A Model for Commodity Hedging Strategies

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Abstract - Commodity prices are known to be volatile in general. The volatility of the commodity prices brings up challenges for the producers that use such commodities in their production. One challenge is to determine what prices companies will pay via different hedging strategies for the needed commodities over the production period. This paper presents a systems dynamics model that incorporates various dynamics for commodity market. This model is then used for developing an algorithm to simulate hedging strategies. How the system dynamics model along with the hedging simulation algorithm can help the producers with their hedging decisions is discussed.

Keywords: commodity market, hedging strategies, system dynamics modeling

1 Introduction and Problem Definition

Producers need different commodities in order to produce their products. Many kinds of commodities may go into a certain product. For example, a frozen food production requires the purchase of numerous food inputs, including wheat, sugar, poultry and flash-frozen vegetables, as well as various packaging materials. Key commodity inputs may come from a variety of suppliers and generally have different seasonal and cyclical price characteristics.

Commodity prices are known to be volatile [5] [7] [8]. The volatility of the commodity prices brings up challenges for the producers that use such commodities in their production. Fluctuations in the price of key inputs make it difficult for manufacturers to anticipate future costs and optimize production, which constrains profitability. Furthermore, producers that must purchase a wide range of commodities with differing supply/demand dynamics may face difficulty managing effective procurement and commodity hedging strategies.

In competitive markets, some producers may be able to purchase certain inputs at lower prices than others and subsequently reflect this difference in the price of their product. In turn, greater pricing flexibility gives the producer a competitive advantage over other producers, allowing it to gain market share and sustain greater gross margins as a result of lower purchase costs.

Producers continually seek ways to smooth volatility in input prices, more accurately forecast future costs or otherwise minimize the risk associated with fluctuating commodity prices. In order to overcome commodity price fluctuations, companies are using hedging for managing the risks that come due to volatile commodity market. Hedging has become a useful tool for producers to manage what prices they will pay for their raw materials over the production period. However, since a number of different contracts may exist for each commodity such as forward buys, toll agreements, relative value, and over varying time periods from 30 days to 3 years, hedging is complicated and the inherent risk of price fluctuation remains with the producers.

This paper presents a systems dynamics model that incorporates various dynamics for modeling the commodity market. Our objectives with the model include:

- Identify and integrate dynamics for understanding the overall commodity market.
- Develop a model for simulating different dynamics in the commodity market for the purpose of optimizing hedging activity.
- Develop a model for maximizing profit margins and minimizing the effect of price fluctuations.
- Address uncertainty and volatility of commodity cost through a risk variance approach.

We will then use the model to simulate hedging strategies. Our objectives with the hedging simulation include:

- Identify the key market dynamics affecting commodity prices and incorporate them into the model.
- Present the best possible commodity candidates for hedging together with price and amount to hedge.

2 Commodity Hedging Dynamics Considered

A producer company takes into account many internal and external impacts in making hedging decisions for required commodities.
Internal impacts include:

- Vertically integrated vs standalone producer
- Hedging strategy
- Overall business structure
- Marketing and promotional expenses (and how management views how such activity will affect demand for their product, and subsequently their expected purchase of the commodity)
- The company’s cost structure

External impacts on the industry/sector only include:

- Product positioning
- Industry conditions
- Average cost structure of the industry

External impacts (global) include:

- Geopolitical factors
- Global demand determinants
- Product substitution
- Technological innovation, new product development
- Shifts in consumer preferences
- Regulatory changes

Considering all above and possibly other impacts together, hedging decisions could be very complex. In this paper, we developed a conceptual model considering various dynamics of the commodity market assuming an unregulated, free market. Our objective is to model the overall commodity hedging system for a producer company by incorporating select internal and external dynamics for effective hedging of the needed commodities. We consider the following internal and external dynamics in the model:

- Product demand
- Product inventory
- Product manufacturing capability
- Product marketing strategy
- Product advertising strategy
- Product distribution capability
- Cost of product
- Product pricing strategy
- Commodity hedging strategy
- Cost of commodity
- Overall production and inventory of the commodity
- Demand to commodity
- Other macro dynamics that affect commodity prices

These dynamics are considered after extensive literature reviews on the commodity market [5] [6] [7] [8]. We believe these factors should be considered in hedging decisions and we incorporated them all in our model which we will present in Section 3. There are other dynamics we haven’t incorporated into the model to keep it simple. We will mention them together with how they can be incorporated in the decision later in the paper.

3 System Dynamics Model

This paper assumes the reader already has a broad understanding of system dynamics modeling [1] [11] [12]. System dynamics is a useful analysis tool for analyzing and studying the behavior of complex nonlinear dynamic systems by identifying the cause and effect relationships and the feedback control mechanism. In system dynamics, a system is represented by a closed-loop structure which models the relationship and feedback among system factors. A problem or a system is first represented as a stock and flow diagram. Stock shows the quantity of factor under study while flows demonstrate factors which come in and out to change the stock level [1].

The system dynamics (SD) model for the commodity market considering the dynamics mentioned in the previous section is shown in Figure 1 and Figure 2 where Figure 1 showing part 1 and Figure 2 showing part 2 of the same model. This model applies the system dynamics approach to study the overall behavior of the commodity market from the perspective of a manufacturer that relies on several commodities to make its products. The qualitative and conceptual model illustrated in Figure 1 and Figure 2 is built based on the considered dynamics above. The figures are for illustrative purposes only and does not present a comprehensive representation of the model discussed.

In developing this model, we assume producers produce multiple products. Producers use many commodities in producing their products. Most commodities are used in multiple products. For example, a food producer needs many ingredients. These ingredients are used in multiple of their
products. The model is shown above for general products and commodities for simplicity. Also, the model assumes existing and established products for which data for the included dynamics exist or can be reasonably estimated. It does not address new product launch and associated unknowns.

![System Dynamics Model for Commodity Hedging – Part 1](image)

The model is modular in nature. By looking at Figure 1, we can distinguish the following module:

**Commodity Price Dynamics Module:** This module addresses the overall cycle of producing the commodities. This module models the demand and the expected price of the commodity by incorporating the following dynamics from the list in Section 2: Cost of commodity, Overall production and inventory of the commodity, Demand to commodity, Other macro dynamics that affect commodity prices. The stocks in this module are “Capacity Being Transferred”, “Production Capacity” and “Commodity Inventory” and uses variables such as the production capacity of the commodity along with parameters affecting it, the commodity inventory, the commodity production, investment in producing commodity and delay of investment before beginning the production. Another variable is “political stability/conflicts, war, regulatory actions on environments, economic boom/bust” for the decision maker to input his/her estimate about the macro conditions that affect the price of the given commodity.

By looking at Figure 2, we can distinguish the following modules:

**Product Advertisement and Marketing Dynamics Module:** This module models the impact of marketing and advertisement efforts on the product demand. It also models the influence of desired product demand on the marketing and advertisement strategies. This module incorporates the following dynamics from the list in Section 2: Product marketing strategy, Product advertising strategy.

**Product Demand Dynamics Module:** This module addresses estimating the market share and product demand expected by using input from other modules and incorporating the following dynamics from the list in Section 2: Product demand. Since our model is generic, we kept this module very simple. This part of the model can be enhanced for a specific class of products if the producer has more insight into the demand dynamics.

**Product Manufacturing and Inventory Dynamics Module:** This module models the production and inventory control using stock variables “Product Supply Line”, “Product Inventory” and many supporting variables. This module yields the producer’s demand to commodity. This module incorporates the following dynamics from the list in Section 2: Product inventory, Product manufacturing capability.

**Product Distribution Dynamics Module:** This module estimates the total required distribution capacity based on production as well as the capacity to rent, if any.
“Distribution Capacity” and “Distribution Capacity to Rent” are stock variables. This module incorporates the following dynamics from the list in Section 2: Product distribution capability, Product inventory.

Product Pricing Strategy Module: This module applies the producer’s pricing strategies taking input from other modules and incorporating the following dynamics from the list in Section 2: Cost of product, Product pricing strategy.

Commodity Hedging Strategy Module: This module implements the hedging algorithm presented in Section 4. This module takes input from other modules and incorporates the following dynamics from the list in Section 2: Commodity hedging strategy.

Figure 2 System Dynamics Model for Commodity Hedging - Part 2

In summary, for modeling the production, this model involves not only marketing variables, such as pricing, advertising, and channel development, but also supply chain elements such as production capacity and inventory on hand, as well as distribution capabilities. Interactions between production and distribution capabilities, inventory management and advertising, are incorporated in the model as they are researched in the literature [2] [3] [4] [9] [10]. All of these factors indirectly affect product pricing and hedging strategy.
undertaken by producers. Expected demand for products influences the expected need for commodities.

4 An Algorithm for Hedging

Decisions on what different types of hedging tools to use, the price and the quantity of commodities to be hedged depend on many dynamics that are internal and external to the company as explained in Sections 2 and 3.

Simulating hedging strategies requires a systematic view of the entire supply chain that considers both marketing and supply chain activities and their interactions, in addition to the overall commodity production cycle. Our model in the previous section provides a good platform for developing a simulation model for hedging. In our hedging model, we consider the entire product portfolio for a specific producer. For example, a certain food producer may have several different food products and all these products may use the same commodity (e.g. flour or sugar).

In this section, we will elaborate the commodity hedging strategy module of the model, particularly the “hedging strategy”, “hedged price/amount”, “non-hedged amount” variables. As seen in the model, “hedging strategy” takes “commodity price”, “expected commodity price”, “product demand expected”, “pricing strategy” as inputs and it produces the “hedged price/amount” and “non-hedged amount” values. The “non-hedged amount” variable contributes to “variance at risk” variable. Different hedging approaches can be simulated in the “hedging strategy” variable of the model. We will develop a particular implementation within this variable by executing programming code in Java. Most modern simulation tools allow executing Java code within the model variables [11].

Our hedging method considers all products in the portfolio and all commodities needed to produce the products. The amount to produce each product is obtained as an input to this method via the “product demand expected” variable of the model. It is assumed that how much of which commodity is needed for each product is known (e.g. can be obtained via a table lookup). From this information, a list of <product, amount of commodity> for all products and commodities is generated. This initial list is used in the implementation below.

First, the gross margin is determined for each product by taking the price of the commodities in the futures market. Then, gross margin for all products is calculated by adding the gross margins of each product. In this case, the risk due to hedging is zero because only prices in the futures market are incorporated in this calculation. This gross margin is recorded as a baseline for the next steps.

The next step is to rank the <product, amount of commodity> pairs in order to determine which pairs will be subject to hedging. First, calculate the impact of change in the commodity price on the baseline product gross margin. For this step, the price of each commodity is assumed to be given by the “expected commodity price” variable. Normally, this variable is determined by (1) weighted running average of the commodity prices of several earlier years, (2) the “commodity price” value returned by the SD model, (3) and a factor for an adaptive expectation coefficient for various exogenous inputs that may influence the expected commodity price. Once the expected price of the commodity is determined, the impact on the baseline gross margin is calculated for each <product, amount of commodity> pair.

Here how it is done: Take each product one at a time. For each commodity needed for this product, assume the expected price of this commodity but assume futures market price for all commodities needed for this product. Calculate the new gross margin for this product. The impact is defined as the difference between the new gross margin of the product and its baseline gross margin. Save this impact value for this <product, amount of commodity> pair. For commodities with “expected commodity price” lower than the futures market price, the impact will be positive.

Next calculation is to determine how much price change is allowed per product so that the gross margin is the same as the baseline gross margin despite the change in commodity price. This value is the allowable change in the product price. We rather want to calculate the percentage of this price change since this percentage change indicates elasticity of the product for our ranking. This percentage value provides more information to the producer regarding the impact of change in the product price. One advantage of using this elasticity is to help the producer with pricing flexibility if company is willing to go aggressive in the pricing and increase the volume.

We rank the <product, amount of commodity> pairs first based on this elasticity value so that minimum impact product is at the top. Within each product, we rank the <product, amount of commodity> pairs based on the impact on the gross margin where the pair with biggest positive impact will be at the top and the pair with biggest negative impact will be at the bottom. At the end, <product, amount of commodity> pairs are all sorted. For each <product, amount of commodity> pair, a variance-at-risk value is calculated taking into account the two values used above in ranking.

The objective of this ranking algorithm is to identify the <product, amount of commodity> pairs with minimum product elasticity thereby lowering the risk of hedging and with biggest positive impact on the product gross margins thereby increasing the overall gross margin.

In the next step, the output of previous step is presented to the decision makers as a sorted list of <product, amount of commodity, cumulative variance-at-risk> where the third value is the cumulative of variance-at-risk values of all previous items in the list. At this step, decision makers can
determine the risk tolerance by choosing a cumulative variance-at-risk value calculated in previous step. This is a significant decision: the decision maker makes a cut on the level of risk tolerance for the producer in producing all products. Any <product, amount of commodity> pair above the cut will be subject to hedging. That means, the decision maker decides on which <product, amount of commodity> pairs will be considered for hedging based on his/her opinion on the correct risk tolerance for the company at that moment. Based on the selection of the decision maker, all <product, amount of commodity> pairs above the chosen level will be considered in the next step for executing the hedging decision.

The next step in the algorithm is to present the business decision maker the output of “hedged price/amount” and “non-hedged amount” values. Non-hedged amounts are easily calculated for each commodity based on decision maker’s cut in the previous step. The amount to hedge for each commodity is also easily added up. For specific hedge prices and amounts, the algorithm needs to match the amount with available hedge offers from suppliers in commodity markets. We assume available hedge offers are stored in a database for easy matching.

At the last step, for each commodity to be hedged, the algorithm tries matching the available offer starting from the lowest priced offer provided the offer is good for the duration of product horizon and is less than the minimum of futures market price and “expected commodity price” value. The algorithm tries matching for as many commodities possible. For remaining amounts of commodities that are not matched due to lack of available offers in the market, futures market prices are assumed. At the end of this matching, all <product, amount of commodity> pairs are revisited and each pair is assigned a hedging price for the amount of commodity. If the amount of commodity cannot be handled by a single price but multiple prices at the end of the algorithm, <product, amount of commodity> pair is sliced into multiple <product, amount of commodity> pairs for each price.

This concludes the algorithm for the “hedging strategy” variable.

The SD model further outputs the profit margin for the product, the product volume and the overall gross margin. The SD model can be run many times for the purpose of sensitivity analysis. The output helps hedging decision makers and the risk analysis team.

5 Further Dynamics to Consider

The model provides a framework for adding new dynamics, simulating different scenarios, and conducting sensitivity analysis. Several variables, which were not included in the model, can easily be incorporated:

• Trade-weighted index for the U.S. Dollar is a significant factor affecting the commodity prices because most commodities are priced in U.S. dollar. Appreciations or depreciations of dollar affects the commodity prices. This can be added into the model. The model can flexibly incorporate other currencies (not US) as well.

• The word price of crude oil has a significant effect on the price of other commodities. Although the oil price itself is affected by many dynamics including the trade-weighted index for the U.S. Dollar, the oil price can be easily incorporated as an exogenous variable into the model.

The model can be enhanced by introducing other modules such as the following:

• Capacity acquisition module: This module can model the dynamics of capacity acquisition through renting and/or outsourcing. This is needed if the available capacity is not enough for producing the product. Similarly, a module for capital investment to increase the capacity can be introduced.

• Competition pricing module: The SD model presented above does not consider competition pricing. A new module can be developed to model the competition pricing dynamics in various engagements (e.g. Cournot, Bertrand) and leader/follower scenarios.

• The opportunity cost module: This new module can be developed to simulate the opportunity cost by sensitivity analysis of various parameters on risk, pricing, manufacturing and advertising modules.

• Product promotion strategy: This new module can be developed to measure the impact of product promotions on the product demand. It should also model the influence of desired product demand on the promotion strategies.

• Product substitution module: Some products of the same producer may be substitutable with one another. This new module can be developed to simulate the effect of product pricing and manufacturing on the substitute products.

These are left to investigate for other papers.

6 Conclusions

The objective of this study was the development of a generic model for abstracting the dynamics in commodity hedging. System dynamics modeling has been proven to be an effective tool for analyzing complex nonlinear systems that inherently have feedback loops. In this paper, we presented a generic system dynamics model that integrates various commodity and product dynamics. This generic
model is a good abstraction for variety of products and a variety of commodities including agricultural, metals and mineral, chemicals, and The generic model has been shown to be a suitable platform for implementing an algorithm to abstract a hedging strategy.

The hedging algorithm implemented a risk-return simulation model and provided useful output for decision makers. The model can be customized by implementing different hedging strategies. It is also extensible to flexibly add new modules for incorporating further dynamics. To our knowledge, our model is the most comprehensive one taking into account a great deal of commodity and production dynamics, and meanwhile flexible to allow running Java code for implementing hedging algorithm. Our paper presents a model allowing to apply various dynamics and to experiment with different hedging algorithms.

The model allows simulation of a variety of scenarios:

- Different hedging algorithms
- Different manufacturing capacities
- Different level of success of product advertising
- In general, by modifying different dynamics in the system

One challenge corporations face is to coordinate different functional areas such as manufacturing, advertising, marketing, distribution, procurement, hedging, pricing. Our model could facilitate analysis encompassing all these functions, and once the decision makers agree on what the right action for hedging and production would be, then it can help with coordinating the efforts by different functional areas of the organization.

One difficulty using this model is that it contains some exogenous variables representing the extent of external dynamics onto different variables, for example “political stability/conflicts, war, regulatory actions on environments, economic boom/bust" variable. Choosing the right value for such variables is dependent on the decision maker’s intuition and past experience. A lot of times, sensitivity analysis is performed over a set of possible values.

### 7 Future Work

There is plenty of future work to further enhance the presented model. One area of work is to incorporate further dynamics listed in the previous section into the model. Another area is to try the model for different types of commodities and products.

Another area that we are actively working is to combine the neural network algorithms with system dynamics modeling in order to employ machine learning in policy development.

Although this effort could be independent of the presented model in this paper, we would like to apply the approach first into this model for intelligent and adaptive commodity hedging.

### 8 References


