_3) r(e_3)} t_1,
\]

where

\[
A = \frac{\alpha(e_3)}{\alpha(e_3) - 1} r(e_3) - s(e_3) \geq 0.
\]

is the optimal objective value of the \((OC_3)\) problem.

It is clear that the risk of the second period \( t_2 \) is the customer’s own risk, which is not shared by the provider. As \( P_3(r(e_3) + t_1) \geq 0 \) for all \( t_1 \in [t, \bar{t}] \), a better state of nature \( t_2 \) will enhance the utility of the customer. But the risk of nature \( t_1 \) in the first period is shared by the customer and the provider. From (27) and (30),

\[
\frac{\alpha(e_3) r(e_3) - S(e_3)}{\alpha(e_3) r(e_3)} = \frac{A}{\alpha(e_3) r(e_3)} + \frac{\alpha(e_3) - 2}{\alpha(e_3) - 1} \geq 0.
\]

Therefore each part of the coefficient of \( t_1 \) in (40) is non-negative. We obtain that a better state of nature \( t_1 \) will also enhance the utility of the customer. (41) indicates that the utility of the provider will increase as \( t_1 \) increase. Thus, the risk in the first period is shared by the customer and the provider. The contract between the customer and the provider acts as a risk sharing tool in our model. When the state of nature \( t_1 < 0 \), the provider will be at risk of gaining negative revenue.

As for the contract in Theorem 4, similar to the analysis above, the customer’s utility \( U \) and the provider’s utility \( V \) are:

\[
U = 2r(e_4) + t_1 + t_2 - C_4(r(e_4))Q - C_4(r(e_4))Q_2(r(e_4) + t_1),
\]

\[
= 2r(e_4) - S(e_4) + \frac{\alpha(e_4) r(e_4) - S(e_4)}{\alpha(e_4) r(e_4)} t_1 + t_2,
\]

\[
V = C_4(r(e_4))Q - S(e_4) + C_4(r(e_4))Q_2(r(e_4) + t_1)
\]

\[
= \frac{S(e_4)}{\alpha(e_4) r(e_4)} t_1,
\]

The customer takes all risk from \( t_2 \), and the risk from \( t_1 \) taken by the provider is similar to that of the contract in Theorem 3. But the risk from \( t_1 \) taken by the customer is slightly different. Since we only know that \( \alpha(e_4) > 1 \) (Theorem 4), and \( 2r(e_4) - s(e_4) \geq 0 \) as (38) shows, we cannot determine the sign of the coefficient of \( t_1 \) in (42). When \( \alpha(e_4) r(e_4) - S(e_4) \) is positive, a better state of nature \( t_1 \) may increase the utility of the customer, but when the sign is negative, a better state of the nature may decrease its utility.

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6 Conclusion

This paper develops and discusses some optimal incentive contracts between a customer with environmental commitment and its logistics service provider. We point out that a major hurdle in practicing environmentally conscious operations is the lack of understanding of incentive format and amount, and reveal that the information structure significantly affects the contract structure and the risk sharing. We discuss the optimal contract for the following situations:

• a single period, with symmetric information and revealable effort of the provider.
• two periods, with symmetric information and revealable effort of the provider. It is found that longer cooperation will benefit both parties.
• two periods, with unrevealable effort of the provider. We find that although the added incentive compatible constraint is costly for the customer, it makes the provider devote desirable effort for environmentally friendly operations.
• two periods, with unreavelable effort of the provider, the service quantity is adjustable by the customer. We show that the contract not only motivate the provider, but also act as a risk sharing tool.

In this research, the environmentally oriented effort of provider mainly implies that initial facilities investment, and learning effort and related cost. We assume that when the provider makes the effort on environmentally friendly operations in the first period, it is beneficial in its future service without any such effort added. The effort may ultimately enhance the environmental conditions and social welfare. We point that when proper contracts are designed, the environmentally friendly strategy and operations will benefit the customer, the provider and the community. Therefore, the “green” operations strategy should not be simply considered as a costly arrangement.

References