Selection of optimal coordination contract for sustainable supply chain under carbon tax

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Abstract. The purpose of this paper is to find an optimal coordinating contract on a two-echelon sustainable supply chain composed of a manufacturer and a retailer under carbon tax policy. Taking consumer environmental awareness (CEA) and manufacturer’s abatement investment cost into account, this study compares wholesale price contract, revenue-sharing contract and green cost-sharing contract, and finds that none of them can obtain coordination. Then, “Adjusted” contracts are introduced and proved that only adjusted revenue-sharing contract can coordinate the supply chain. Considering the profit redistribution proposition of the two-part tariff contract, the study introduces combined contracts, which are found capable of obtaining supply chain coordination as well as a win-win outcome.

1. Introduction

Governments around the world have issued various regulations to control carbon emission in production in recent years, for which the main instruments used are carbon cap-and-trade and carbon tax. According to the study of Avi and Uhlmann, carbon tax is more effective in abatement than other regulations [1]. In addition to increased taxational incentive, growing consumer environmental awareness (CEA) is making consumers more willing to pay high prices for green products. Under such circumstances, companies need to reduce their carbon emission in reaction to new consumer preferences as well as governmental regulations. Sustainable supply chain coordination under carbon regulations considering CEA is becoming an important issue.

These years, both theorists and practitioners are focusing on sustainable supply chain coordination. Swami and Shah (2013) use two-part tariff (TPT) contract to coordinate a two-echelon supply chain where both the manufacture and the retailer put in abatement effort [2]. Considering both CEA and retailer’s sales efforts, Basiri and Heydari (2017) compare integrated scenario, decentralized scenario and collaborative scenario and conclude that collaborative model can enhance the profit of both manufacturer and retailer [3]. Since many countries have announced emission regulations to control carbon emission, more and more scholars are beginning to pay attention to supply chain coordination under certain policies. Dong et al. (2014) consider a two-echelon supply chain under cap-and-trade policy. Their study suggests that revenue-sharing contract (RS) can coordinate the supply chain with sustainable investment but the buyback contract (BB) and TPT contract cannot, and that sustainability investment affects optimal decisions [4]. Xu et al. (2016) focus on cap-and-trade policy, in whose model the downstream invest in sustainable technology. They show that TPT contract can achieve coordination with win-win outcome whereas RS contract can only obtain coordination [5]. Krass et al. (2013) explore the green technology selection and supply chain operation under carbon tax regulation.
They find that with an increase in tax, firms first tend to choose a greener technology but then reverse later [6]. Yu and Han (2017) introduce modified WP and modified CS contract to coordinate the supply chain and find that, in a supply chain with carbon tax, consisting of a manufacturer and a retailer, both modified WP and modified CS obtain coordination at the expense of manufacturer’s profit [7].

The above literatures all focus on sustainable supply chain coordination with contracts, with some featuring CEA in their analysis. Nevertheless, most researches focus on cap-and-trade policy and not enough attention is paid to sustainable supply chains under carbon tax policy. Scholars have not considered both the abatement investment and CEA under carbon tax policy yet, which is commonplace in reality since carbon tax is gradually being implemented in many countries. Therefore, this paper studies a sustainable supply chain under carbon tax policy considering both CEA and abatement investment. By comparing different contracts, the paper tries to find mechanisms to obtain supply chain coordination and promote Pareto improvement for supply chain members.

### Table 1. Model parameters and notations.

| Parameter | Description                                      |
|-----------|--------------------------------------------------|
| $c_m$     | Unit production cost of manufacturer             |
| $c_r$     | Marginal retail cost of retailer                 |
| $c$       | Product unit cost $c = c_m + c_r$                |
| $w$       | Wholesale price                                  |
| $p$       | Retail price                                     |
| $q$       | Market demand (order quantity)                   |
| $e$       | Carbon emission for producing per unit product   |
| $t$       | Carbon tax for per unit carbon emission          |
| $s$       | Abatement level                                  |
| $\lambda$ | Investment coefficient of carbon emission reduction |
| $a$       | Basic market size                                |
| $a_1$     | Effective coefficient of retail price on market demand |
| $a_2$     | Effective coefficient of abatement level on market demand |
| $\pi_m$  | Manufacturer’s profit                            |
| $\pi_r$  | Retailer’s profit                                |
| $\pi_c$  | Supply chain profit, $\pi_c = \pi_m + \pi_r$    |
| $\alpha$ | Coefficient of revenue sharing                   |
| $\theta$ | Coefficient of green cost sharing                |

### 2. Sustainable supply chain model under carbon tax

This paper focuses on exploring coordination contract for sustainable supply chain under carbon tax policy. A two-echelon supply chain consisting of one manufacturer and one retailer is considered. The manufacture produces an environmental-friendly product at a unit production cost $c_m$, and sells to the retailer at a unit wholesale price $w$. Carbon emission per unit product caused during production is $e (e > 0)$ and carbon tax per unit carbon emission is $t (t > 0)$. After buying from the manufacturer, retailer sells products to the consumer at a unit retail price $p$ with a marginal retail cost $c_r$. Due to carbon tax policy and CEA, the manufacturer has incentives to reduce carbon emission. Assume that the abatement level is $s$. Since manufacturer cannot reduce emission entirely, $0 < s < 1$. After taking the carbon emission reduction measures, carbon emission per unit product
will decrease into \((1 - s)e\). Similar to Taleizadeh et al. (2018), the green cost in this paper is defined as \(c_s = \frac{1}{2} \lambda s^2\), where \(\lambda\) is the investment coefficient of the carbon emission reduction [8].

Referring to Aslani and Heydari (2019), the market demand can be defined as a linear function of retail price and abatement level:

\[ q = a - a_1 p + a_2 s, \]

where \(a_1(a_1 > 0)\) is the effective coefficient of the retail price on market demand and \(a_2(a_2 > 0)\) is the effective coefficient of the abatement level on market demand [9]. Assume that there is no stockout or inventory during the selling period, and all information is symmetric. In addition, both manufacturer and retailer are risk-neutral and the reservation profit of them is zero.

This study considers the situation where the manufacturer is the Stackelberg leader and the retailer is the Stackelberg follower. At the beginning of the selling period, manufacturer moves first, selects contract type and related parameters, and decide their abatement level. Then, as the follower, after observing all the information that manufacturer provides, retailer decides to accept the contract or not. If the retailer accepts, then she needs to provide order quantity to the manufacturer.

Main parameters and notations are summarized in Table 1.

### 3. Decisions under different contracts

#### 3.1. Centralized supply chain

Firstly, centralized situation is analysed, where the manufacturer and retailer make decisions together as an integrated company. The profit function of this centralized supply chain is:

\[ \pi_c = (p - c)q - \left( \frac{1}{2} \lambda s^2 - (1 - s)teq \right) \]

**Theorem 1.** In the centralized situation, the optimal decisions are:

\[
\begin{align*}
  s_c^* &= \frac{AB}{2a_1 \lambda - A^2} \\
  p_c^* &= \frac{\lambda \left[ a_1 (c + te) + a \right] - A \left[ a_2 (c + te) + ate \right]}{2a_1 \lambda - A^2} \\
  q_c^* &= \frac{a_1 \lambda B}{2a_1 \lambda - A^2}
\end{align*}
\]

where \(A = a_1 + a_2 te, B = a - a_1 (c + te)\) and \(2a_1 \lambda - A^2 > 0, 2a_1 \lambda - (a + a_2 - a_1 c)A > 0\).

#### 3.2. Decentralized supply chain in Wholesale Price Contract (WP)

In decentralized situation, the manufacturer and the retailer make decisions separately to maximize their own profit without considering the whole supply chain. Under wholesale price contract (WP), profit of them can be formulated as:

\[ \pi_{t, WP} = (p - w - c_t)q \]

\[ \pi_{m, WP} = (w - c_m)q - \left( \frac{1}{2} \lambda s^2 - (1 - s)teq \right) \]

According to Stackelberg Game Theory, backward solution is used to solve this problem.

**Theorem 2.** In the decentralized situation with WP, the optimal decisions are:
\[
\begin{aligned}
    s_{WP}^* &= \frac{AB}{4a_1r - A^2}, \quad w_{WP}^* = \frac{2\lambda[a_1(c_m + te - c) + a] - A[a_2(c_m + te) + ate - a_1c_te]}{4\lambda_r - A^2} \\
    p_{WP}^* &= \frac{\lambda[a_1(c + te) + 3a] - A[a_2(c + te) + ate]}{4\lambda_r - A^2}, \quad q_{WP}^* = \frac{a_1\lambda B}{4\lambda_r - A^2} \\
    \pi_{c,WP}^* &= \frac{\lambda B^2}{4\lambda_r - A^2}, \quad \pi_{m,WP}^* = \frac{\lambda B^2}{4[4\lambda_r - A^2]}, \quad \pi_{c,WP}^* = \frac{\lambda[6\alpha a_1\lambda - A^2]B^2}{2[4\lambda_r - A^2]^2}
\end{aligned}
\]

where \( A = a_1 + a_2te \), \( B = a - a_1(c + te) \) and \( 4a_1\lambda - A^2 > 0, 4a_1\lambda - (a + a_2 - a_1c)A > 0 \).

If the supply chain is coordinated, then \( q_{WP}^* = q_c^* \) and \( s_{WP}^* = s_c^* \). Obviously it’s impossible when \( A > 0, B > 0 \). Actually, it is find that \( s_{WP}^* < s_c^* \), so \( q_{WP}^* < q_c^* \), \( s_{WP}^* < s_c^* \). Therefore, basic WP contract cannot coordinate the sustainable supply chain under carbon tax policy, and the abatement level, order quantity and supply chain’s profit are smaller than those in centralized situation.

3.3. Decentralized supply chain under Revenue-sharing Contract (RS)

In RS contract, the manufacturer first decides his abatement level \( s \), wholesale price \( w \) and revenue-sharing coefficient \( \alpha \), and then the retailer announces her order quantity \( q \), where \( \alpha \) is the fraction of retailer’s income that manufacturer shares. Profits of retailer and manufacture can be formulated as:

\[
\begin{aligned}
    \pi_{c,RS} &= (ap - w - c)q \\
    \pi_{m,RS} &= (w - c_m)q - \frac{1}{2} \lambda s^2 - (1 - s)teq + (1 - a)pq
\end{aligned}
\]

**Theorem 3.** In the decentralized situation with RS, the optimal decisions are:

\[
\begin{aligned}
    s_{RS}^* &= \frac{AB}{2(1 + \alpha)a_1r - A^2} \\
    w_{WP}^* &= \frac{2\lambda[\alpha a_1(c_m + te) + \alpha^2a - a_1c]}{2(1 + \alpha)a_1r - A^2} \\
    p_{RS}^* &= \frac{\lambda[a_1(c_m + te) + 3a] - A[a_2(c_m + te) + ate]}{2(1 + \alpha)a_1r - A^2}, \quad q_{RS}^* = \frac{a_1\lambda B}{2(1 + \alpha)a_1r - A^2} \\
    \pi_{c,RS}^* &= \frac{\lambda B^2}{2[1 + 2\alpha]a_1r - A^2}, \quad \pi_{m,RS}^* = \frac{\lambda B^2}{2[1 + \alpha]a_1r - A^2} \\
    \pi_{c,RS}^* &= \frac{\lambda B^2}{2[1 + 2\alpha]a_1r - A^2}
\end{aligned}
\]

where \( A = a_1 + a_2te \), \( B = a - a_1(c + te) \) and \( 2(1 + \alpha)a_1r - A^2 > 0 \), \( 2(1 + \alpha)a_1r - (a + a_2 - a_1c)A > 0 \).

If the supply chain is coordinated, \( q_{RS}^* = q_c^* \) and \( s_{RS}^* = s_c^* \). Obviously it’s impossible when \( A > 0, B > 0, 0 < \alpha < 1 \). Comparing to Theorem 2, \( s_{RS}^* > s_{WP}^*, q_{RS}^* > q_{WP}^* \). Thus Theorem 3 shows that although basic RS contract cannot coordinate the sustainable supply chain under carbon tax policy, it can improve the abatement level and order quantity.
3.4. Decentralized supply chain under Green Cost-sharing Contract (GCS)

Expensive green technology puts a heavy burden on manufacturers, so Green Cost-sharing Contract (GCS) plays a very important role. In GCS contract, manufacturer first decides his abatement level \( s \), wholesale price \( w \) and Green Cost-sharing coefficient \( \theta \), and then the retailer provided her order quantity \( q \), where \( \theta \) is the fraction of green cost that retailer shares. Profits of them are:

\[
\pi_{r,GCS} = (p - w - c_r)q - \frac{1}{2} \theta \bar{s}^2 \\
\pi_{m,GCS} = (w - c_m)q - \frac{1}{2} (1 - \theta) \bar{s}^2 - (1 - s)teq
\]  

(9)  
(10)

**Theorem 4.** In the decentralized situation with GCS, the optimal decisions are:

\[
s_{GCS}^* = \frac{AB}{4(1 - \theta)A_i - A^2} \\
w_{GCS}^* = \frac{2(1 - \theta)[a_1(c_m + te - c_r) + a] - A[a_2(c_m + te) + ate - a_1c_rte]}{4(1 - \theta)A_i - A^2} \\
p_{GCS}^* = \frac{(1 - \theta)[a_1(c + te) + 3a] - A[a_2(c + te) + ate]}{4(1 - \theta)A_i - A^2} \\
q_{GCS}^* = \frac{a_1(1 - \theta)\lambda B}{4(1 - \theta)A_i - A^2} \\
\pi_{r,GCS}^* = \frac{\lambda \left[2(1 - \theta)^2a_1(1 - A)B^2 \right]}{4(1 - \theta)A_i - A^2} \\
\pi_{m,GCS}^* = \frac{(1 - \theta)\lambda B^2}{24(1 - \theta)A_i - A^2} \\
\pi_{c,GCS}^* = \frac{\lambda \left[6(1 - \theta)^2a_1A - A^2B^2 \right]}{24(1 - \theta)A_i - A^2} \\
\]

where \( A = a_1 + a_2te \), \( B = a - a_1(c + te) \) and \( 4(1 - \theta)A_i - A^2 > 0 \), \( 4(1 - \theta)A_i - (a + a_2 - a_1c)A > 0 \).

Similarly, if the supply chain coordinated, \( q_{GCS}^* = q_{c}^* \) and \( s_{GCS}^* = s_{c}^* \), which is impossible when \( A > 0, B > 0, 0 < \theta < 1 \). And it’s obviously that \( s_{GCS}^* > s_{WP}^*, q_{GCS}^* > q_{WP}^* \). Therefore, although basic GCS contract cannot coordinate the sustainable supply chain under carbon tax policy, it can improve the abatement level and order quantity.

4. Coordinate sustainable supply chain via contracts

According to section 3, basic WP contract, RS contract and GCS contract cannot coordinate the supply chain. In this section, “Adjusted” contracts and combining these “Adjusted” contracts with Two-part tariff contract (TPT) are introduced to explore whether they can obtain coordination.

TPT contract is being widely used in supply chain management. In TPT contract, manufacturer sells products to the retailer at a wholesale price \( w \) and asks for a fixed fee \( F \). \( F \) is also called franchise fee that the retailer pays to manufacturer for the permit of selling the products. Although a positive \( F \) is more common, this study allows \( F < 0 \) here to adapt to the situation in which manufacturer pays retailer \( F \) to subsidize selling.

4.1. Coordinate with AWP+TPT contract

A new contract \( \{w_{AWP}, s_{AWP}\} \) named “Adjusted WP contract (AWP)” is introduced, in which manufacturer simulate retailer to decide like centralized situation by setting proper \( w_{AWP} \) and \( s_{AWP} \).

When supply chain coordinated, \( q_{AWP}^* = q_{c}^*, s_{AWP}^* = s_{c}^* \), so profit of the retailer and manufacturer
are \(\pi_{c,AWP} = \frac{a_4 \lambda^2 B^2}{[2a_1 \lambda - A^2]^2} > 0\) and \(\pi_{m,AWP} = -\frac{1}{2} \lambda s^2 < 0\). It is assumed that the reservation profit of them is zero in section 2, which is not satisfied here. Therefore, manufacturer will not select this contract.

TPT contract is an effective mechanism to redistribute total profit between supply chain members without changing decision variables, so a new combined contract named “Adjusted WP+TPT contract (AWP+TPT)” is introduced in order to obtain supply chain coordination.

**Theorem 5.** Under AWP+TPT contract \(\{w_{AWP+TPT}, s_{AWP+TPT}, F_{AWP+TPT}\}\), there exists fixed fee \(F_{AWP+TPT} \in (F_{AWP+TPT}, TPT)\) that can coordinate sustainable supply chain under carbon tax policy and obtain win-win between the two firms, where

\[
\begin{align*}
F_{AWP+TPT} & = \frac{\lambda B^2}{2[4a_1 \lambda - A^2]} + \frac{\lambda A^2 B^2}{2[2a_1 \lambda - A^2]} \\
F_{AWP+TPT} & = \frac{a_4 \lambda^2 B^2}{[2a_1 \lambda - A^2]^2} - \frac{a_4 \lambda^2 B^2}{4[2a_1 \lambda - A^2]^2}
\end{align*}
\]

(12)

**4.2. Coordinate with AGCS+TPT contract**

Similarly, based on GCS contract, a new contract \(\{w_{AGCS}, s_{AGCS}, \theta_{AGCS}\}\) named “Adjusted GCS contract (AGCS)” is introduced then to coordinate supply chain. In this contract, \(\pi_{c,AGCS} = \frac{2a_1 \lambda^2 - \theta \lambda A^4}{2[2a_1 \lambda - A^2]} B^2 > 0\), \(\pi_{m,AGCS} = -\frac{1}{2} \lambda s^2 < 0\). Similarly, AGCS contract cannot coordinate this supply chain.

Next, TPT contract is combined with AGCS contract, trying to implement supply chain coordination. A new combined contract named “Adjusted GCS+TPT contract (AGCS+TPT)” is introduced.

**Theorem 6.** Under AGCS+TPT contract \(\{w_{AGCS+TPT}, s_{AGCS+TPT}, F_{AGCS+TPT}\}\), there exists fixed fee \(F_{AGCS+TPT} \in (F_{AGCS+TPT}, TPT)\) that can coordinate sustainable supply chain under carbon tax policy as well as obtaining win-win, where

\[
\begin{align*}
F_{AGCS+TPT} & = \frac{\lambda B^2}{2[4a_1 \lambda - A^2]} + \frac{(1 - \theta) \lambda A^2 B^2}{2[2a_1 \lambda - A^2]} \\
F_{AGCS+TPT} & = \frac{2a_1 \lambda^2 - \theta \lambda A^4}{2[2a_1 \lambda - A^2]} B^2 - \frac{a_4 \lambda^2 B^2}{4[2a_1 \lambda - A^2]^2}
\end{align*}
\]

(13)

**4.3. Coordinate with ARS+TPT contract**

Based on GCS contract, “Adjusted RS contract (ARS)” is introduced then. In this contract, \(\pi_{c,ARS} = \frac{a_4 \lambda^2 B^2}{[2a_1 \lambda - A^2]^2} > 0\), \(\pi_{m,ARS} = \frac{2(1 - \alpha) a_4 \lambda^2 - \lambda A^2 B^2}{2[2a_1 \lambda - A^2]^2}\). When \(2(1 - \alpha) a_4 \lambda^2 - \lambda A^2 > 0\), \(\pi_{c,ARS} > 0\) and \(\pi_{m,ARS} > 0\) are simultaneously established, which means ARS contract can coordinate the supply chain in this condition. Then, if ARS contract can obtain win-win should be
further explored. Let \( \pi_{e,ARS} > \pi^*_{e,WP} \), \( \pi_{m,ARS} > \pi^*_{m,WP} \), it is find that when

\[ 0 < \frac{2a_1 \lambda - A^2}{4a_1 \lambda - A^2} < \alpha < \frac{2a_1 \lambda - A^2}{4a_1 \lambda - A^2} < 1, \]

both manufacturer and retailer’s profit will be Pareto improved.

**Theorem 7.** ARS contract can coordinate sustainable supply chain under carbon tax policy and Pareto improve the two firms’ profit when

\[ 0 < \frac{2a_1 \lambda - A^2}{4a_1 \lambda - A^2} < \alpha < \frac{2a_1 \lambda - A^2}{4a_1 \lambda - A^2} < 1, \]

where

\[ s^*_ARS = s^*_c, W^*_ARS = \frac{(aa - a_1c_t)A^2 - a_2AB - \left[aa_1(c + te) - a_2c_t\right]2a_1 \lambda}{a_1(A^2 - 2a_1 \lambda)}. \]

Next, TPT contract is combined with ARS contract and “Adjusted RS+TPT contract (ARS+TPT)” is introduced.

**Theorem 8.** Under ARS+TPT contract \( \{w_{AWP+TPT}, s_{AWP+TPT}, a_{AWP+TPT}, F_{AWP+TPT}\} \), there exists fixed fee \( F_{ARS+TPT} \in \{F_{ARS+TPT}, F_{ARS+TPT}\} \) that can coordinate sustainable supply chain under carbon tax policy as well as obtaining win-win, where

\[
\begin{align*}
F_{ARS+TPT} &= \frac{\lambda B^2}{2[4a_1 \lambda - A^2]} + \frac{[2(1 - a)a_1 \lambda - \lambda A^2]B^2}{[2a_1 \lambda - A^2]} \\
F_{ARS+TPT} &= \frac{aa_1 \lambda^2 B^2}{[2a_1 \lambda - A^2]} - \frac{a_1 \lambda^2 B^2}{[4a_1 \lambda - A^2]}.
\end{align*}
\]

5. **Numerical analysis**

In this section, this paper uses a numerical example to verify and further illustrate the results above. In order to satisfy all the conditions mentioned above, suppose that: \( a = 20, a_1 = a_2 = 1, e = 10, \)
\( t = 0.1, c_m = 3, c_i = 2, \lambda = 160, \alpha = \theta = 0.4. \)

5.1. **Impact of carbon tax on optimal decisions under different contracts**

![Figure 1. Impact of carbon tax on abatement level.](image1)

![Figure 2. Impact of carbon tax on order quantity.](image2)
Figure 3. Impact of carbon tax on retailer’s profit. Figure 4. Impact of carbon tax on manufacturer’s profit.

Figure 1 shows that the manufacturer’s abatement level $s$ is increasing with carbon tax $t$ when $t$ is relatively small and decreases then. In this numerical setting, under same carbon tax $t$, $s^*_GCS > s^*_RS > s^*_WP$, the abatement level is highest in GCS contract.

Figure 2 shows that the retailer’s order quantity $q$ in three contracts are all decreasing with carbon tax $t$ and $q^*_RS > q^*_GCS > q^*_WP$ in this numerical settings. With carbon tax increasing, gap between RS and WP shrinks and the order quantity is getting close to zero.

Figure 3 and Figure 4 also shows that the retailer’s and manufacturer’s profit $\pi_r$ and $\pi_m$ are all decreasing with carbon tax $t$ no matter in which contract. Under this numerical assumption, there is no certain relationship among $\pi^*_r, \pi^*_RS, \pi^*_GCS$, it is related to numerical relationship among parameters. For manufacturer’s profit: $\pi^*_GCS > \pi^*_RS > \pi^*_WP$, and the gap among them shrinks when $t$ increases.

5.2. The impact of CEA on optimal decisions under different contracts
Figure 7. Impact of abatement level coefficient on retailer’s profit.

Figure 8. Impact of abatement level coefficient on manufacturer’s profit.

Figure 5 indicates that the manufacturer’s abatement level $s$ increases with effective coefficient of abatement level on market demand $a_{2}$ and under these numerical settings, $s_{GCS}^* > s_{RS}^* > s_{WP}^*$, the abatement level is highest in GCS contract.

Figure 6 shows that the retailer’s order quantity $q$ decreases with $a_{2}$ in all these contracts, and $q_{RS}^* > q_{GCS}^* > q_{WP}^*$. With $a_{2}$ increasing, gap between RS and GCS shrinks while order quantity under WP contract increases slowly.

Figure 7 illustrates that retailer’s profit $\pi_i$ is increasing with $a_{2}$ in WP and RS contract, while in GCS contract, $\pi_i$ is increasing with $a_{2}$ when $a_{2}$ is relatively small and decreasing otherwise, which is consistent with Proposition 6. In addition, retailer’s profit in GCS contract is always lower than that in WP contract, whereas retailer’s profit in RS contract in not necessarily.

Figure 8 shows a similar tendency to Figure 6 that manufacturer’s profit in three contracts are all increasing with $a_{2}$, and $\pi_{m,GCS}^* > \pi_{m,RS}^* > \pi_{m,WP}^*$.

6. Discussion

According to analysis in previous sections, based on model formulation in this paper, basic WP contract, RS contract and GCS contract cannot coordinate the supply chain. So in section 4.1-4.3, combined contracts—AWP+TPT, AGCS+TPT, ARS and ARS+TPT are introduced, and it is find that all of them can obtain supply chain coordination and win-win.

Comparing AWP+TPT and AGCS+TPT, it is surprising to find that they are essentially the same. Due to the combination of TPT contract, the cost-sharing part in GCS+TPT contract is reflected in $F_{AWP+TPT}$ in AWP+TPT contract. Because of the simplicity, supply chain members are more inclined to use AWP + TPT contract in practice. As for ARS and ARS+TPT, when $2(1 - \alpha)_{I_{1}}\lambda^{2} - \lambda A^{2} > 0$, they can achieve the same results so ARS is better due to the simplicity. However, if $2(1 - \alpha)_{I_{1}}\lambda^{2} - \lambda A^{2} > 0$ in some cases, ARS cannot coordinate the supply chain any more. Manufacture should choose ARS+TPT.

7. Conclusions

After analyzing and comparing optimal decisions under three basic supply chain contract (WP contract, RS contract, GCS contract), this study finds that although none of them can coordinate supply chain,
RS and GCS contract can improve the abatement level and order quantity. Then, the concept of “Adjusted” contracts is introduced. It is found that only ARS can obtain coordination while AWP and AGCS cannot. However, by combining with TPT contract, all of them (AWP+TPT, ARS+TPT, AGCS+TPT) can coordinate the supply chain and promote Pareto improvement in both manufacturer and retailer’s profit. Furthermore, an interesting discovery is that AWP+TPT and AGCS+TPT are essentially the same. Manufacturers may choose AWP+TPT for its simplicity in reality.

In future extension, this model can be extended into multi-stage and to a nonlinear demand function. Moreover, in this model, it is assumed that supply chain members are risk-neutral and information is symmetric, which is not true in reality. Thus, coordination mechanisms considering risk preference and information asymmetry should be studied in the future.

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