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Futures Hedging on Both Procurement Risk and Sales Risk Under Correlated Price and Demand

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Abstract. Futures hedging has played a pivotal role to mitigate the operational risks embedded in the uncertain business environment. It is common to use input commodity futures to hedge procurement risk or use output commodity futures to hedge sales risk. Due to the rapid development of the commodity markets, an increasing variety of commodities can now be exchanged. It is possible for commodity processors to hedge both the procurement risk and sales risk simultaneously. This study develops a both-end-hedging approach to hedge the operational risks under a positive correlation between procurement price and sales price, and a negative correlation between sales price and customer demand. We consider a risk-averse commodity processor that procures input commodity and sells output commodity in the spot markets, while hedging both the procurement sales risks via the commodity markets. The objective includes the expected profit and its risk exposure. A stochastic programming model is developed to implement the approach on a typical corn-ethanol plant in the U.S.. The results show that a significant improvement can be obtained compared with traditional single-end-hedging approaches and that the proposed approach is robust in various circumstances.

Keywords: Operational Management; Financial Hedging; Risk Management; Stochastic Programming.

1 Introduction

Due to the growing operational risks existed in today's fast-changing business environment, manufacturers have an increasing concern of the risk exposures to their profits. They are looking for various methods to mitigate the risk exposures. They start from operational methods such as procurement management and inventory control. After the value of financial hedging to a nonfinancial corporation is recognised, financial instruments are also included and integrated with operational methods to mitigate the risk exposures. One of the widely used financial instruments is the commodity futures traded in the commodity markets. Traditionally, users of the commodities can use the futures to hedge their procurement risk, and producers of the commodities can use the futures to hedge their sales risk, respectively. Such a single-end-hedging approach has been applied for a long time.

Along with the rapid development of the commodity markets and information technology, an increasing variety of commodities can now be exchanged in these markets. An interesting phenomenon emerging with the development is that both the input and output commodities of a commodity processor might be simultaneously traded in the commodity markets. For example, corn is the input material for producing ethanol used in fuels. Since the launching of ethanol futures in the Chicago Board of Trade (CBOT) on April 1, 2005, both corn and ethanol futures have been traded in the CBOT. Therefore, it is now possible for some commodity processors to hedge both their procurement risk and sales risk simultaneously via trading futures on both their input and output commodities in the commodity markets.

This study aims to develop an approach that could utilise such an opportunity to better manage the operational risks. It considers a risk-averse commodity processor that procures input commodity and sells output commodity in the spot markets. The operational risks addressed in this study include the uncertain procurement price, sales price and customer demand. In order to control these risks, futures hedging is performed by trading both the input commodity futures and the output commodity futures in the commodity markets. To reflect the risk-aversion of the processor, the objective function is composed of both expected profit and risk exposure. Operational decision on spot procurement and financial hedging decisions on input futures position and output futures position are to be optimised in respect of the objective function.

Specific issues are addressed in this study for developing such a both-end-hedging approach. Firstly, as the input commodity is the main raw material of the output commodity, the input commodity price and the output commodity price should be considered positively correlated. Secondly, for short-term planning, exogenous output price and demand are generally considered negatively correlated in economics, which is also a common observation in practical economy. Therefore, this study examines how the proposed both-end-hedging approach could benefit the processor under these correlations that need to be addressed.

2 Literature Review

Financial hedging has received growing attention in the operational management literature. Gaur and Seshadri address the problem of hedging inventory risk based on a single-period inventory model in which the demand is correlated with the price of a financial asset [1]. Caldentey and Haugh propose an integrated modelling framework for making operational and financial decisions of a nonfinancial corporation that also trades in financial markets [2]. A stochastic programming approach for procurement and inventory replenishment planning in the presence of commodity market is developed by Xu, in which both expected profit and risk exposure are included in the objective [3]. Chen et al. also show how to manage inventory risk through financial instruments in a partially complete market for a risk-averse decision maker [4]. Ding et al. explore the production and financial hedging decisions under a foreign currency exchange rate risk [5]. Goel studies the procurement policies in the presence of commodity markets for different supply chain structures [6]. These studies mainly focus on the financial hedging effect from the perspective of procurement management or inventory control. The risks addressed in these studies mainly come from the volatility of the input commodity price and the uncertain customer demand. Hedging by means of commodity futures is not applied to hedging sales price risk.

Recent researchers have started to investigate the commodity processing problem in which both input and output are commodities. Plambeck and Taylor consider a problem where the commodity processor is a price taker for both input and output commodities and the input price and output price are correlated [7]. They develop a single-period profit maximization model in the absence of financial hedging. Goel and Tanriserver include financial hedging into the operational problem in which the futures on both input and output commodities are both traded in commodity markets [8]. Besides the correlation between input price and output price, they also consider a negative correlation between the demand and price of the output commodity. They establish a model to maximize the value of stakeholders of the commodity processor by jointly determining the operational policy and financial hedging ratio. However, they only focus on hedging the sales price risk instead of simultaneously hedging both the procurement and sales risks. Moreover, they only consider systematic risk by discounting future cash flows instead of including a comprehensive risk measure in the objective.

So far as we know, there has been no previous research that integrates operational decisions and financial hedging decisions on both input and output commodity futures trading. This study intends to fill this research gap and develop an approach for commodity processors to hedge both the procurement risk and sales risk simultaneously by optimising the operational and futures hedging decisions in a holistic manner.

3 The Both-end-hedging Model

3.1 Problem Framework

This study proposes a novel both-end-hedging planning approach for the commodity processors to deal with the operational risks. We consider a problem framework that a commodity processor procures input commodity from the spot markets to produce output commodity and sell it to downstream retailers. Besides spot trading, the processor would also like to hedge the procurement risk and sales risk through trading futures in the commodity markets.

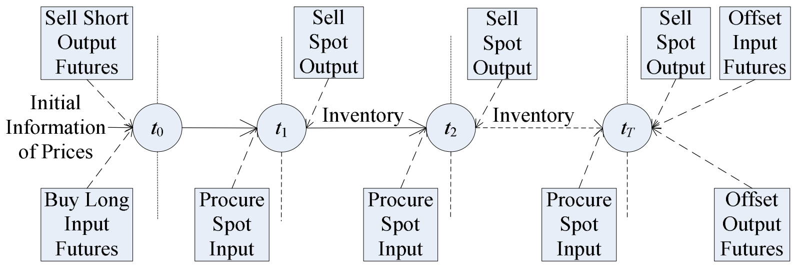

Fig. 1. The Decision Sequences

A multiperiod planning model involving operations and futures hedging is developed under this framework, as illustrated in Fig. 1. Procurement price risk and sales price risk are to be hedged during the planning horizon from time point t_0 to time point t_T. Each time point represents the ending of the previous period and the beginning of the next period. At the beginning of the planning horizon, initial information about the spot and futures prices of both input and output commodities are observed. Then the processor decides on the position of long input futures to buy and the position of short output futures to sell at t_0. At each time point from t_1 to t_T, the processor must also decide on the spot procurement of the input commodity for the next period after observing the procurement price at that time. Notice that this decision must be made before the realisation of the sales as the processor has to respond to customer demand promptly. Excess inventory of the output will be stored to fulfil future demand and incur a holding cost. Excess demand will be lost. At the end, both the input and output futures are offset at t_T to complete the hedging. A typical corn-ethanol plant in the U.S. is employed as an example.

3.2 Corn-Ethanol Industry in the U.S. and Model Assumptions

Ethanol is an alcohol fuel that could be derived from starch or sugar-based feedstock. As the largest corn production country in the world, the U.S. has encouraged this renewable fuel production since 2007 to reduce the reliance on fossil fuels import [9]. According to the U.S. Department of Agriculture (USDA), ethanol production accounts for 45.6% of domestic use of corn in the year 2011/2012. On the other hand, 93.9% capacity of ethanol production uses corn as the main input. Therefore, corn price and ethanol price have been positively correlated with each other. Based on the capacity data published by the Renewable Fuels Association (RFA), the corn-ethanol industry in the U.S. is quite competitive. Therefore, any ethanol plant is assumed a price-taker for both input price and output price.

Some research concerns the transportation of corn and ethanol [10]. A vast majority of corn procured by ethanol plants is grown within a radius of about 50 miles. As ethanol has an affinity for water, most ethanol is distributed by truck or rail instead of through pipelines. This results in almost 10 times higher transportation cost for ethanol as compared to gasoline [11]. Therefore, it is assumed that the ethanol plant sells ethanol only to nearby retailers and the transportation cost and lead time are ignored. Due to the high transportation cost of ethanol, the plant prefers to carry excess inventory into subsequent periods as compared to shipping the inventory to distanced retailers. Excess inventory incurs an extra holding cost. As most ethanol plants in U.S. are concentrated in the Midwest and close to each other as implied by the corn procurement radius, the retailers could easily turn to another nearby ethanol plant when their demand could not be fulfilled. Therefore, excess ethanol demand that could not be fulfilled in current period is assumed lost.

After production, ethanol is sold to downstream retailers and finally consumed by vehicle owners. As the vehicle owners have multiple choices of their fuel among ordinary gasoline and gasoline mixed with various percentage of ethanol, ethanol demand could be quite price elastic as ethanol is competing with fossil fuel. Luchansky has investigated the price elasticity of demand of ethanol in the U.S. [9]. The empirical study concludes a significant negative correlation between the price and demand of ethanol. Therefore, this study models the price and demand of ethanol under a negative correlation with the concept of elasticity.

Referring to the contract specifications in the CBOT, corn futures contracts mature on the business day prior to the fifteenth calendar day of the delivery month, and ethanol futures contracts mature on the third business day of the delivery month. Therefore corn futures contracts and ethanol futures contracts would never mature at the same day. Under this situation, the corn futures contract that matures at the end of planning horizon, and the first ethanol futures contract to mature after the end of planning horizon are adopted for the hedging. The contracts are also assumed settled in cash instead of physical delivery, as a common practice in commodity markets. In addition, certain managerial constraints can be imposed on the financial hedging decisions. Since the plant holds the futures to mitigate the risk exposure instead of speculating, the input or output futures positions should be no more than the accumulated expected spot procurement or demand, respectively. To model the behaviour of the risk-averse processor, a constraint could be placed on the downside risk exposure expressed by an appropriate risk measure.

3.3 Stochastic Programming and Conditional Value-at-Risk

Under the problem framework and decision sequences, there are five random events evolving through time: input spot price, input futures price, output spot price, output futures price, and customer demand. Stochastic programming (SP) is suitable to model such sequential decision processes under uncertainty. It performs the optimisation under an objective function of expected value [12]. The SP problem could be transformed to its equivalent deterministic linear programming problem and then solved with well developed simplex algorithm.

For a risk-averse decision maker, expected profit maximisation has no longer been the only concern. Risk exposure should also be measured and considered in the evaluation. In this study, Conditional Value-at-Risk (CVaR) is employed to measure the risk exposure. It could be integrated into the objective function by a weighted linear combination with the expected profit [13]. By optimising the overall objective function, the expected profit and risk exposure could be optimised simultaneously.

3.4 Model Formulation

Decision Variables

i_0: Position of long corn futures to be taken (Bushel).

x_t: Corn procured from spot markets in period t (Bushel). t□$\{1,...,T\}$

o_0: Position of short ethanol futures to be taken (Gallon).

State Variables

i_T: Position of corn futures to be offset (Bushel).

o_T: Position of ethanol futures to be offset (Gallon).

I_t: Inventory or lost sales of ethanol in period t (Gallon). t□$\{0,...,T\}$

I_t^+: Ethanol inventory in period t (Gallon). t□$\{0,...,T\}$

I_t^-: Lost sales of ethanol in period t (Gallon). t□$\{0,...,T\}$

z: $\max(L-VaR,0)$, the possible loss excess of VaR (USD).

Parameters

T: The amount of periods in the planning horizon.

f_{it}: Corn futures price at each time point (USD/Bushel). $t\in\{0,...,T\}$

f_{ot}: Ethanol futures price at each time point (USD/Gallon). $t\in\{0,...,T\}$

s_{it}: Corn spot price at each time point (USD/Bushel). $t\in\{0,...,T\}$

s_{ot}: Ethanol spot price at each time point (USD/Gallon). $t\in\{0,...,T\}$

d_t: Demand for ethanol in each period (Gallon). t□$\{1,...,T\}$

γ: Production yield from corn to ethanol (Gallon/Bushel).

h: Ethanol holding cost for one period (USD/Gallon).

θ: Weight factor of CVaR in the objective function.

α: Confidence level.

A: Upper bound on CVaR (USD).

P: Long-term average value of spot price of ethanol (USD/Gallon).

D: Long-term average value of ethanol demand (Gallon).

e: Price elasticity of demand of ethanol.

ε_t: Random part of the ethanol demand in period t (Gallon). t□$\{1,...,T\}$

Objective

$$\min \quad O = \mathrm{E}[L] + \theta CVaR \tag{1}$$

$$L = i_0 f_{i0} - o_0 f_{o0} + \sum_{t=1}^{T} (x_t s_{it} - (d_t - I_t^-) s_{ot} + h I_t^+) - i_T s_{iT} + o_T f_{oT} \qquad (2)$$

$$d_t = \frac{e(s_{ot} - P) + (s_{ot} + P)}{(s_{ot} + P) - e(s_{ot} - P)} D + \varepsilon_t, t \in \{1, \cdots, T\} \qquad (3)$$

As both the expected profit and risk exposure are to be optimised, the objective function could be expressed as a linear combination of the expected value of loss and a weighted CVaR, as in Eq. (1). Loss (*L*) is the opposite of profit, and *CVaR* is the measure of risk exposure. In this way, both the expected profit and risk exposure could be simultaneously optimised by minimizing the objective function *O*. Equation (2) defines *L* as the expense of buying long input futures, procurement cost, inventory cost and offsetting output futures, minus the income of sales revenue, selling short output futures and offsetting input futures. Ethanol demand is calculated in Eq. (3)**Erreur ! Source du renvoi introuvable.** according to the definition of price elasticity. Long-term average value of the demand and price is used for identify the changes of the price and demand. A random part independent of the output price is added to the price-dependent part of the demand to reflect demand uncertainties as suggested in [14]. For convenience, the random part is assumed to follow a normal distribution with mean zero and standard deviation σ.

Constraints

$$I_0 = 0 \qquad (4)$$

$$I_t = I_t^+ - I_t^-, t \in \{0, \cdots, T\} \qquad (5)$$

$$I_t = I_{t-1}^+ + \gamma x_t - d_t, t \in \{1, \cdots, T\} \qquad (6)$$

$$i_0 = i_T, o_0 = o_T \qquad (7)$$

$$i_0 \le \sum_{t=1}^{T} \mathrm{E}(x_t), o_0 \le \sum_{t=1}^{T} \mathrm{E}(d_t) \qquad (8)$$

$$z = \max(L - VaR, 0) \qquad (9)$$

$$VaR + \mathrm{E}[z]/\alpha \le CVaR \qquad (10)$$

$$CVaR \le A \qquad (11)$$

$$\text{All } x_t, i_0, o_0, I_t^+, I_t^- \ge 0 \qquad (12)$$

Equations (4)-(6) reflect the possible inventory or lost sales due to the uncertain demand and the inventory balance between successive periods. Equations in (7) are to ensure all the futures taken are offset in the end. The inequalities in (8) prevent the plant from over speculating in the financial market by constraining the input hedging position within expected total spot procurement and constraining the output hedging position within expected total demand. It is ensured that CVaR is minimized simultaneously by Eqs. (9)-(11).

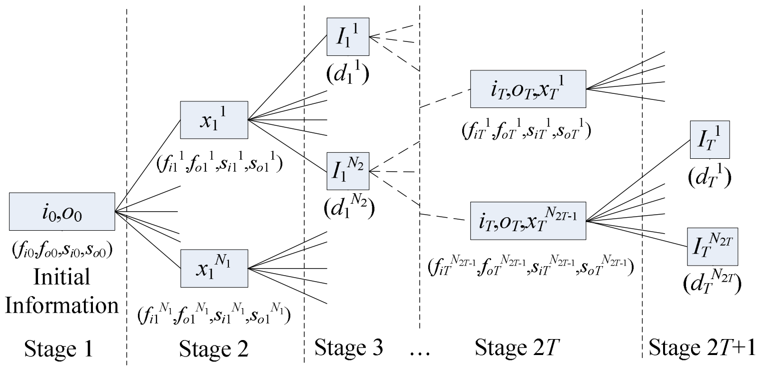

Fig. 2. The Multistage Structure of the Scenarios

4 Implementation

4.1 Scenarios Generation

The stochastic programming model is implemented on a typical ethanol plant in the U.S.. An appropriate generation of scenarios that accurately reflect the stochastic properties of the random events is fundamental to a successful SP. Figure 2 illustrates a multistage structure of the scenarios. At Stage 1, initial information about the spot and futures prices is observed and the first stage decisions on input futures position i_0 and output futures position o_0 are made. Stage 2 decisions on spot procurement x_1 are made at each node on N_1 branches according to the realisations of current stage random events. The random customer demand d_1 is realised in Stage 3 and possible inventory or lost sales is ascertained. The scenarios generation process repeats as at Stage 2 and Stage 3 until the end of the planning horizon when the futures are offset.

Consider a situation that the decision maker would like to make a plan on November 15, 2013. Five years' historical futures price data collected from the CBOT are used to model the stochastic commodity prices to generate the scenarios. As there are no spot trading of corn or ethanol in the CBOT, the spot prices are unobservable. A two-factor model developed by Gibson and Schwartz has been demonstrated an effective approach to model the commodity prices when only the futures price is observable [15]. State space form and Kalman filtering are then applied to estimating the parameters of the two-factor model with the historical data [16]. Then scenarios of the correlated prices could be generated with Latin hypercube sampling (LHS) [17]. The normal distributed random part of the demand could be discretized to generate the scenarios of the customer demand [18].

4.2 Stochastic Programming

To evaluate the effectiveness of the proposed both-end-hedging approach, numerical experiments are designed for comparing the results obtained from the proposed model to the results obtained from traditional models. The traditional models include no-hedging model, sales-hedging model, and procurement-hedging model. The four models are implemented in stochastic programs with practical parameters from the corn-ethanol plant example. Constant values are assigned to the parameters as in Table 1. To examine the robustness of the proposed approach, various scenarios and parameter values are applied to the experiments. We adopt a planning horizon with two periods each containing two weeks.

Table 1. Values Assigned to SP Parameters

Notation	Value	Notation	Value
γ	2.85 Gallon/Bushel	P	2.3587 USD/Gallon
h	0.0004 USD/Gallon	D	2.4 Million Gallon/Week
θ	2	e	−2
α	0.01	σ	0.12 Million Gallon
A	−300,000 USD		

4.3 Results

The optimal results obtained from the four models are shown in Table 2. The both-end-hedging model improves the objective value by 53.81%, 52.25%, and 23.99% as compared with no-hedging model, sales-hedging model and procurement-hedging model, respectively. Particularly, downside risk exposure is largely mitigated as indicated by a much lower CVaR. A small portion of expected profit is surrendered for a trade-off with risk mitigation. The optimal hedging ratios show that much stronger hedging is imposed on both the procurement end and the sales end in the both-end-hedging model compared to single-end-hedging models.

Table 2. Optimal Results of the Four Models

Results	No-hedging	Sales-hedging	Procurement-hedging	Both-end-hedging

Objective Value($)	−3041901	−3072929	−3773499	−4678640
CVaR($)	−362628	−400464	−706991	−1242020
Expected Profit($)	2316645	2272001	2359517	2194600
Input Futures(Bushel)	Null	Null	1488789	1936190
Input Hedging Ratio	Null	Null	48.46%	63.01%
Output Futures(Gallon)	Null	982309	Null	3970403
Output Hedging Ratio	Null	10.83%	Null	43.79%

Besides the strengthening of the hedging on both ends, it could also be noticed that the improvement on the objective value in the both-end-hedging model is even better than those in the two single-end-hedging models added together. This implies that the proposed approach is not a simple addition of the single-end-hedging approaches. There is a synergy achieved between the hedging activities on each end in the proposed model.

Another noticeable result is that both the expected profit and risk mitigation are improved in the procurement-hedging model instead of a trade-off between them as in other models. It must be pointed out that such an advantage is just due to the underlying price trend as shown in Table 3. The scenarios applied to the above experiments have a rising price trend. As a result, trading long input futures would contribute to the expected profit while mitigating the risk exposure. Table 4 shows the results when the scenarios with a falling price trend in Table 3 are applied to the experiments. It turns out that the sales-hedging model becomes more effective than the procurement-hedging model under the falling price trend. This implies that the price trend will affect the effectiveness of single-end-hedging models. For a commodity processor using single-end-hedging approach, the decision maker may better have some knowledge on the price trend to choose the appropriate futures for hedging. On the contrary, due to the synergy between the hedging on both ends, the effectiveness of the proposed approach is not affected by the price trend and significant improvements are obtained under both price trends.

Table 3. Price Trends of Different Scenarios

Prices	Rising Trend	Falling Trend
Input Futures Taken($/Bushel)	4.220	6.000
Input Futures Offset($/Bushel, Expected)	4.254	5.932
Output Futures Taken($/Gallon)	1.668	2.500
Output Futures Offset($/Gallon, Expected)	1.713	2.445

Table 4. Optimal Results of the Experiments Under a Falling Price Trend

Results	No-hedging	Sales-hedging	Procurement-hedging	Both-end-hedging
Objective Value($)	−1765225	−2283241	−1869160	−3684854
CVaR($)	−53864	−268526	−113112	−977976
Expected Profit($)	1657497	1746190	1642936	1728902
Input Hedging Ratio	Null	Null	14.76%	70.52%

Output Hedging Ratio	Null	39.12%	Null	60.05%

Table 5. Optimal Results Under Various Price Correlations

Price Correlation	0.55	0.6	0.65	0.7	0.75
Objective Value Improvement(B to N)	70.9%	88.8%	71.7%	36.1%	26.3%
Objective Value Improvement(B to P)	33.3%	26.2%	31.1%	15.5%	17.2%
Input Hedging Ratio in B Model	73.4%	79.0%	82.0%	65.3%	56.0%
Output Hedging Ratio in B Model	52.0%	49.2%	56.5%	47.2%	40.6%

The effectiveness of the both-end-hedging approach is also examined under various correlations between the input and output prices. Various sets of scenarios with price correlations from 0.55 to 0.75 are applied to the both-end-hedging (B) model, procurement-hedging (P) model and no-hedging (N) model. The results are shown in Table 5. The improvements on the objective value are all significant (more then 15%) under these price correlations. This demonstrates the robustness of the proposed approach in various price correlations. It could also be noticed that, larger improvement might be obtained under a lower price correlation. This may be due to that a high price correlation provides a natural hedging on the price risks hence reduces the reliance on futures hedging, as indicated by the hedging ratios.

As the risk attitude might be different among individual decision makers, the effectiveness of the both-end-hedging approach is further examined in various θ values as shown in Table 6. A larger θ represents a more risk-averse attitude. The results show that the improvement obtained from the both-end-hedging model increases along with θ. When the decision maker takes risk mitigation as an more important goal, stronger hedging are imposed on both of the procurement end and the sales end as indicated by the hedging ratios and larger improvements are obtained. Notice that when θ is 0.1, the both-end-hedging model is reduced to a procurement-hedging model. Recalling the effect of the price trend discussed above, trading the input futures could contribute to the expected profit when there is a rising price trend. Therefore, only the procurement hedging is used when risk mitigation is not important. This implies that when there is a strong price trend, and/or the decision maker is not so risk-averse, the both-end-hedging model might become less effective or might even reduce to a single-end-hedging model.

Table 6. Optimal Results Under Various Risk Attitudes of the Decision Maker

Risk Attitude (θ)	0.1	0.5	1	2	5
Objective Value Improvement(B to N)	3.7%	13.0%	28.3%	53.8%	103. 6%
Objective Value Improvement(B to P)	0.0%	4.0%	12.1%	24.0%	42.6%
Input Hedging Ratio in B Model	67.9%	61.5%	62.6%	63.0%	63.8%
Output Hedging Ratio in B Model	0.0%	38.7%	42.7%	43.8%	44.6%

5 Conclusion

For a commodity processor whose input material and output product are both exchanged in the commodity markets, the both-end-hedging approach proposed in this study is demonstrated more effective than the traditional single-end-hedging approaches for risk-averse decision makers. It is the synergy amongst the decisions that distinguishes this proposed approach. The robustness of the proposed approach has also been validated in various price trends, price correlations and risk attitudes of the decision maker. Moreover, it is found that the proposed approach would be especially effective when the future price trend is difficult to predict and/or when the decision maker has a strong risk-averse attitude.

The approach proposed in this study could be extended in several ways. Firstly, more sources of risk could be addressed such as currency exchange rate. If currency exchange rate risk is addressed, the approach will be more applicable to international corporations in the globalising world. Secondly, other financial instruments such as options might be included in the hedging methods. As options contracts behave differently from futures contracts, new insights might be obtained if options are used. Thirdly, the approach could be extended to including several hedging periods. The processor can adjust the hedging positions in successive periods to utilise newly arrived information to achieve a better performance.

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