E3 Journal of Business Management and Economics Vol. 4(7). pp. 166-172, July, 2013
Available online http://www.e3journals.org
ISSN 2141-7482 © E3 Journals 2013

*Full length research*

# Risk management of agricultural supply chain in China with weather compensatory contract

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Accepted 10 June, 2013

**This paper is based on some situations in China that agricultural products are transported directly to distribution centers and / or super markets. The retailer supplies an additional weather compensatory contract to the farmer before the planting time, in which the compensatory parameters are designed according to the forecast of temperature of the forthcoming demanding season. Such kind of contract can induce farmer to plant more properly to meet the market demands and increase the farmer's profits at the same time control market risk. This contract also helps the retailer as well as the farmer to reduce their weather risks.**

**Keywords:** Weather; Compensatory contract; Agricultural supply chain; Risk management

## INTRODUCTION

Weather risk is the uncertainty in cash flow and earnings caused by weather volatility (Cogen, 1998; Wang, 2010), which includes the impacts on financial performance of enterprises and individuals caused by weather temperature higher or lower than normal, and other abnormal weathers such as heavy torrential rain, snow storm and hurricane. Weather risk is pervasive in agriculture sector and is the main risk during the production and operation of agriculture. Farmers' economic benefits are influenced heavily and even decided by weather. In a 1998 testimony to Congress, former secretary of commerce in the United States, William Daley once stated that about 40% of the American economy is weather sensitive. China is a huge country with about 657 million rural population which account for 48.73% of the total population (NBSC, 2012). At the same time, the agricultural modernization degree in China is still much lower than that in developed countries. That means agriculture in China is affected more heavily than in developed countries.

Chinese agriculture is still small scale peasant economy, the characteristic of which is lacking of science technology, scale and capital (Huang et al., 2012). The farmers' anti-risk capacity is weakest in agricultural supply chain because of a couple of factors. First, the agricultural products themselves are sensitive to weather volatility. The weather risks impose great influence directly on agricultural productivity. In the beginning of 2010, the heavy drought which swept across five provinces in southwest China led to zero harvest in 1.1 million hectares fields and 64.2 million victims. In some places of Chongqing and Guangxi, flood and hurricane came before the drought relief was finished. Such kind of rugged weather seriously dampens the peasants' enthusiasm for production.

Second, weather volatility affects the choice of consumers (Firth, 2009), and then affects the sales of agricultural products. There is no doubt that the sales of watermelons will drop in a cool and rainy summer. The farmers who plant watermelons are the direct victims if the watermelons can't be sold out.

Last but not least, farmers plant blindly because of lack of knowledge about market quotation, which may result in farmers' loss seriously, despite bumper harvest because the price falls heavily. A farmer had to invite citizens to

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pull up turnips free in his 4 hectares lands because the wholesale price is only about 10 cent RMB per kilogram, which is too low to afford the labor costs of pulling up those turnips (Chen, 2011).

According to the above analysis, it is necessary to take some actions to help farmers to plant right breed and right volumes of products in order to protect their benefits and to enhance farmers' enthusiasm for production. Weather insurance and weather derivatives are two kinds of tools used to manage weather risks. Weather insurance is a kind of insurance product that insurance companies compensate companies or individuals for the loss caused by unusual weather. Weather derivatives are a kind of financial instruments to help companies hedge their weather risks (Considine, 1998). The arising of weather derivatives attracts a great deal of hedgers and capital, expands greatly the scope of diversification and transfer of weather risks (Zeng, 2000; Garman et al., 2000; Li and Zhang, 2006; Liang, 2009; He, 2010). However, Chinese farmers are not interested in such two kinds of instruments at current stage for their special situations: there is no weather risk product in China until now, Chinese farmers are not consciously aware of risk management and have fluke mind to avoid risk, Chinese farmers haven't enough money so that they don't want to spend money on insurance and derivatives.

Many researchers have studied risk management of agricultural supply chain, most of which focus on weather insurance and weather derivatives. Hartell et al. (2006), introduces the weather risk management of agricultural supply chain including risk value and insurance; Xu (2008), studied the application of weather derivatives in agribusiness; Jaffee et al. (2010), analyzed the identification, transmission, management methods and assessment of several kinds in risks of agricultural supply chain; Hazell et al. (2010) and Bryla and Syroka (2007) discussed the application of weather index insurance in agricultural industry. Inspired by the rebate contract put forward by Chen and Yano (2010), this paper study's a kind of weather compensatory contract supplied by the agricultural retailer to the farmer. This kind of contract can increase the income of farmers without increasing investment. It also can reduce the risks of farmer and retailer and coordinate the supply chain.

## THE BASIC MODEL

### Assumptions of model

This paper doesn't consider those small scale farmers who plant and sell by themselves, but the agricultural supply chain that the products are transported directly to distribution center or supermarket, just like the supply chains in figure 1 and figure 2. These two kinds of supply chains in figure 1 and figure 2 are similar to a large degree. The distribution center (not wholesaler) in figure 1 and large-scale supermarket in figure 2 are both large-scale, have strong capital and risk resistance capacities. They can afford the weather derivatives and insurance and easy to cultivate the idea of purchasing them. Only the two-echelon supply chain with one product from farmer to distribution center / supermarket are analyzed in this paper. For the sake of convenience, both of distribution center and supermarket are regarded as retailers. Thus these two kinds of supply chains are simplified to a farmer-retailer supply chain, in which the retailer is the leader of Stackelberg game while the farmer is the follower. This is contrary to normal product supply chain in which the manufacturer is usually the leader.

The Compensatory contract discussed in this paper is based on the impacts of temperature change on agricultural products. Similarly, other weather indices such as rainfall, wind speed and so on impose impacts on agricultural products too. So some other kinds of weather compensatory contracts can be designed according to different weather indices and agricultural products. Suppose the increase of temperature leads to increase of market demands for a product in the supply chain, e.g. the demand for watermelon in summer. If the retailer can foresee the temperature range and distribution during the forthcoming selling season, he can predict the demand of a product. While the farmer isn't able to forecast the weather volatility and market demands due to lack of information. He has to plant according to his experience which causes him to plant more or less than market demands. The retailer applies a weather compensatory contract to the farmer to guide him to plant suitable more products in order to meet the demands and achieve more benefits. The retailer himself then chooses weather derivatives to hedge against the weather risks or purchase weather insurance. As the leader of Stackelberg game, the retailer decides the structure and parameters of the contract, according to which the farmer decides the scale of planting. Suppose the main parameters are as follows:

$c$ —— unit planting cost of farmer;

$w$ —— wholesale price per product;

$p$ —— retail price per product;

$q$ —— yields decided by the farmer;

$t$ —— real temperature in selling season;

$t^*$ —— the threshold value of $t$ to activate the compensatory contract;

$d(t)$ —— distribution density of market demand at temperature $t$;

$f(t)$ —— probability density function of temperature $t$;

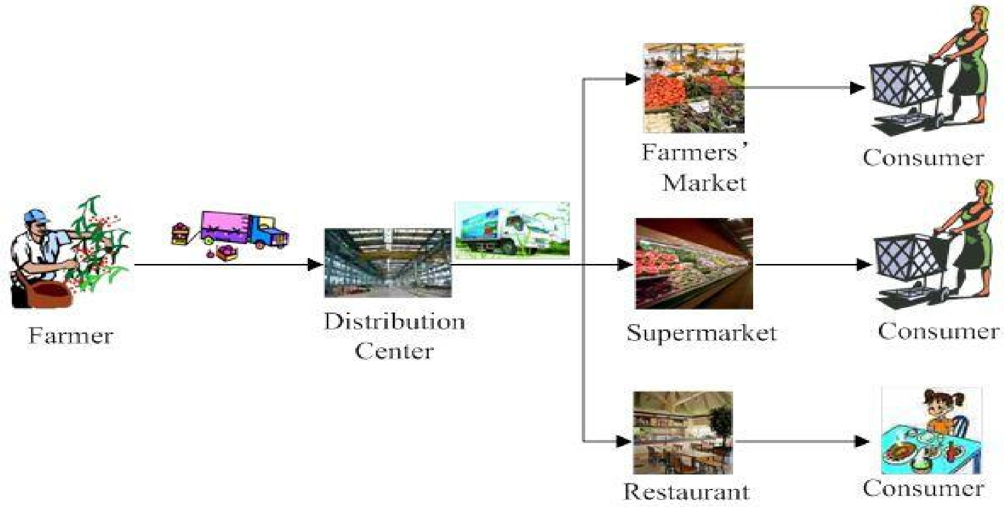


**Figure 1.** Farmer- distribution center supply chain

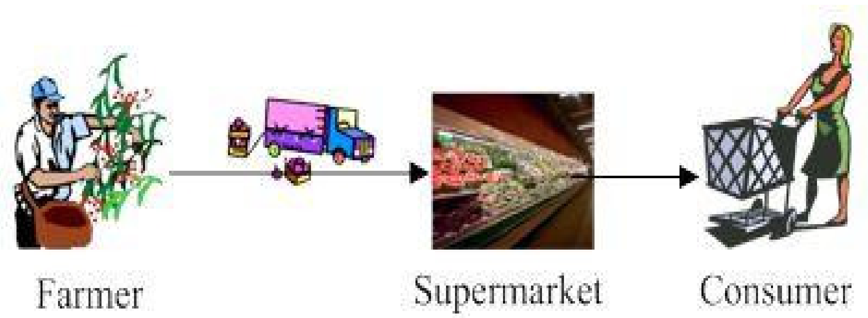


**Figure 2.** Farmer- supermarket supply chain

$D(t,u)$ —— demand function, influenced by temperature $t$ and random variable $u$.

Suppose that $c < w < p$ according to normal conditions of agricultural products. Set the values of $c$, $w$ and $p$ all depend on market and value for surplus products is zero. Because agricultural products circulate fast and are perishable, the retailer orders the products in time according to sales. The order quantities of retailer are equal to demands or yields (if the yields are less than demands) so that there are no surplus products in the retail market. Otherwise, the surplus products will emerge in the farm if the orders from the retailer are less than yields. That means the farmer has to face the risk of dull sale because of planting too much. The influence of extreme weather on yields and demands are not considered in this paper. The acreage of planting is not considered since the farmer can transfer the yields to planting acreage easily.

## Models without compensatory contract

The situation without compensatory contract is demonstrated in order to compare contrastively the results with compensatory contract and without compensatory. The farmer will choose the historical demands as his production $q_d$. Therefore, the expected profits of farmer and retailer are individually shown as equation (1) and equation (2):

$$\pi_p^d(q) = E[w \cdot min(D(t,u), q_d)] - cq_d \quad (1)$$

$$\pi_r^d(q) = E[(p-w) \cdot min(D(t,u), q_d)] \quad (2)$$

$\pi_p^d(w)$ —— farmer's expected profit without compensatory contract;
$\pi_r^d(w)$ —— retailer's expected profit without compensatory contract.

Assume there is no loss of out of stock for retailer and farmer for the convenience of calculation. However, the retailer would like to take some actions to stimulate the farmer to plant more products properly for the sake of acquiring more profit.

### Models with compensatory contract

The retailer is able to get the forecast of average temperature in the forthcoming selling season before the planting time, according to which he can foresee the sales volume through historical data. In order to encourage the farmer's initiatives in planting, the retailer signs compensatory contract with the farmer before the farmer decides his planting area. The compensatory contract is $K(t^*,q)$ in equation (3).

$$K(t^*,q) = \begin{cases} 0 & t \geq t^* \\ k(t,q) > 0 & t < t^* \end{cases} \tag{3}$$

Here $k(t,q)$ is non-increasing in both $t$ and $q$. According to the contract, the retailer will compensate farmer with $k(t,q)$ if the real temperature $t$ is lower than the threshold value $t^*$ and vice versa. The threshold value $t^*$ is a constant during the whole selling season. In fact, even though the farmer cannot acquire compensation if the real temperature is higher than $t^*$, his profit is guaranteed because of the increasing of sales. The farmers' expected profit with compensatory contract is:

$$\pi_p(q) = E[w \cdot min(D(t,u),q)] - cq + E_{t<t^*} k(t,q) \tag{4}$$

$$E_{t<t^*} k(t,q) = \int_{-\infty}^{t^*} k(t,q) f(t)\,dt$$

Where is the compensation that the farmer receives from retailer. Therefore the expected profit of the retailer is:

$$\pi_r(q) = E[(p-w)\cdot min(D(t,u),q)] - E_{t<t^*} k(t,q) \tag{5}$$

And the expected profit of the supply chain is:

$$\pi_s(q) = E[p \cdot min(D(t,u),q)] - cq \tag{6}$$

Suppose $q_s$ is the yield of farmer which maximize the expected profit of supply chain $\pi_s(q)$, that is, $q_s$ is the yield to coordinate the supply chain. There exist a $q_s$ if assuming $\pi_s(q)$ is continuous in $q$, even though there may be several maximum values of $\pi_s(\cdot)$.

### Supply chain coordination with weather compensatory contract

#### Supply chain coordination

It will be analyzed in this sub-section that the supply chain coordination can be achieved through weather compensatory contract. Impose a constraint of minimum yield $\Lambda$ on the farmer considered that he has basic yield in most conditions. He can gain the compensatory only for the part of yield which is beyond $\Lambda$. The new contract with $\Lambda$ is:

$$\int_{-\infty}^{t^*} k(t,q) f(t)\,dt = (p-w)(q-\Lambda)^+ \tag{7}$$

Make an assumption that $\Lambda \leq q_s$, then the farmer's expected profit is:

$$\begin{aligned}\pi_p(q) &= E[w\cdot min(D(t,u),q)] - cq + (p-w)(q-\Lambda)^+ \\ &= E[w\cdot min(D(t,u),q)] + (p-w-c)q - (p-w)\Lambda\end{aligned} \tag{8}$$

The retailer's expected profit is:

$$\pi_r(q) = E[(p-w)\cdot min(D(t,u),q)] - (p-w)(q-\Lambda)^+ \tag{9}$$

The expected profit of supply chain is unchanged:

$$\pi_s(q) = E[p \cdot min(D(t,u),q)] - cq$$

In such a condition, the supply chain will be coordinated easily. What is needed is that the farmer chooses a suitable $q$ to maximize $E[w\cdot min(D(t,u),q)] - cq$.
The concrete structure of the compensatory contract can be very flexible under the constraints of (3) and (7). Therefore, the retailer can choose the structure of $k(t,q)$ and value of $t^*$ by himself, or value them by negotiation with the farmer.

#### Confirmation of minimum yield

The objective of compensatory contract is to stimulate the farmer to plant appropriately more through transferring part of retailer's profit to farmer. The weather compensatory contract in equation (7) can help to achieve supply chain coordination with any given $w$.

However, if the wholesale price is cut down because of compensatory contract, the farmer will not want to accept the contract probably. So it should be ensured that the wholesale price is in the compensatory contract $w = w_d$. Here $w_d$ is the wholesale price without compensation.

The farmer can expect higher profit under any forms of compensation if $w = w_d$. He could prefer to plant the same area of products with yield of $q_d$ if he doesn't like the compensatory scheme, or he could plant more to increase yield and bear the possible risk of dull sale if he agrees with the compensation. The farmer's expected profit become poor if he agrees with the compensatory scheme but $\Lambda$ is very high.

The range of $\Lambda$ in the compensatory contract under constraints (3) and (7) should be found in order to realize Pareto improvement. Two conditions $\Lambda = q_d$ and $\Lambda = [\pi_s(q_s) - \pi_p^d(w)]/(p-w)$ are considered individually. As analyzed above, $q_d$ and $\pi_p^d(w)$ are the farmer's optimal yield and expected profit without compensation.

The farmer will choose his yield $q = q_s$ if $\Lambda = q_d$. Under such situation, the retailer's expected profit $\pi_r^d(w)$ still equals to $E[(p-w)\cdot min\,(D(t,u),q_n)]$, while the farmer's expected profit increases because

$$\pi_p(q_s) = E[w \cdot min(D(t,u),q_s)] - cq_s + (p-w)(q_s - q_d) \geq E[w \cdot min(D(t,u),q_d)] - cq_d = \pi_p^d(w)$$.

This means the farmer gets all the incremental channel profit. Noted that the retailer's expected profit will be lower than that without compensation if $\Lambda < q_d$. It is impossible for retailer to make such a choice. Hence, $\underline{\Lambda} = q_d$ is the lower limit of $\Lambda$ to realize Pareto improvement.

When $\Lambda = [\pi_s(q_s) - \pi_p^d(w)]/(p-w)$, it can be proved that $\Lambda = [\pi_s(q_s) - \pi_p^d(w)]/(p-w) \geq q_d$ because

$$\pi_s(q_s) - \pi_p^d(w) = E[p \cdot min(D(t,u),q_s)] - cq_s - E[w \cdot min(D(t,u),q_d)] + cq_d \geq (p-w)q_d$$

. Under such situation, the retailer gets all the incremental profit, while the farmer's expected profit is still the same with that without compensation. The farmer can't acquire any benefit from the compensatory scheme for any $\Lambda = [\pi_s(q_s) - \pi_p^d(w)]/(p-w)$. Hence $\bar{\Lambda} = [\pi_s(q_s) - \pi_p^d(w)]/(p-w)$ is the upper limit to realize Pareto improvement.

It is valid for the compensatory contract only when it meets the requirement in equation (7) and the value of $\Lambda$ is set within the range $(\underline{\Lambda}, \bar{\Lambda})$

**Decreasing the risks of both sides with compensatory contract**

There are two methods for the retailer to control his weather risks: choosing the suitable parameters of weather compensatory contract or purchasing weather derivatives. Only the first method is analyzed in this paper.

**Controlling retailer's risk**

The expected profits of the retailer and farmer will not vary with the change of $t^*$ only if $K(t^*,q)$ can meet equation (7). However, the assignment of profits are affected by $t^*$. Therefore the value of $t^*$ should be confirmed according to the risk attitude of both sides or by negotiating so as to adjust the assignment of profits. For example, the high value of $t^*$ is equivalent that the retailer sells all the products exceeding $q_d$ with discount price, while with low value of $t^*$, the farmer will be interested in the weather compensatory contract only when the compensatory is high enough.

When the retailer constructs the compensatory contract, he may add a constraint of probability as in equation (10) to ensure his benefit.

$$Prob\{E[(p-w)\cdot min(D(t,u),q)] - E_{t<t^*}k(t,q)[(p-w)\cdot min(D(t,u),q_d)]\} \leq \gamma \quad (10)$$

In equation (10), $\gamma \in (0,1)$ is set by retailer beforehand. The value of $\gamma$ is related directly with the retailer's risk attitude. Set the compensatory equation is shown as in equation (11).

$$K(t^*,q) = k \cdot (t^* - t)^+ \cdot (q - \Lambda)^+ \quad (11)$$

If $q \geq \Lambda$, the compensatory can be re-defined with equation (12).

$$t^* \leq F^{-1}(1-\gamma) - (p-w)(q-q_d)/[k \cdot (q-\Lambda)] \quad (12)$$

The compensatory become what as shown in equation (13) when specially $\Lambda = q_d$.

$$t^* \leq F^{-1}(1-\gamma) - (p-w)/k \quad (13)$$

Under such situation, the retailer can control his risk though set the value of $t^*$.

In order to analyze the impacts of $t^*$ on assignment of profits, raisen the threshold of temperature to $t^{**}$ ($t^{**} > t^*$). The new compensatory is more than old one, which is shown in equation (14).

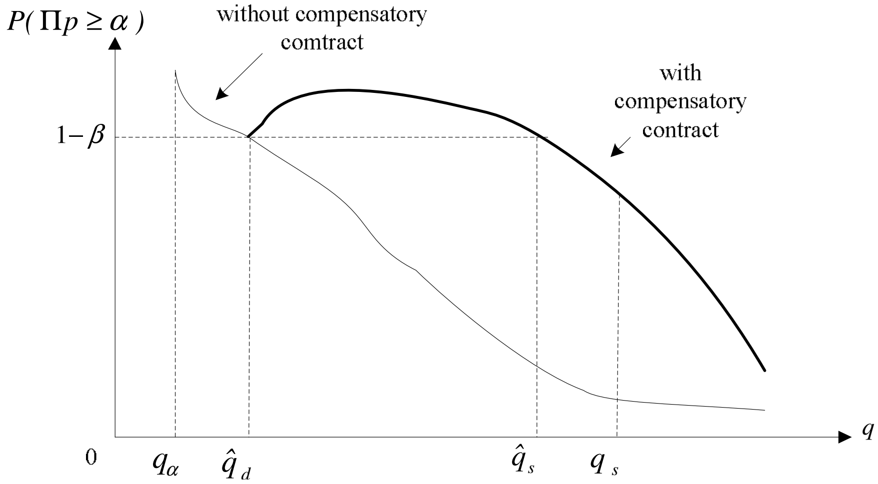


**Figure 3.** The probability curves of farmer's expected profits with and without compensatory contract (Chen and Yano, 2010)

$$\int_{-\infty}^{t^{**}} k(t,q)f(t)dt > \int_{-\infty}^{t^{*}} k(t,q)f(t)dt = (p-w)(q-\Lambda)^{+} \quad (14)$$

The farmer will get more profit under such condition. Otherwise, the retailer will get more profit if $t^*$ is low enough. Equation (14) reflects the influences of $k$ on assignment of profits, the farmer will get more expected profit if $k$ is increased and other parameters are unchanged. When $k$ is big enough and $t^*$ is decreased, volatility of farmer's profit will become greater. That means the farmer will get more compensation each time with less times. The volatility of retailer's profit will become greater too for the same reason.

The retailer can also hedge or transfer his weather risk through purchasing weather option or weather insurance so that his risk is double controlled.

### Controlling farmer's risk

The farmer would like to increase the planting area to get more yield only when the compensation is attractive enough. If there is not enough compensation, the farmer will have to bear the risk of dull sales by himself once he increases the yield but doesn't receive more order.

Because the farmer can't decide the parameters of the compensatory contract directly, the retailer has to enable the compensation to decrease farmer's risk to induce him to accept the contract. The object can also be achieved through modifying the basic contract. Add a constraint for farmer's risk so that the probability of his expected profit isn't lower than threshold value $\alpha$ is higher than $\beta$. When there is no compensation, the farmer's expected profit is:

$$\max\ \pi_p^d(q) = E[w \cdot min(D(t,u),q)] - cq$$
$$s.t.\ \Pr\{\Pi_p^d(q) \le \alpha\} \le \beta \quad (15)$$

Here $\Pi$ is the random variable of profit.

Gan et al. (2005) find that the constraint (15) is invalid if $q$ is so small as to $q < q_a = \frac{a}{p-w}$. The probability of getting a profit more than $a$ for farmer will low with the increase of $q$ if $q$ is higher than a critical value, as shown with the thin curve in figure 3. So the optimal yield is $\hat{q}_d = \min\{q_d, \bar{q}_d\}$, in which $\bar{q}_d = \max\{q: \Pr\{\Pi_p^d(q) \le \alpha\} \le \beta\}$.

If there is compensatory, as discussed in section 3.2, the farmer's profit is shown in equation (16) with the assumption of $\Lambda = \hat{q}_d$.

$$\max\ \pi_p(q) = E[w \cdot min(D(t,u),q)] - cq + (p - w)(q - \hat{q}_d)^{+} \quad (16)$$
$$s.t.\ \Pr\{\textstyle\prod_p(q) \le \alpha\} \le \beta \quad (17)$$

As has been noted that $q_s$ is the farmer's optimal yield when there is compensatory contract. It is sure that $q_s \ge \hat{q}_d$ because the compensatory is always beneficial to the farmer. If $q_s$ can meet the farmer's demand of risk control, it is necessary to go in for proving continually, otherwise it should prove the existence of the optimal yield $\hat{q}_s$.

According to the monotonic decreasing of $\Pr\{\Pi_p^d(q) \le \alpha\}(q \in [\hat{q}_d, q_s])$, the continuity of $\Pr\{\prod_p(q) \le \alpha\}$, and $\Pr\{\Pi_p^d(\hat{q}_d) \le \alpha\} = \Pr\{\prod_p(\hat{q}_d) \le \alpha\}$, it can be deduced that the probability curve of farmer's expected profit with compensatory contract can be expressed with the thick curve in figure 3. As shown in figure 3, A $\hat{q}_s \in [\hat{q}_d, q_s]$ exists to meet $\Pr\{\prod_p(q_s) \ge \alpha\} = 1 - \beta$, that is,

$\mathrm{Pr}\{\prod_p(q_s) \leq \alpha\} = \beta$. The farmer's optimal yield is $\hat{q}_s$ and his demand on risk control can be satisfied.

The farmer may control his risk by decrease planting area if $\Lambda > \hat{q}_d$. He will not accept the compensatory contract if $\Lambda$ is too high, which is same with that in the situation without compensatory contract. This explains the danger for the retailer to choose a high $\Lambda$.

## Conclusions

This paper studies the compensatory contract designed by retailers for farmers. This kind of contract can help to coordinate supply chain and adjust the assignment of profits between the retailer and farmer. It will not discourage the retailer's marketing efforts and can stimulate the farmer's planting activity. This kind of contract is very flexible because several parameters are variable, including threshold temperature, the minimum yield and the contract compensatory style. These parameters can be adjusted according to the risk attitudes of both sides. At the same time, the retailer can avoid risk through purchasing risk derivatives. Therefore, it is feasible to realize the weather compensatory contract. The retailers with great foresight can design such kind of weather compensatory contract to attract farmers to ensure the supply of products and then to achieve more competence and profits.

However, there are several defects in this paper. On the one hand, this paper doesn't propose the method to determine the parameters in the contract. The determination of these parameters is very complicated and worth to be studied continually. On the other hand, this paper only studies the weather compensatory contract based on temperature but not other weather indices. These will be studied continually in the future. It is another future research direction about how the retailers choose the weather derivatives or how the financial service firms supply weather derivatives to the retailers.

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