# The Use of Financial Hedging in Supply Chain Risk Management

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A Thesis in

The Department of

Mechanical and Industrial Engineering

Presented in Partial Fulfillment of the Requirements for

The Degree of Master of Applied Sciences (Industrial Engineering) at

Concordia University

Montreal, Quebec, Canada

Summer 2015

**CONCORDIA UNIVERSITY**

**School of Graduate Studies**

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Entitled: The Use of Financial Hedging in Supply Chain Risk Management

and submitted in partial fulfillment of the requirements for the degree of

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**ABSTRACT**

The Use of Financial Hedging in

Supply Chain Risk Management

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Supply chain risk management deals with the identification and control of potential risks along the supply chain.

With business growth and the emergence of new markets presenting new opportunities for companies, the scope of the supply chain has grown along with the exposure to possible risks. The potential for higher gains has paved the way for higher losses too, which might not be sustainable for a business to survive.

Companies face many uncertainties in the form of demand, exchange rates, commodity prices, production, etc., and have started to consider using financial risk management tools such as financial derivatives which were traditionally used by the financial firms.

A literature review of existing material showed the different operational, financial and integrated hedging strategies used and proposed by practitioners and academicians. Surveys covering the use of such financial hedging instrument among non-financial entities showed that these tools are gaining traction. However, they also cite a great deal of confusion among those practitioners on how and when these risk management tools should be used, indicating the need for more research on the topic.

By considering the case of a manufacturer that uses a certain commodity in its production process; a practical guide is developed to assist managers with the decision making process of choosing which financial derivatives, according to the different commodity price scenarios it can face, is the most suitable one that meets their risk approach and financial capabilities.

Through a simulation-based optimization model, the manufacturer is exposed to both price and demand volatility, where four metrics are used to measure the performance of each strategy; the average profit, standard deviation, Value-at-Risk (VaR) and Conditional Value-at-Risk.

The results shed some insight on the use of financial derivatives under different pricing schemes, such as that they perform better when facing high levels of price volatility. In addition to that, financial hedging is more successful when used under a risk averse approach maximizing the profit VaR, than when trying to raise the average return. Financial hedging can still benefit the manufacturer with the risk neutral approach, but when there is a trend in the commodity price.

## ACKNOWLEDGEMENTS

I would like to express appreciation to my supervisor, Dr. Nadia Bhuiyan for her guidance, leadership and support. Dr. Bhuiyan was my first professor as an undergraduate student at Concordia and I wanted to thank her for granting me the opportunity to explore a multi-disciplinary topic, which confirmed what she said in my very first class at Concordia; that industrial engineering has no boundaries and there are no limits to where it could lead. She will always be a role model of the modern professional I aspire to be.

I would also like to thank Dr. Satyaveer Singh Chauhan who patiently guided me throughout the process. He introduced me to the exciting world of finance, his advice and ideas greatly benefited me throughout the many meetings we had. His input and support were essential.

I also thank Concordia University and the MIE department for accepting my enrollment into the program to pursue my degree, while providing me with essential financial assistance. I made the right choice with choosing Concordia for my undergraduate and graduate degrees, with the many hours spent and memories created, I have to come think of Concordia as my home away from home.

I thank my family for their ever continuing support and the faith they have blessed me with. I couldn't have completed my degree without them behind me.

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# 1. INTRODUCTION

Companies face uncertainty in their day to day operations in the form of demand and price variability, whose impacts can be mitigated through the use of operational and financial hedging techniques. This work investigates how different financial tools, already well known in the finance industry, can be used to mitigate the impact that price fluctuations inflect on a company's profits and reduce their risk exposure.

The first section in the chapter provides a background on the topic and describes how the field of supply chain management is evolving and the problems being encountered as a result of said growth. The second section defines the exact problem we aim to investigate in this report and the final section describes how the rest of the report is organized.

## 1.1 Background

Supply chain risk management is the field in which its practitioners try to identify and manage potential risks along the supply chain, that may cause disruptions to one or more of its members and hence, to the supply chain as a whole. With business expansion and the ever-growing trend of globalization opening up new markets for different companies, firms face both increased risks and opportunities for growth.

In order to take advantage of all these extra opportunities, companies have to face the challenges that come with them. Some of these challenges are a natural result of this growth and extra exposure to elements and issues that did not exist before, while others were always there, but were largely unnoticed or less influential due to the limited scale of the business.

In order to run the business in this environment, companies have recognized the need to better equip themselves with tools and knowledge that are most appropriate to tackle these concerns.

Companies and academics have responded to this growing need by studying and treating the supply chain as a whole integrated business, rather than as being constituted of separate independent entities. A considerable amount of research has already been done on this topic to enable a company to significantly improve its performance at an operational level, that is in terms of inventory levels and ordering quantities based on a company's targets.

However, as mentioned before, companies now operate on a bigger playing field and the challenges and risks are consequently more significant. Companies now realize the next phase of development is introducing risk management to the supply chain, to better equip businesses with different analytical and managerial tools to face these risks.

Some of the risks companies face include demand variability, as there is no guarantee that the market demand will be what the company forecasts it to be and this has a strong implication on a company's inventory position and policy. Demand variability is always a present risk for companies of all sizes, however, as the business opportunities and competition grow, so does the demand variability. This reduces the level of error allowance to a degree that could deliver a great blow to a company if it cannot properly anticipate and manage the demand uncertainty. These uncertainties in the demand are offset by taking logistical decisions which affect the company's inventory and ordering policies. Using such operational activities and decisions to mitigate risk is known as operational hedging.

Other influential risks are of a financial nature; such as currency exchange rates; with companies starting to source/operate from/in international markets and dealing with international suppliers and customers, company's operating costs may fluctuate severely depending on the exchange rates. Another example of financial risk is the commodity market, where prices change daily, presenting actual and potential gains and losses for businesses that vitally need these resources for their operations.

Financial risks are mitigated by placing buffers of sorts that could absorb some of the variability, a strategy known as financial hedging. This involves the use of financial tools known as 'derivatives' such as stocks, warrants, bonds, swaps options, forwards and futures. Firms purchase one or more of these tools, which could have a direct or inverse relationship to the asset's price they're uncertain of, and use them as a backup should prices deviate from what the firm initially expected them to be, in order to reduce their impact on the firm's profits.

To manage these risks, companies are starting to look for solutions that encompass both operational and financial tools to hedge off, or offset, the effect of these risks.

### 1.2 Thesis Statement and Contribution

There is a need for managers, especially non-financial ones, who face price fluctuation with the resources they use, to be better equipped with tools that can help them figure out what kind of financial derivatives they should use to benefit them the most, when hedging against price volatility.

This thesis aims at shedding insight and providing guidance among derivatives users, to resolve some of the existing confusion about the role of futures and options. This is done by looking at a simple stochastic problem with the objective of optimizing the performance, through a simulation-based optimization approach. The experiment identifies the effects of four factors on supply chain performance; price variability, price trend, risk level and resource availability. The purchasing price can have an increasing, decreasing or no trend, as well as a high or low level of variability. The risk approach can be at a risk averse or risk neutral level; a risk averse approach that maximizes the profit's value at risk (profit distribution's 5$^{th}$ percentile) and a risk neutral approach whose objective is to raise the average profit. Resource availability covers a manufacturer with surplus in funds and without.

The results are compared to an optimized hedge free model. The optimized hedge free model's ordering limits and quantities are used in all models to be able to compare the derivatives' impact. The comparison is done though four metrics measuring the profits the manufacturer will make; average profits, standard deviation, the Value-at-Risk and the Conditional Value-at-Risk.

This thesis considers the case of a manufacturer over a 3 month period which uses a commodity for production. The price of said commodity is volatile and used to meet a fluctuating monthly demand. The price of the commodity has six price scenarios that vary in terms of volatility level and price trend.

The thesis looks at the use of futures contracts and call options, to compete with spot market purchasing of the commodity for production. It also looks at using futures contracts versus call and put options for trading, using excess funds from the budget.

The target is to gain some insight on the performance of financial risk management tools under different situations. The results will provide a practical guide which can assist non-financial decision makers with the use of such tools.

### 1.3 Thesis Organization

The thesis is organized as follows:

Chapter 2 looks at defining and identifying some basic concepts and ideas used in this report.

Chapter 3 uses past literature to explain the various aspects of supply chain risk management and provides a review of financial and operational hedging literature.

Chapter 4 describes the model and the different scenarios to be experimented.

Chapter 5 discusses the results obtained for the risk averse and risk neutral approaches.

Chapter 6 concludes the report and identifies the limitations of the report, as well as areas for future research.

# 2. CONCEPTS & DEFINITIONS

This chapter defines some of the basic concepts used in this thesis report.

The first section defines what supply chain management is, how it is evolving and why world events are causing an evolution in the field's basic concepts.

The second section revolves around supply chain risk management, highlighting some examples of why the practices, which were mainly used by financial institutions, are coming into play with supply chain practitioners. The section then shows how supply chain risk management issues are organized and defines Value-at-Risk, an important risk management tool used by investors trying to reduce their portfolios risk. The final sections clarify and define important term in hedging.

## 2.1 Supply Chain Management

The Global Supply Chain Forum (GCSF), which consists of a group of academics and field professionals, define supply chain management as being an integration of key business processes from the original suppliers to the customer that provides goods, information and services that add value for customers and other stakeholders. [1]. Supply chain management is one of the business world's solutions that aims at providing a company and its partners (supply chain) with the means to gain competitiveness by lowering costs, providing high product variety and quality with short lead times to eventually maximize company profits [2] [3].

The emphasis being on the term "partners", this term signifies the evolution of the concept from the past view that treated supply chain management as logistics outside the firm [1]. Under the older approach, companies treated each other as different entities with each party seeking to maximize its own profits, regardless of how they affect their business partners. A catalyst to this change is that as companies seek to maximize profits, and that is what supply chain management does by treating the supply chain as one cohesive unit [4] [3], they recognized the potential organizational competitiveness and effectiveness that supply chain management can provide by improving their own and their suppliers' performance [5].

This paradigm shift in the understanding of the boundaries and level of partnership in supply chain management can also be witnessed at the most basic equation used in inventory management; the optimal economic order quantity (EOQ), and how its use has evolved with the shift. The simple equation states that the optimal order quantity for a resource, with some simple assumptions, is as follows:

$$EOQ = \sqrt{\frac{2AD}{vr}} \tag{1}$$

Where A is the fixed ordering cost, D is the demand rate in units per year, v is the unit cost and r is the carrying cost per unit as a percentage of unit cost. A retailer would use this equation to identify how much it has to order regardless of the supplier. But with time, this same equation started to be used differently; now when calculating the optimal quantity, the fixed setup and units costs the supplier incurs are also taken into account, in order to find the optimal quantity which charges the least to the supply chain as a whole, giving the supply chain an edge against the other supply chains they are competing with [6].

In an analysis of revenue sharing between supply chain partners, it is recognized that customers switch between brands and retailers with price increases and hence a business partnership based on mutual cooperation and coordination between the retailer and its manufacturers is required. They work together to determine the retail and wholesale price, profit margins and inventory levels to attain a greater share of the market. A model is provided on how to maximize their total profits and sharing it proportionally according to each party's risk. [2]

### 2.2 Supply Chain Risk Management

#### 2.2.1 Definition

Supply chain risk management (SCRM) is defined as "the identification and management of risks for the supply chain, through a coordinated approach amongst supply chain members, to reduce supply chain vulnerability as a whole" [7]. Another similar definition words it as "the management of supply chain risk through coordination or collaboration among the supply chain partners as to ensure profitability and continuity" [8]. Simply put, it is the identification and control of potential risks along the supply chain that may incur losses to one or more members of the supply chain and hence to all members.

#### 2.2.2 Framework

There seems to be agreement in the literature on the overall approach and framework on how to deal with these risks and minimize or reduce their impact on the business.

The first step is identifying the different potential risk sources and categorizing them. The financial literature also acknowledges that the first step needed is to recognize the risk exposures a firm can face [9] and the following list provides some examples of said risks:

1. Market risk
2. Shape risk
3. Volatility risk
4. Sector risk
5. Currency risk
6. Credit risk
7. Liquidity risk
8. Residual risk

From a supply chain risk management perspective however, the different categories are labeled as being either operational (demand uncertainty and price variation) or disruptive, with the latter referring to those of greater disruptive impact caused by man-made and natural disasters [10] [8]. A more thorough classification however, had them divided into supply, operational, demand, security, macro, policy, competitive and resource risks. The first four are viewed as being under the umbrella of operational risks and the latter under the disruptive risks umbrella [3]. Table 1 summarizes this.

*Table 1: Types of risk*

| Operational Risks | Disruptive Risks |
|---|---|
| Those regular and frequent type of risks a business anticipates to face<br>Examples:<br>• Demand variability<br>• Price variability<br>• Equipment failure or inefficiency<br>• Supplier delivery issues<br>• Cash flow problems | Uncommon and rare risks in terms of occurrence<br>Examples:<br>• Political instability<br>• Earthquakes<br>• Terrorist attacks |

The second step, is to analyze the risk sources by assessing them and identifying what are the odds of them occurring and if so, how would they affect the company. Then the company would prioritize these findings and address them by developing countermeasures [3].

The final step is to mitigate the risk by reducing the impact they might have if they occur, or to exploit them to the company's advantage [3] [11]. It is this last phase, risk mitigation, which is lacking research material that academics agree is greatly needed [7] [3].

The following table summarizes the framework just covered:

*Table 2: Framework for dealing with risks*

| Risk Identification | Risk Analysis | Risk Mitigation |
|---|---|---|
| • Identify potential sources<br>• Categorizethem as either operational/ disrputive | • Assess risk sources<br>• Probabilites of occurance<br>• Risk effects<br>• Prioritize findings | • Develop countermeasures<br>• Take actions to reduce their impact<br>• Look for opportunities |

### 2.2.3 Value at Risk

An important risk management factor that will be used in this thesis is the Value at Risk tool used by corporate treasurers, fund managers and financial institutions.

Traditionally, investors decided on how to shape up their portfolios by looking at the average profits they would receive and the variability of theses profits. However later on, they started to be more concerned with the amount of losses they could sustain, by looking at the left tail of the profits probability distribution. VaR translates to ask how bad things can get, for a confidence level X. It looks at the $X^{th}$ percentile of profits in order to be able to say that there is an X% chance that the profits won't be higher than the VaR. Despite the fact that the VaR absolutely neglects the size of losses beyond that point, it remains the most popular risk measure among regulators and risk managers [12]. Figure 1 shows an example of the VaR.

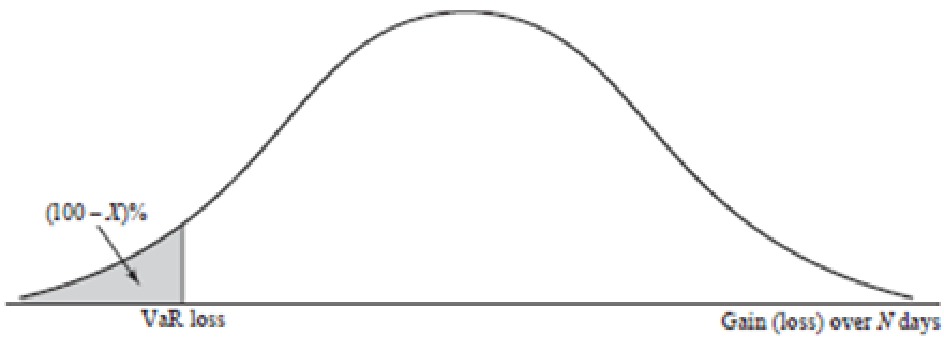


Figure 1: Profit distribution 1

Another measure is the Conditional Value at Risk (CVaR), which is known as the expected shortfall. It measures the average profits below the VaR. VaR has the ability to answer the question of what is the maximum loss with a specified confidence level, while CVaR allows the qualification of the mean excess loss, or the mean loss/profit, resulting from the worst X percent scenarios. Figure 2 shows the weakness of VaR, as it is possible for this profit distribution to have the same VaR as the one in the previous graph, but obviously have different losses/ profits beyond it.

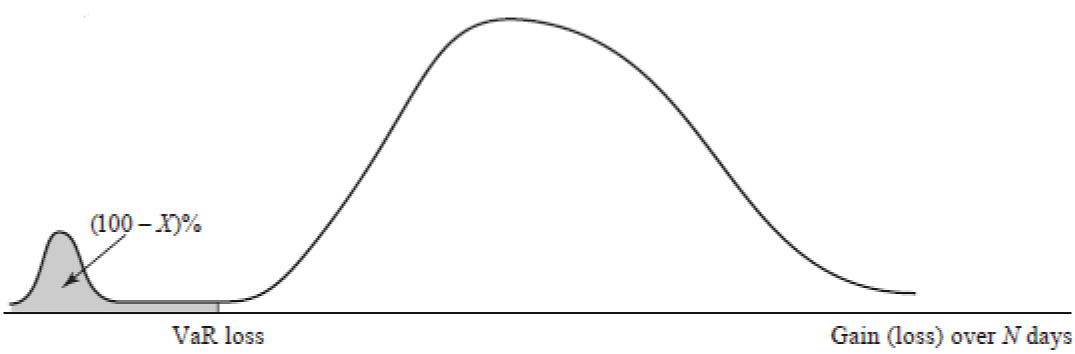


Figure 2: Profit distribution 2

### 2.2.4 Risk Positions

It can be said that there are three types of risk positions an investor can take [12].

*Risk Averse:* those who would like to avoid any risk and would hence prefer to receive a more guaranteed low return. This represents the most common type of investors.

*Risk Neutral:* those who are indifferent between certain payments that have different risk levels but the same overall expected payout.

*Risk Seeker:* those who seek a higher payout, even at a high level of risk.

### 2.3 Financial Hedging

Financial hedging refers to the use of financial derivatives to offset risks [13].

Companies can invest their funds and offset their risks by investing in government risk free bonds, which provide a low guaranteed income. The benefit of using these types of bonds is that their returns are considered risk free; guaranteeing the hedger a certain level of income regardless of price fluctuations. The drawback though, is that the interest received is quite low and there still is a certain type of risk present here; interest rate risk. The risk for using these bonds is present, since the investor receives a fixed interest rate regardless of anything else. They will have an opportunity cost should interest rates go up later on [12].

Financial derivatives are the most popular hedging tools used by CFOs [13]. A derivative can be defined as a financial instrument whose value depends on (or derives from) the values of other, more basic, underlying variables [12].

First, companies can invest in the stock market and go with stocks that have a strong covariance with the commodity it uses, so that if there was any sudden rise in the commodity's price, its position with regards to the stocks would rise as well and cover the extra costs.

Secondly, there are future and forward contracts, which represent an agreement to buy or sell a quantity of an asset at a certain date for a certain price. This is in contrast to a spot contract of purchasing the asset right now at its current price. The difference between futures and forwards is that forwards represent an agreement between two parties, whose exact terms are customized through an agreement achieved by the buyer and seller. Futures on the other hand, are standardized contracts traded in the futures exchange market and are hence highly regulated and less risky than forwards. These contracts are available for commodities, currencies and other finance; assets. Forward contracts on foreign exchanges are very popular and usually involve large banks acting as the buyer or seller; this bank involvement reduces the risk of default usually associated with forwards. These types of contracts are also quite popular among farmers trying to guarantee the prices on their crops before the harvest.

The third main type of derivatives is options. Options are also available in exchanges and over the counter markets. Options are financial contracts that give the option holder the right, but not the obligation, to buy or sell an underlying asset or instrument at a specified price (known as the strike/

exercise price) on or by a certain date (known as the expiration/ maturity date). This right is obtained by the option holder/ bearer by paying a fee known as the premium to the seller/ writer.

If the option held gives its owner the right to buy the asset later, it is known as a call option. If the option gives the owner the right to sell the asset, it is known as a put option.

There are two different types of options available: American and European options. American options can be exercised at any point of time up until the expiry date, while European options can only be exercised on the expiry date itself. However, most studies carried on either type are usually applicable on the other since they behave similarly. For example, if an American call option's prices increases, the investor can simply exercise the option right away, and even though the European option holder cannot exercise his/ her option, they can just sell it, as its price will increase, since buying a call option with the newer and higher price will cause it to be more expensive than before.

Options usually deal with agreements to buy or sell a certain quantity of the asset (usually 100 shares per option). Options are not limited to shares but can almost buy anything; including agricultural commodities, metals, energy products, stock indices and even weather derivatives for ski resorts and theme parks to hedge against unfavorable weather. There are even options for futures contracts, called futures options. These give the holder the option to enter a futures contract at a certain futures price, if the futures exercise price is reached by a certain date.

Although futures and forwards contract do not cost anything to enter, they do obligate their members to go forward with the transaction, regardless of the actual price at the time of maturity. Options being exercised on the other hand depend on whether the spot price, at the time of exercise, has reached the strike price or not. This extra flexibility over futures and forwards is why option holders have to pay a premium to purchases them.

Some important terms related to options should be identified now, buyers are said to have a long position while sellers have a short position. Selling an option is known as writing the option. If an option's exercise price has been reached, the option is said to be at the money. If the option's price has been surpassed, it is said to be in the money. While options that have not met their exercise price are said to be out of the money [12].

## 2.4 Operational Hedging

It is the exercise of real options to be able to respond to demand, price and exchange rate variability through operational activities [11].

Since the problem being faced is uncertainty, a company has to be a in a position to respond to said uncertainty as quickly as possible without incurring major costs upon themselves. To do that a company has to be flexible and robust, to be able to continuously change and adapt to the new dynamics of each new situation [6] [14].

The risks that companies face and can be tagged under the operational hedging umbrella are categorized into three; supply, process and demand risks [14].

The most basic operational hedging strategy is determining order quantities from a supplier, which aims at finding a balance, between meeting customer demand and the costs that the demand uncertainty induces, since having too much inventory means higher storage costs because of space constraints, tied-up capital and risk of damage, while not having enough inventory means losing potential customers and sales [6]. The other basic strategy is diversification of the company's activities; whether it is producing more than one product or serving several customers or markets (local or international), the objective is not to have all the eggs in one basket.

# 3. LITERATURE REVIEW

This chapter covers the literature review performed for existing materials on the topic.

Section 1 provides a review on the material that discuss why supply chain risk management as a field is growing and gaining traction.

The following three sections review existing literary works on operational, financial and integrated hedging. This is followed by a section that summarizes the chapter.

## 3.1 Rise of Supply Chain Risk Management

With increasing globalization blossoming amongst us and making the world ever smaller, businesses have responded by restructuring themselves to be more capable of operating on the global stage, whether it is to open up new markets to gain access to, or to take advantage of the wide array of foreign suppliers, labor, material and different laws that were not available before [3]. This means companies and their supply chains have grown, but these new business opportunities haven't arrived without a cost; companies now face greater risks than before, as recent events have shown that a disruption affecting any entity in the supply chain, can have a direct impact on its ability to continue operations, deliver goods to the market or provide the necessary service to customers [7].

As mentioned before, companies treated themselves as separate entities, seeking to optimize their own individual performance and just passed on any problem to one of its trading partners, as if playing a game of Hot Potato [15]. Earthquakes, strikes, economics crises and terrorist attacks have proven to have devastating effects for supply chains, causing many disruptions [3]. Ericson for example, lost 400 million euros after their supplier's semiconductor plant caught on fire in Albuquerque, New Mexico back in 2000. Despite the fire just lasting for 10 minutes, millions of chips that were being stored had been contaminated and hence rendered useless. This caused a massive blow for Ericson in the cell phone market and caused it to lose significant ground against major rivals like Nokia. This was obviously followed by a poor financial performance and a great drop share prices [16] [17]. A similar situation happened when Taiwan was hit by an earthquake in 1999, sending shockwaves of disruptions in the semiconductor market. [10]. An empirical study to observe stock return patterns in response to supply chain disruptions, reported up to 40% lower returns than expected [18].

Another example of incorporating more factors in the supply chain spectrum, is a study that considers the impact of supplier delivery and price volatility in an undertaken construction endeavor. The study looks at a project whose exact start date is not certain, and has a deterministic probability distribution modelling the possible start/ delay times. The supplies used in the project represent a significant cost, and receiving and storing them ahead of schedule also comes at a high cost, as the nature of these materials poses a lot of problems for the supplier due to its capacity constraints. Accepting the materials later than scheduled enforces a penalty scheme the buyer has to follow. Prices also vary because of the delay. The objective is to select a set of suppliers that would fulfill the demand at the lowest possible cost, while considering the minimum and maximum order quantities the suppliers have [19].

Basically, companies are coming to realize the need to incorporate more factors in their decision making process, the many variables that they face, which they cannot control, cause a serious threat to the long term stability of their operations and returns. Hence the need for risk management, which can provide a means of reducing the impact these variables can inflict.

### 3.2 Financial Hedging

Risk management departments in companies have been utilizing financial derivatives for quite some time now, with figures estimating the nominal value of derivatives being used in the US alone reaching trillions of dollars, with 65% of US firms reportedly using them, 37.4% of these firms using derivatives are in the form of foreign exchange reserves [20].

A study on Canadian firms that regularly deal in the US, also shows the importance of hedging their currency risk exposure. It showed that firms with assets in the US were less likely to use financial derivatives, as their possession of assets would act as a sort of operational hedging. The survey also showed that companies that just exported to the US, were more reliant on these financial tools [21].

Even in New Zealand derivatives are gaining traction, where a survey on 79 firms deemed that compared to before, companies have become more active users of derivatives than their American counterparts (relative to their size) [22].

Many articles report that in "the perfect world" financial risk management does not really add value, but since that is not the case, they argue that risk management does add value indeed by reducing tax liabilities, bankruptcy costs, the underinvestment problem from external financing and agency problems such as managerial risk aversion [11] [23] [20] [24].

The use of financial derivatives have been directed to manage three sources of risk; exchange rate risk, interest rate risk and commodity price risk, with the majority of the literature focused on the exchange rate dilemma, whether it is for a company which exports or operates internationally, indicating a gap in the literature for companies that face interest and commodity price risks [13].

A study on 424 firms reports that financial hedging is used to deal with the transactional exposure companies face on the short term from currency price variation. This is the case for example, for manufacturers that import a component and are charged in the currency of the components country of origin [20]. The same concept applies to companies with a foreign presence in terms of assets and operations, however, the use of financial derivatives at that point doesn't become as predominant as with those that export, since their assets would imply a long term risk exposure, while financial derivatives just provide a short-term cover [23].

There are constant changes in the prices of commodities, and how companies deal with these variations by exploiting them to their benefits, as opposed to their competitors, makes all the difference between failure and success. A company cannot simply keep changing its prices every day, with the dynamic nature of the price variations that the commodities face. The use of financial hedging does give a breathing space of sorts, where they aim to try and absorb that variation to not only reduce the impact, but to use it to the company's advantage by maintaining cost levels or even reducing them [13] [11].

Financial derivatives have been used rather successfully by airline companies to hedge off the price of jet fuel, which represents the most significant variable cost for airliners [25]. These costs are so significant that Samoa Airlines actually started to charge customers based on their weight, as being heavier meant the plane would need to consume more fuel for the extra weight, a move that had mixed reactions from customers [26].

Again studies showed that those companies which hedged their fuel costs had that reflected positively on firm value which makes sense, as less cost variability means less variability with cash flow and company performance [25].

The use of financial derivatives is also quite popular among farmers, who try to lock in prices for their crops ahead of harvest [12].

In a survey of Michigan dairy farmers in 2011 (which was compared to one performed in 1999), to show how financial risk tools were being used to face the price volatility they encountered; their use of risk management tools was noted, as well as the size of their herds and level of education on the matter. Firstly, there was a definite growth in the use of derivatives. Second, the results showed a positive relation between herd size and the use of risk management tools, which confirms that the bigger the field, the greater the need for protection against price fluctuations. There was a lower probability for sole proprietors to use financial derivatives, which were also shown to be more popular among the younger generations. The survey also cited that the most common reasons farmers didn't use any risk management tools were basis risk, cost and a lack of understanding of how they operate. The paper concludes that there is a need for more educational programs on the topic [27].

In a paper on production, hedging and speculating with futures and options, a model reaches the conclusion that when cash prices are represented by a linear function of futures prices, there would be no place for options and just futures. This could be attributed though to the fact that options contracts are non-linear while futures are [28].

In a paper that cited a survey of Montana farmers, it was shown that 19% of crop farmers used options, while 14% of them preferred using futures contracts. The survey also showed that 11% of livestock farmers used options and 6% used futures. These numbers show a different story from the Lapan, Moschini and Hanson (1991) paper just mentioned in the previous paragraph, this raises the question about what are the conditions needed to dictate whether options or futures should be used for hedging. The paper also cites a general lack of understanding of how options work exactly among users. The paper introduces production uncertainty to the Lapan, Moschini and Hanson model to further investigate, and the simulation results show that both, futures and pull options have a role to play in hedging against price and production risk respectively. It should be noted that it is assumed that prices are influenced by production levels [29].

The next section covers operational hedging and some of the more common methods followed.

### 3.3 Operational Hedging

The simplest strategy to face these risks is avoidance, this is used when the risks are associated with operating under specific circumstances, like a given product, geographical market or dealing with certain entities, deemed as being unacceptable. An example of this is Disney theme parks opening in places with favorable weather, or when terminating all dealings with a certain supplier because of a known poor track record [13] [7] [3].

A major strategy in operational hedging is multi-sourcing to deal with supply risks. This leads to several suppliers competing against each other to provide the company with lower prices. Another advantage companies gain from multi-sourcing, is the possibility of shifting production between suppliers, to obtain a certain level of flexibility by giving each supplier a share, and have a backup that could fill any gap, if the other one temporarily or permanently fails. The drawback of this however, as opposed to a single supplier, is that with a single provider a company can more or less dictate the relationship, as it is going to be more dedicated to that company and will put more efforts into satisfying it [8].

Another major operational strategy is postponement, to face uncertain demand risks [14]. Postponement refers to when a company tries to delay the decision, on how to commit its resources between its different variants as much as possible, to be able to commit once the actual demand has been realized or can be better predicted. Postponement can be viewed as delaying that decision through labeling, packaging, assembly and manufacturing, this leads to the company having shorter lead times [6] [3] [11]. Delaying assembly and manufacturing is done through component commonality. This is when a manufacturer redesigns some of the components between its product variants, so that it has to only store one standard form of the component, rather than keep an inventory of each different option. It leads companies to storing less overall, because when they are standardized the total demand is aggregated, meaning the variability of this aggregated total is less than the sum of the variability of each form alone. An example of this is how Dell stores standard parts of their laptops and commit the components only once an order has been made [6]. Another example of postponement is how IKEA packs its products. Since IKEA ships worldwide from their production facilities in Sweden, it has to label each product according to the intended destination. IKEA finishes the product and provides assembly instructions that just use pictures (a picture is worth a thousand words and in different languages apparently), package the product and just label it externally according to where it is going to be shipped to [30].

A business can also shift its customer demand across time, meaning it would offer special rates to customers who would make their purchases in advance, enabling the business to secure a portion of its sales from demand variability. Business such as airlines and hotels also set high prices during their peak season, where the demand is more or less guaranteed, to shift some of their customers to promote their offseason period and fill up capacity. This helps serve a business' two different types of clientele, those who plan ahead can secure good prices and "business travelers", who usually require extra flexibility to accommodate and are prepared to pay more for this extra flexibility [31] [8].

The last strategy covered here is when businesses go with shifting the demand across products, which can be divided into product substitution and product bundling.

Product substitution refers to selling more than one product with similar features and attributes, so that their total aggregated demand would reduce the overall variance. It could also mean that if a company sells the same product at a high and low quality, the high quality one could fill in for the latter in case of a stock out. This is also the case for offering different price mechanisms for the same product, like a donut shop selling the same product at different prices depending on how fresh they are.

Product bundling can be developed by businesses to encourage and force the customers to buy all the products in the bundle, a common practice by cosmetics (makeup, shampoos and conditioner for example) and electronics stores (laptops, mouse and printers) [8].

Table 3 summarizes the different operational hedging strategies covered.

*Table 3: Operational hedging strategies*

| Risk Aversion | Multi-sourcing | Postponement | Shifting demand over time | Product building & substitution |
|---|---|---|---|---|
| •Avoid risky conditions completely<br>•Example: Disney opening in places with good weather | •Deal with several suppliers to cover supply risk<br>•Might lead to losing some leverage as opposed to one | •Delaying the decision on how to dedicate the resources<br>•Example: Dell laptop assembly | •Special rates for advanced purchases and off-season bookings<br>•Example: airlines and hotels | •Several products in the same market, similar products of different grades<br>•Creating bundles of family products |

### 3.4 Integrated Operational and Financial Hedging

A majority of the literature looks at integrated hedging for exporting firms and deal with exchange risk and demand variability. There is a general consensus on the need for more integrated approaches for hedging, especially dynamic ones which consider current performance rather than just snapshot scenarios [32] [33] [13] [34] [8] [35].

A major paper in the field of supply chain risk management that laid the groundwork for many papers later, looks at a variation of the newsvendor single period problem, where a company has a certain budget C, which can be used to purchase inventory for a product it makes and has a random demand in the following period. The rest of the capital is invested in a project with a random return as well. So the paper analytically looks at how much capital should be allocated to each endeavor to maximize the shareholders' value [36].

In a paper that investigated exchange-rate hedging in large firms, with both operational and financial means, it was determined that operational hedging by locating in several countries cannot help against currency exposure, as opposed to financial hedging, however the use of both hedging types together can improve firm value [33].

A paper that looks at a firm with the option to operate both domestic and foreign plants investigates under what circumstance the firm should operate just one or both these plants. The firm also has to decide how to dedicate its production capacities between these locations, in order to hedge off its risk exposure. It is concluded that operational hedging will only take place when a corporation has both, exchange rate and demand, uncertainties present. The paper also states that operational hedging is less important for managing short-term exposures, since demand variability is lower on the short run. It shows that firms with plants present home and away, won't have a foreign currency cash flow independent of the exchange rate, and that to financially optimize them, forwards contracts are not sufficient hedging tools, but that there is also a need for call and put options [34]. Another paper based on this one confirms that operational hedging, in the form of operational flexibility, acts as a strategic complement to any variance-minimizing financial hedge [23].

A study of Canadian firms exporting and operating in the US shows that an integrated hedging strategy is needed, as operational hedging in the form of operating in two markets isn't sufficient. The study also shows that a 14% increase of value is realized with the use of an integrated approach [21].

In another study of 424 firms, half of them with export sales and the other half with foreign operations, both needed an integrated hedging approach, but those with a foreign presence used less financial derivatives. Financial hedging was of more value for short-term transactional exposure, while operational hedging is better for long-term economic exposure [20].

To address the issue of customer demand and price variability, a simulation-based optimization model is developed which establishes a quantitative procurement risk management framework for two commodities; copper and electricity. The model uses an integrated approach of procuring inventory in different periods, while financially hedging by trading futures contracts in parallel to regular purchasing, to offset price fluctuations. The results show higher profits and lower risk exposure when using futures as opposed to when they are not used [37]. The same model is then published, but trading is done with options instead of futures as a financial hedging tool [38].

In a case study that considered the case of a beer can supply chain, studying the entire supply chain attempting to minimize the overall costs; an integrated simulation-based optimization model is created to determine when and how much to order supplies (operational hedging). The model also decides on how to allocate European call and put options on futures contracts (financial hedging). The results showed that the integrated approach of deciding how to hedge financially and operationally simultaneously, yielded lower costs than that when taking the decisions in a sequential manner, or without financial hedging tools at all [13].

### 3.5 Summary

The uncertainties businesses face are growing, where they have come to realize the benefits of using financial and operational hedging tools, in facing price and demand uncertainties respectively. However, there is a consensus that there still is a great deal of confusion, especially among non-financial practitioners when it comes to finical hedging in a production environment. This is the gap in the literature that this report will fill by creating a simulation based optimization model for different price scenarios and with different situations. The results will provide valuable practical information that will enable non-financial managers to properly select which financial hedging strategy would complement their operations in attempt to raise profits.

# 4. MODEL FORMULATION

In this chapter, the general considerations and problem statement are considered in the first two sections, describing the case this thesis models and what the model will aim to achieve.

The following section defines the different decision variables used in the model, as well as the parameter values.

In section 4, we first describe how the price and demand randomness are modeled, then explain general equations and constraints used in all models, followed by the financial derivatives equations that are added to each one according to which strategy is used. The section also covers the objective functions used by the manufacturer if they're risk averse or risk neutral.

Section 5 provides a brief explanation on simulation based optimization various settings. This is followed by identifying the six price fluctuating scenarios, used in modeling the commodity price movements to cover the different situations the manufacturer might encounter.

Sections 7 and 8 go through the hedging strategies that are modeled and the metrics used to measure how the hedging strategies perform, respectively.

This is followed by a section which defines the hedge-free model which sets the inventory limits that are used, as well as identifying how the hedge-free manufacturer performs without any derivatives under the six pricing schemes.

The last section summarizes the chapter.

## 4.1 Problem Definition

This section first explains what happens in the traditional inventory ordering policy and then describes how financial hedging can help, in order to define the general issue this thesis is tackling.

In the classical (s, S) approach, it is assumed a manufacturer, that uses a commodity in production, would choose its reorder point and order up to level based on the forecasted average demand and standard deviation. This is done without any regards to the potential price fluctuations the commodity might face.

If the manufacturer uses its budget to buy the required inventory in a time period to be stored and use it in the following time period, there are three potential scenarios the price might go through: it can increase, decrease or remain the same. If the price increases, then the early purchase will seem to have been a good decision that saved the manufacturer from the cost increase. If the price remains the same or decreases, the manufacturer will have lost the opportunity to profit by purchasing the inventory in the latter time period, while investing the funds in the earlier time period in a risk free endeavor. It should be noted that if the purchasing is made in the latter time period instead, then the manufacturer will have paid extra if the prices were lower in the earlier time period.

If financial hedging is introduced, then the manufacturer can use a part of its budget to purchase the inventory to be used in production and the rest can be used to purchase financial derivatives, such as options for example. If the manufacturer had call options purchased in a time period when inventory wasn't bought and prices then went up in the following one, then the manufacturer can exercise its right to buy inventory at the strike price to use in production or to sell at the higher existing market price. The selection of which type of derivatives to invest in would depend on the situation faced by the manufacturer and that is what the model in this thesis aims to shed light on.

Table 4 summarizes the mentioned differences.

*Table 4: Summary of difference between the traditional inventory approach and the integrated hedging approach*

| Classical Inventory Approach | Integrated Hedging Approach |
|---|---|
| In order to maximize profits, the manufacturer sets its inventory and ordering limits based on level of demand variability | In order to maximize profits, the manufacturer considers the levels of both demand and price variability |
| Inventory and ordering limits (operational hedging) are set to mitigate against the demand uncertainty | Operational hedging is used to mitigate against the demand uncertainty, while financial hedging is used for the price uncertainty |

**4. 2 General Considerations**

The case this paper looks at is that of a manufacturer over a three-month period. The manufacturer uses a commodity, whose price regularly changes each month, to use in the making of a product, which is sold at a fixed price, and has a fluctuating demand each month as well. They both follow a mean reverting process (i.e. are random but have a tendency to move to the average price over time, except for the price scenarios which have a trend).

The manufacturer follows a base stock model (s, S), where as soon as the inventory of the commodity on hand drops to a predetermined trigger point “s”, the manufacturer orders new supplies of the commodity to reach “S”. The limits are based on the hedge free model in 4.9.

It is assumed that 1 unit of the commodity is used to make 1 unit of the final product. The manufacturer purchases the commodity from the spot market each month according to the required amount. Excess inventory is carried over to the following period at a carrying charge, equivalent to the risk free interest rate, except in the last time period where they are sold as scrap at that period’s commodity spot price. Unmet demand is backlogged at a charge as well. There is a fixed ordering cost which is charged whenever an order takes place. Lead time is assumed to be sufficient to fulfill the month’s production requirements.

The manufacturer has a starting budget and the profits for each month are added to the following month’s budget. Any unused funds remaining from the budget are used to invest in a risk free endeavor (such as government bonds).

To financially hedge off the price risks the manufacturer faces, two strategies are used to model two levels of financial power it might have. First is the case of a financially “tight” manufacturer that has a budget which just suffices to cover the costs of purchasing. For this case, the model will determine how derivatives (call options vs. futures contracts) can be used to buy the commodity for its inventory to use in production; this approach will be referred to as “purchasing”. The second case considered is that of a more financially “relaxed” manufacturer that has extra funds which can be used in derivatives trading (call and put options vs. futures contracts). This approach will be referred to as “trading”.

It is assumed that the call and put options for the commodity in question are European, with a maturity of one month. Options bought each month can have different premiums, but calls and puts will each have the same strike price throughout the 3 periods. Futures are assumed to be bought at the current price/expected price from the previous time period, while options are priced according to the Black-Scholes-Merton model [12]. As explained in section 2.3, options are purchased by paying a premium in the beginning, whether or not the option is exercised. There are different models and theories on how this premium should be priced, but the most popular model is the one developed by Fischer Black, Myron Scholes and Robert Merton in 1973 for which they were awarded a Nobel Prize in Economics. The model calculates the premium for European call and put options by considering the underlying asset's current and strike prices, time to expiration, interest rates and the price volatility. The equations and insight behind the model are located in section 4.4.5.

The simulation-based optimization (simulations of 5,000 sets of numbers each) takes place over a 3 month period, where the manufacturer automatically buys the necessary inventory at the spot rate, unless otherwise mentioned, and uses the rest of the budget to invest in a risk free project of low return (government bonds) or with financial derivatives (call and put options and futures contracts). All the simulations including financial derivatives are compared to the ones that do not include them (but include the risk free project for the surplus funds).

The model determines how many derivatives of each type should be bought for the different price scenarios, based on the financial standing of the manufacturer and the type of risk it is willing to take to optimize profits (either being risk averse or risk neutral). This will provide some insight for managers as to which derivatives they should use, based on their financial position and risk targets.

To summarize, without financial hedging this manufacturer would just purchase the necessary commodity from the spot market each month based on the demand and the existing inventory levels, without giving any regard to the price of the commodity. Any funds remaining from the budget would be used to purchase risk-free bonds that would provide a low fixed income irrespective of the price of the commodity.

However with this model considering how volatile the price levels are and whether or not there is a trend, each month the manufacturer would be able to purchase some of the required inventory through derivatives, if it is limited in resources, or would be able to trade with derivatives. These financial hedging activities would help the manufacturer be more robust and less exposed to price fluctuations. The model determines how many of the derivatives should be bought each month, as well as the strike prices for options.

### 4.3 Variables and Parameters

The variables and parameters involved in the model are as follows:

Decision Variables

X: number of units to be purchased with futures

Nc: number of call options to buy
Kc: call option strike price
Np: number of put options to buy
Kp: put option strike price

Parameters
s: the manufacturer's unit selling price (100)
h: holding cost per period (0.23)
b: penalty cost per unit of unmet demand (20)
w: fixed ordering cost (500)
v, $\sigma_y$: commodity spot price average and volatility (50, 2.5 for low volatility and 15 for high volatility)
D, $\sigma_d$: demand per month (1000, 50)
F: futures price per unit
I: inventory status
Q: the quantity ordered each period (through the spot market unless otherwise mentioned)
(s, S): (inventory reorder trigger point, order up to level)
r: risk free interest rate (5.5%)
c: call premium to purchase one call option
p: call premium to purchase one put option
B: starting budget (100,000)
VaR: Value at risk
CVaR: conditional value at risk

### 4.4 General Equations and Objective Function

The following mean reverting equations are used to simulate the monthly demand and commodity prices [37]:

$$D_t = (1 - e^{-\alpha\Delta t})\overline{D} + e^{-\alpha\Delta t}D_{t-1} - 1 + \sigma_D\sqrt{\Delta t}\Phi(0,1) \tag{2}$$

$$y_t = (1 - e^{-\alpha\Delta t})\bar{y} + e^{-\alpha\Delta t}y_{t-1} - 1 + \sigma_y\sqrt{\Delta t}\Phi(0,1) \tag{3}$$

$\overline{D}, \bar{y}$: long term equilibrium demand and price levels
α: mean reverting speed (0.01)
$\sigma_D$, $\sigma_y$: annual volatility in demand and commodity price
$\Phi(0,1)$: random variable with mean and standard variation of (0, 1)
Δt: time between each period (in this case one month so Δt= 1/12)

#### 4.4.1 Inventory and Ordering Positions

$$Q_t = If(I_{t-1} \leq s, S - I_{t-1}, 0) \tag{4}$$

$$Inventory\ Surplus, I_{st} = Max(Q_t + I_{t-1} - D_t, 0) \tag{5}$$

$$Inventory\ Backlog, I_{bt} = Max(D_t - Q_t - I_{t-1}, 0) \tag{6}$$

$$I_t = I_{st} - I_{bt} \tag{7}$$

### 4.4.2 Holding and Backlog Costs

$$h * Max(I_t, 0) + b * Max(-1 * I_t, 0) \tag{8}$$

### 4.4.3 Ordering Costs

$$Q_t * y_t + If(Q_t > 0, w, 0) \tag{9}$$

### 4.4.4 Sales Revenue

$$s * Min\big(D_t + Max(I_{bt-1}, 0), Q_t + Max(I_{st-1}, 0)\big) \tag{10}$$

Except for t=3 where, as mentioned in 3.1, excess inventory is sold in the spot market, the following expression is added to the one above:

$$Max(I_3, 0) * y_3 \tag{11}$$

### 4.4.5 Call and Put Options

For the pricing of call and put options' premiums, the famous Black-Scholes-Merton formula is used [12]:

$$c = yN(d_1) - N(d_2)K_c e^{-rt} \tag{12}$$

$$p = K_p e^{-rt} N(-d_2) - yN(-d_1) \tag{13}$$

where,

$$d_1 = \frac{\ln\left(\frac{y}{K}\right) + \left(r + \frac{\sigma_y{}^2}{2}\right)t}{\sigma_y \sqrt{t}} \tag{14}$$

$$d_2 = d_1 - \sigma_y \sqrt{t} \tag{15}$$

Where N(x) refers to the cumulative probability distribution for a standardize normal distribution.

It can be seen from the Black-Scholes-Merton formula that the premium paid increases as the option's time to maturity increases. This is because the longer the time to maturity, the more chances there are for the asset's price to move beyond the strike price. Even though the option can only be exercised at the time of maturity, its value still fluctuates with the price movements the underlying asset goes through; meaning the call option's price would appreciate when the asset price goes up and the put option's price would appreciate when the asset price goes down. The same logic applies for the asset's volatility level; the higher it is, the more chances there are for the options holder to have their options in the money (beyond the strike price).

The following three equations are constraints on the number of options that can be bought at any period, strike prices and premiums non-negativity

$$0 \leq Nct, Npt \leq 10000 \tag{16}$$

$$10 \leq K_c, K_p \leq 90 \tag{17}$$

$$0 \leq c_t, p_t \tag{18}$$

These two equations are the profits for any model which include calls and/or puts that aren't used for purchases, but just for hedging through derivatives trading:

$$Call\ options: 100 * Nct * (Max(y_t - K_c, 0) - c_t) \tag{19}$$

$$Put\ options: 100 * Npt * \left(Max\left(K_p - y_t, 0\right) - p_t\right) \tag{20}$$

The ordering costs in 4.4.3 are replaced by these equations if calls are used for purchasing inventory:

$$\begin{aligned} If(y_t \geq K_c, N_{ct} * K_c, 0) + K_c c_t + y_y * \left(Q_t - If(y_t \geq K_c, N_{ct} * K_c, 0)\right) \\ + If(Q_t > 0, w, 0) \end{aligned} \tag{21}$$

It should be noted from the above equations that the premiums are charged in all cases, but the strike price purchasing and revenue are only counted when the option becomes in or at the money.

### 4.4.6 Futures Contracts

The following equation is used to represent the profit from using futures contracts as a hedging tool when used in trading:

$$X_t(y_t - F) \tag{22}$$

The ordering costs in 4.4.3 are replaced by this equation if futures are used for purchasing inventory:

$$X_t F + y_t(Q_t - X_t) + If(Q_t > 0, w, 0) \tag{23}$$

### 4.4.7 Budget

The sum of all the mentioned costs used in purchasing inventory and in financial hedging each month, is subject to a constraint preventing them from surpassing that month's budget. All funds remaining are used to purchase risk free bonds, with their returns being added to the profits.

The initial budget and the additional generated profits are then set as the following month's budget.

### 4.4.8 Objective Function

The profits are calculated by deducting all the previously mentioned costs from the sales revenue equation, in addition to the revenue and expenses of the derivatives being used. The objective function is also dependent on whether the manufacturer is risk-averse or risk-neutral.

## 4.5 Simulation Settings

As there is a factor of uncertainty in terms of the demand and price inputs, simulation optimization is used to go through many iterations to improve the objective function based on thousands of generated sets of input. This thesis uses a simulation based optimization tool provided by @Risk, an excel add-on provided by the Palisade Corporation as part of their Decision Tools Suite. Starting with initial values of the decision variables, Risk Optimizer combines the Monte Carlo simulation system and powerful optimization tools to allow the optimization of models that have uncertain factors.

Each scenario is simulated with 5,000 iterations generated. In each iteration, a random value is generated for the price and demand functions based on their probability distributions. Then the software uses genetic algorithms to find solutions for the decision variables which can further improve the value of the objective functions [13]. Each simulation had a run time of two and a half hours, on a 2.40 GHz processor, to find an optimal solution. 54 simulations were run to cover the two risk approaches, the two hedging strategies, the two types of derivatives being studied, the two price volatility levels, the three price trends and the hedge free model for each price scenario.

For the objective of maximizing the profits' value at risk, the software seeks a solution that optimizes the $5^{th}$ percentile from the profits distribution, rather than just the average [12].

For the objective of maximizing the profits' average, the software seeks a solution that optimizes the $50^{th}$ percentile of profits while considering the VaR constraint.

### 4.6 Risk Approach

In the expected utility theory, a risk averse approach would lead the utility function to follow a concave shape, meaning an investor would prefer to receive a guaranteed return that is less in value than the expected utility. A risk neutral approach concerned with the mean profits represents the linear part of the utility function and a risk seeking approach represent the convex segment [39].

For a risk-averse manufacturer, it is assumed that it would like to maximize the value-at-risk (VaR) of its profits, similar to an investor concerned about the worst-case scenario of their investment as discussed earlier in section 2.2.3. This means that the objective is to maximize the $5^{th}$ percentile of its profits from the profits probability distribution. For Monte-Carlo based simulations of 5,000 scenarios, as in this report, it means that the objective is to maximize the $250^{th}$ lowest profit value (the $5^{th}$ percentile) from the profit distribution generated from the selected decision variables.

For the risk-neutral manufacturer, the objective is to maximize its average profits. However in order to display the advantages of using derivatives for this type of manufacturer, an extra constraint is added to the model, which is not to have a value at risk lower than that without derivatives.

A risk-seeking manufacturer that would want to maximize its best case scenario profits is not considered, since it is not a regular risk approach a company would practically consider.

The financial literature covers many different optimization techniques. The model in this thesis can be looked at being similar to the classical mean-variance approach.

Assuming that an investor's return can be represented by a function of their profit distribution's mean and variance, the optimal situation for them would be to have a high profit mean and low variance. This translates to either achieving the smallest possible variance for a given level of average profits, or making the highest possible profit for a certain level of variability [9].

The objective functions for the models in this report are similar to the mean-variance approach, but instead of the variance, the profit Value-at-Risk (VaR) is used, but since in this case the VaR is measured for the profits and not the costs; the higher the VaR the better.

The risk averse approach, where the VaR is being maximized, can be viewed as the mean-variance approach when trying to reduce the variability at a certain level of profit. The risk neutral approach seeks to maximize the average return, given a minimum profit VaR, and this is similar to when the return is being maximized given a level of variability. However, considering the importance of the profit variability, it is still used as a metric to compare between models.

### 4.7 The Use of Financial Hedging Tools

This thesis looks at two types of financial hedging activities in which the manufacturer can engage depending on its available financial resources.

#### 4.7.1 Purchasing with Financial Derivatives

The first method, involves using call options or futures contracts for purchasing the commodity itself for the manufacturer's inventory, to be used in manufacturing alongside the regular purchasing from the spot market. This method is useful when a manufacturer does not have extra funds to engage in any trading operations.

In the beginning of the month, the call option premium is paid to give the manufacturer the right to purchase the commodity at the strike price when the commodity's spot rate is revealed. If the spot rate is higher than the strike, the manufacturer will go ahead and get the contracted amount at the strike price. If the spot rate is lower however, the manufacturer will have to buy at the spot price for acquiring their supplies, however the manufacturer will have already paid the call premium in the beginning of the month without exercising the option.

The second derivative looked at for procuring the commodity are futures contracts, where the manufacturer arranges to purchase its requirements at the previous month's rate. The difference between this arrangement and the one before is that the manufacturer pays for the contracted amount in full, regardless of whether or not the new spot rate is higher or lower than the price specified in the contract.

So the objective of this approach is to decide how much of the inventory should be purchased from the spot market, at the spot rate, and how much should be purchased using these derivatives.

#### 4.7.2 Trading with Financial Derivatives

The second method is to use any extra funds from the budget to purchase call and put options or futures contracts on the commodity. In this method, the manufacturer can offset variations in the commodity's price by trading with these derivatives, where this would take place "in parallel" to the manufacturer's regular activity to "absorb" these price fluctuations.

For call and put options, the manufacturer can purchase them at the beginning of the month and pay their premiums fully, their prices will depend on the actual price the commodity reached in the previous month. Once the spot prices are realized in the new month, the manufacturer can exercise those options and reap their returns if their strikes prices were reached (for call options, that means buying the commodity at the strike price and selling at the actual higher spot price and for put options, that means selling them at the strike price and purchasing them at the lower spot price), otherwise the manufacturer will have just paid their premiums from the beginning of the month when the options were initially bought.

For futures contracts, the manufacturer sets to buy the contracts at the commodity's current price in the beginning of the month and holds on to them until the new spot price is revealed. At that point, the manufacturer exercises the contract and purchases the commodity and sells it at the new spot price, or just immediately sells the contract to someone else at the current price. As discussed in the previous chapter, futures contracts do not have any premiums to pay, but are always "in the money", so the manufacturer is committed to proceed with the entire transaction for better or worse.

So the objective of this approach is to decide how much money remaining from the budget, after purchasing inventory for production, should be invested in these financial tools and not in risk-free bonds.

### 4.8 Price Simulation Scenarios

In order to identify which derivatives under which circumstances would best suit the manufacturer; two levels of price volatility are used to represent a high level one and a low level one, 30% for the high level case and 5% for the lower level case. These are based on the figures used in similar work [13] [37]. The following scenarios regarding price fluctuations are covered:

1. Price variability of 30% with no trends
2. Price variability of 5% with no trends
3. Price variability of 30% with an increasing trend
4. Price variability of 5% with an increasing trend

5. Price variability of 30% with a deceasing trend
6. Price variability of 5% with a decreasing trend

In order to model the price trends, a small adjustment is made to the price modeling equation mentioned in 4.4, where instead of using $\Phi$ with a normal distribution of mean 0 and a standard deviation of 1, the mean is replaced by 0.5 for the price increasing trend model and with -0.5 for the price decreasing trend model [13] [37].

Figure 3 summarizes the different factors the model looks at.

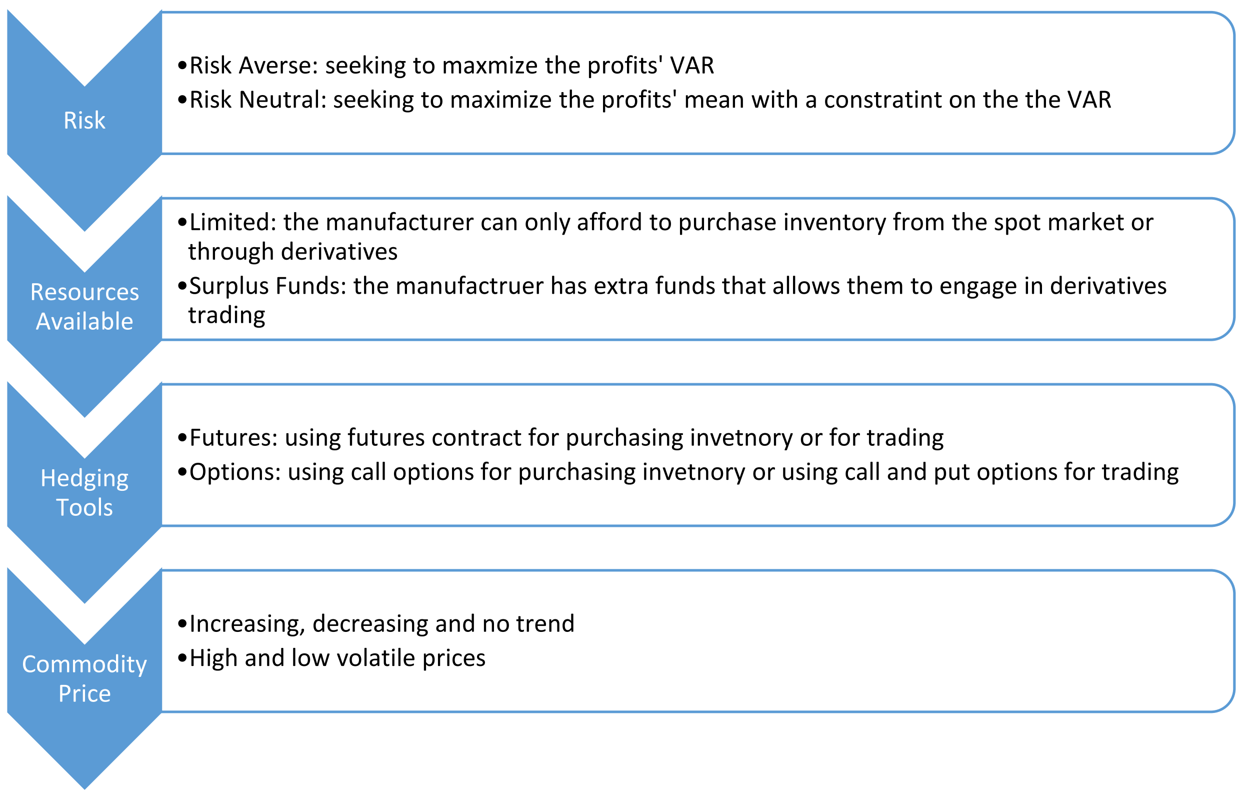



*Figure 3: Summary of models being looked at*

### 4.9 Metrics

To compare between strategies objectively, table 5 shows the four metrics used to measure the manufacturer's' profits.

*Table 5: Metrics used*

| | |
|---|---|
| **Mean** | Simply the average profits achieved which remains a standard metric. |

| | |
|---|---|
| | The objective of the risk-neutral manufacturer is to maximize this figure. |
| **Standard deviation** | An important metric which helps determine the level of risk as it measures how "consistent" the average is. |
| **Value-at-Risk (VaR)** | A standard risk metric used by financial and risk managers.<br>The objective of the risk-averse manufacturer is to maximize this figure.<br>It is obtained by identifying the $5^{th}$ percentile of the profit distributions (i.e. the $250^{th}$ worst profit scenario out of 5,000) |
| **Conditional Value-at-Risk (CVaR)** | Measures the average profit/ loss under the VaR.<br>It is obtained by calculating the average profit/ loss of the worst 250 profit results out of 5,000 |

### 4.10 The Hedge-Free Model

In order to properly identify whether or not the use of financial hedging tools can provide any benefits and where they stand exactly; a hedge-free model (without futures or options) is created whose objective is to maximize the manufacturer's profits by setting the limits for the base stock model's reordering point and ordering level (s, S).

This is the only model where the decision variables are going to be the inventory limits, as these resulting ordering limits will be used in all scenarios, since it is assumed the manufacturer cannot keep changing its inventory limits with each different price scenario and with each different use of financial derivatives.

In this model, all extra funds remaining from the budget after purchasing the necessary inventory are used to be invested in the risk-free project.

The model is run for 5,000 iterations (i.e. 5,000 sets of numbers) and the optimal model provided a reorder limit "s" equal to 1086 and an order up to level "S" of 2141.

With these ordering limits now set in place, the model is run under the six different prices scenarios mentioned earlier without any derivatives and the results shown in table 6 are obtained:

*Table 6: Results of the hedge-free model*

| Price Scheme | Mean | σ | VaR | CVaR |
|---|---|---|---|---|
| **Price volatility of 30% with no trend** | 299,141 | 11,143 | 281,031 | 276,533 |
| **Price volatility of 5% with no trend** | 299,080 | 4,887 | 291,413 | 288,702 |
| **Price volatility of 30% with an increasing trend** | 290,963 | 11,138 | 273,065 | 271,250 |
| **Price volatility of 5% with an increasing trend** | 297,752 | 4,722 | 290,139 | 287,634 |
| **Price volatility of 30% with a decreasing trend** | 307,268 | 11,219 | 289,143 | 285,309 |
| **Price volatility of 5% with a decreasing trend** | 300,488 | 4,686 | 292,818 | 290,766 |

The results for the hedged models are located in chapter 5. Figure 4 shows one of the graphs plotting the profit distribution of a hedge-free model. It can be seen that it has a normal bell shaped curve with a high level of symmetry (skewness).

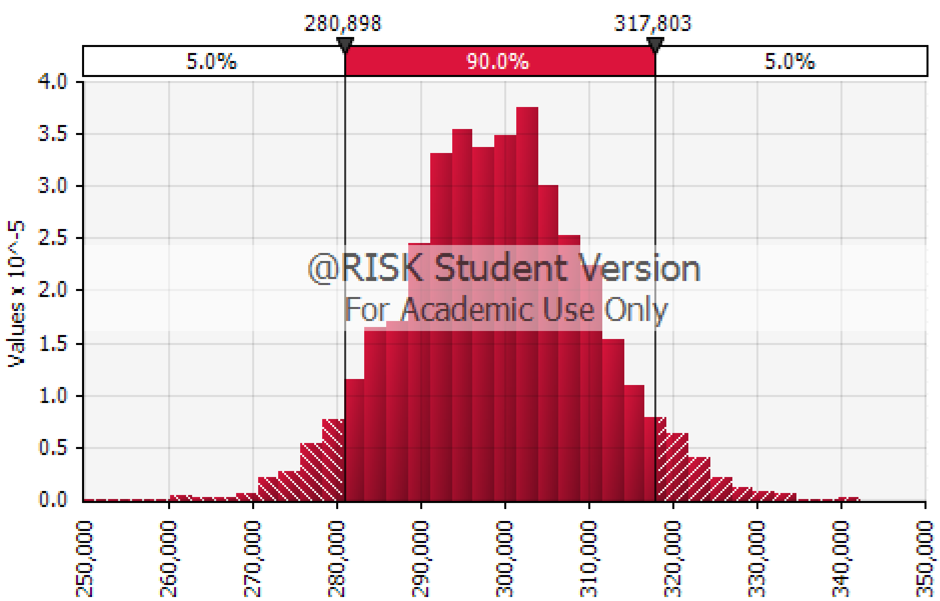



*Figure 4: Profit distribution without hedging with 30% price volatility and no trend*

The graphs plotting the other hedge free profit distributions are located in the appendix of the report. They all more or less have a regular bell shaped curve.

These results are then compared in the next two chapters with the hedged models' figures, who are modeled using the same (s, S) limits used here.

### 4.11 Summary

The model considers two types of manufacturers; a risk averse one, who wants to maximize its profits' value at risk, and a risk neutral one, who wants to maximize its average profits while not going below the value at risk they would encounter without any financial derivatives.

The financial derivatives can be used in two different ways depending on the manufacturer's available resources; either engaging in derivatives trading, using call and put options or futures contracts, or can be used to actually purchase some of the commodity for production in combination with spot market procuring.

All of this is modeled in 6 different price fluctuating situations, where they can have high or low price variability levels, as well as an increasing, decreasing or random trend.

The model will provide a practical guide for procurement managers who face price fluctuations on how they can hedge off these price movements. This gives insight on which derivatives a manufacturer, of two different mindsets and two different abilities, would benefit from under the six different scenarios mentioned earlier.

# 5. DISCUSSION AND IMPLICATIONS OF RESULTS

This chapter refers to the results obtained from the different models in the previous chapter using the @Risk software. The goal was to optimize the expected value of the objective function. Since these are stochastic programming models, we used simulation based optimization. Random values of the probabilistic input with continuous distributions are generated using the simulation program available with @Risk. It is expected that the solutions should be close to optimal. We generated 5,000 scenarios based on the on the probabilistic distributions of the inputs. The software's solver then worked on improving the objective function using its generic engine over the course of 5,000 iterations.

For each simulation scenario, the results for the financially hedged and non-hedged versions are displayed to compare. We compare the VaR profit and the average profit for the risk averse and the risk neutral manufacturer respectively. In case of a tie of results, the profits mean (for the ones maximizing the VaR), the profits VaR (for the ones maximizing the mean), the CVaR and the standard deviation are considered.

This first section of the chapter covers the results recorded for the risk averse manufacturer, which is attempting to optimize the profits' value at risk. The following section covers the results for the risk neutral manufacturer, which is maximizing the average profits with a constraint on the profit VaR. This is followed by a section that discusses the observed results.

## 5.1 Risk Averse Manufacturer

This section covers the risk averse approach when optimizing profits.

### 5.1.1 High Price Variability without a Trend

This section covers the results obtained for a risk averse manufacturer facing a price volatility of 30% without any trends.

Figure 5 presents the mean, VaR, and CVaR for each strategy:

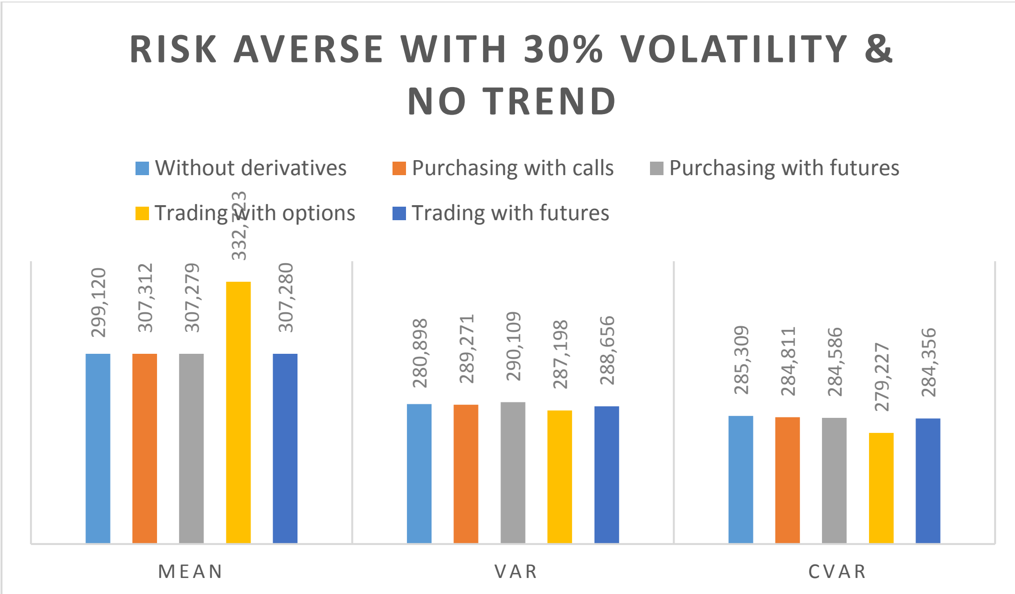


*Figure 5: Summary of risk averse approach with 30% volatility and no trend*

Standard deviation for each strategy is presented in table 7.

*Table 7: Standard deviations of risk averse approach with 30% volatility and no trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Trading with calls & puts | Trading with futures |
|---|---|---|---|---|---|
| σ | 11,112 | 6,975 | 6,856 | 6,969 | 4,315 |

Firstly, it can be observed under these circumstances that using derivatives in any fashion leads to more successful figures with regards to the objective; similar profits are achieved but with a higher VaR, higher CVaR and with significantly lower levels of variation.

In this scenario and strategy, there does not seem to be much difference between using call options or future contracts, when purchasing inventory alongside the spot market. Both lead to average profits that aren't any different from when derivatives aren't used. They also improve the profits' VaR by nearly 2.5%, while reducing the profit distribution standard variation by around 37%, bringing in more stability to the manufacturer's profits. However, it would be recommended for the manufacturer to use futures rather than call options, since a slightly higher CVaR improvement of 4.3% was realized, as opposed to the 3% improvement presented by the use of call options.

Figure 6 shows the profit distribution the manufacturer receives when using call options and futures contracts for purchasing inventory respectively.

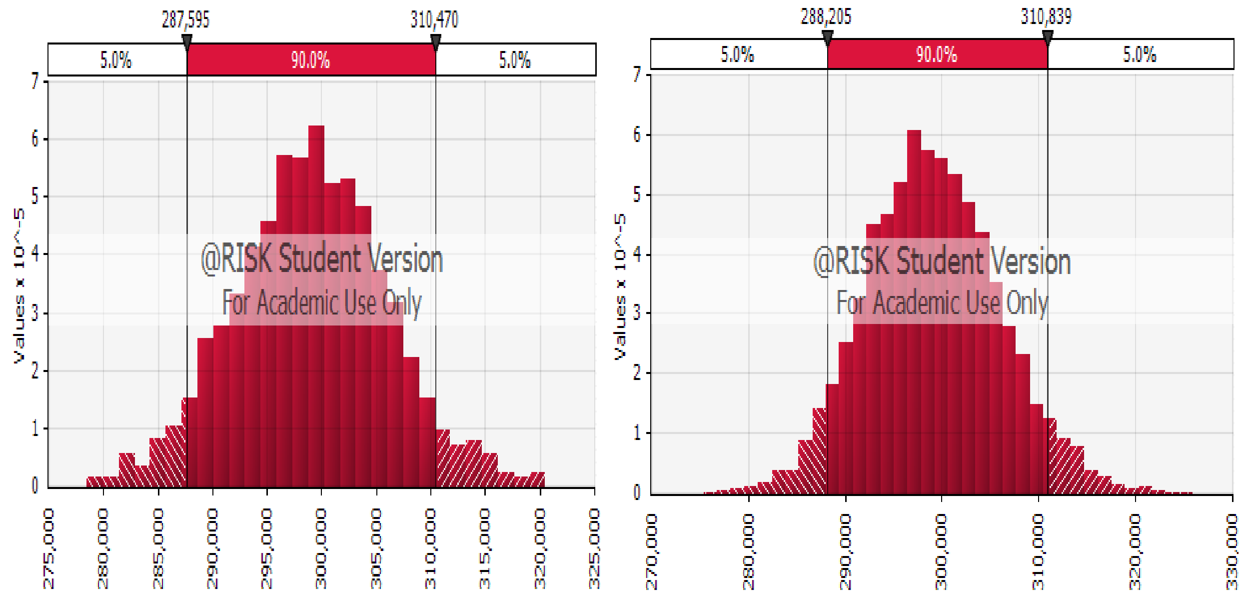



*Figure 6: Profit distribution purchasing with call options and futures contracts with 30% price volatility and no trend*

Both graphs resemble the regular normal bell curve with a high level of skewness, however, the call options graph has a slightly lower level of kurtosis as can be seen from the "thicker" tails which is why they produced a higher level of variation and lower CVaR than futures contracts.

For the other approach of using extra funds to trade with, average profits were similar to the case of the hedge-free figure, but the use of futures contracts outperformed trading with options by reducing the profits standard variation by 61% as opposed to 40%, raising profits VaR by 4.16% as opposed to 2.3%, and raising the profit CVaR by nearly 5%, while options trading did not really raise it. Figure 7 shows the profit distributions for the trading strategies.

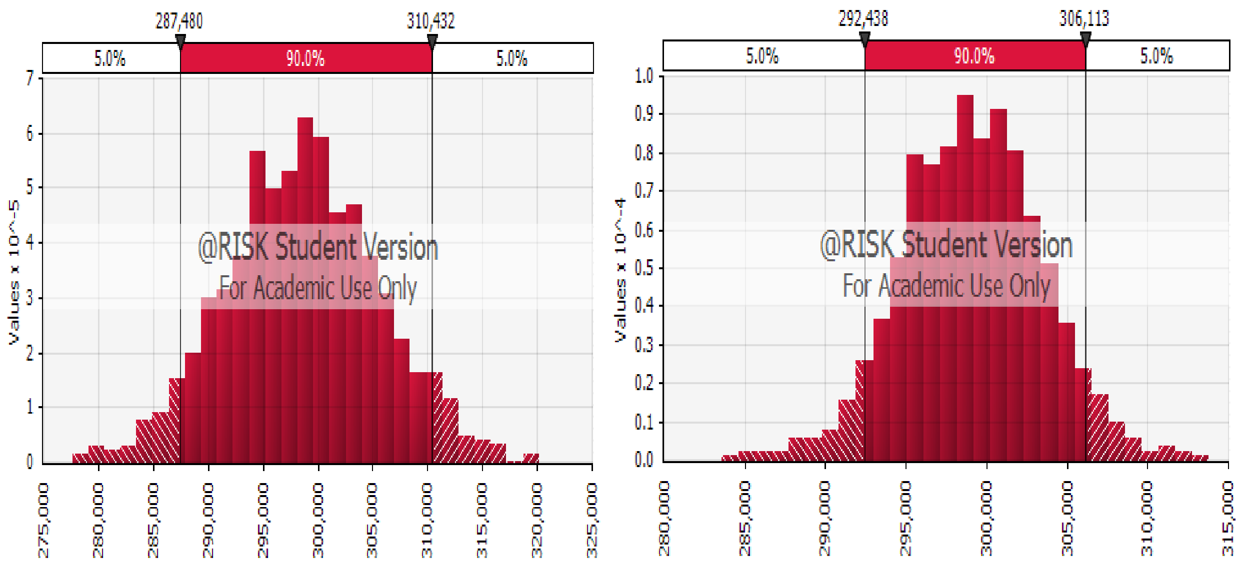



*Figure 7: Profit distribution trading with options and futures contracts with 30% price volatility and no trend*

### 5.1.2 Low Price Variability with no Trend

This section covers the results obtained for a risk averse manufacturer facing a price volatility of 5% without any trends.

Figure 8 presents the mean, VaR, and CVaR for each strategy:

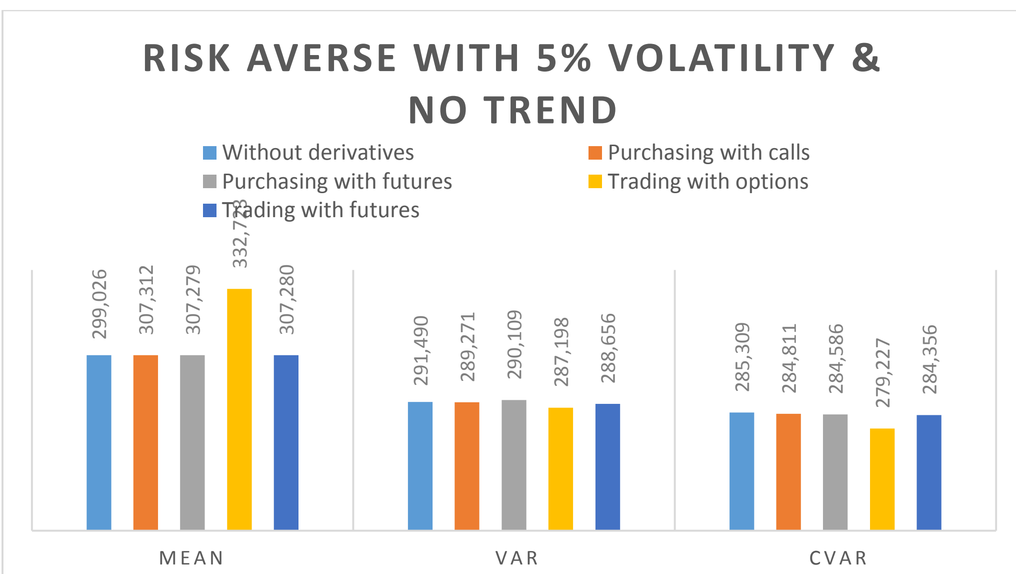



*Figure 8: Summary of risk averse approach with 5% volatility and no trend*

Standard deviation for each strategy is presented in table 8.

Table 8: Standard deviations of risk averse approach with 5% volatility and no trend

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 5,385 | 5,270 | 5,215 | 5,496 | 4,235 |

The first thing to note is that the hedge-free model improved greatly from the previous section, when the price had a high level of variability. Profits are more "secure", since the manufacturer achieves the same profit, but with half the standard deviation it had before and with lower levels of risk, due to the higher VaR and CVaR.

Purchasing inventory improved the VaR by nearly 0.5% under both strategies, as similar average and CVaR profits are achieved.

Due to the very limited extra benefit provided to the VaR and the higher standard deviation, it might be recommended not to use any derivatives when purchasing inventory in a trend-free low volatile price scenario. The graphs for these profit distributions are shown in figure 9.

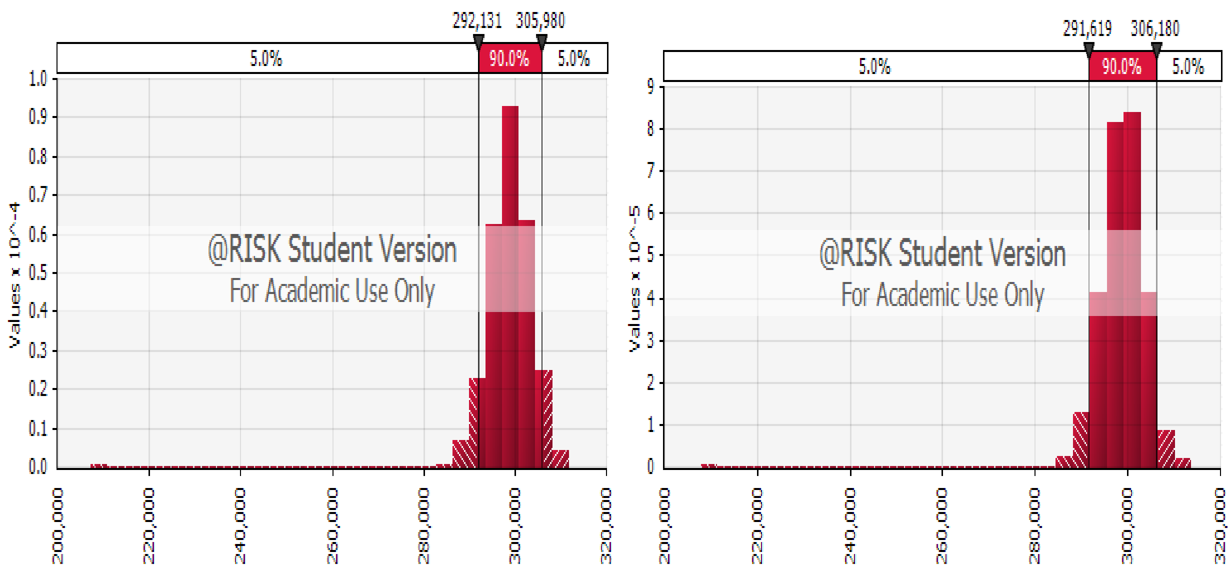



Figure 9: Profit distribution purchasing with futures contracts and call options with 5% price volatility and no trend

Similarly, the VaR does not really differ much between the hedge-free model and the hedged ones, when extra funds are used in trading. The only significant different figure observed was the reduction in the profit standard deviation when futures contracts are traded, they managed to reduce it from the hedge-free one by nearly 15% at similar levels of average profits, VaR and CVaR. Shown in figure 10 are the profit distributions for each one.

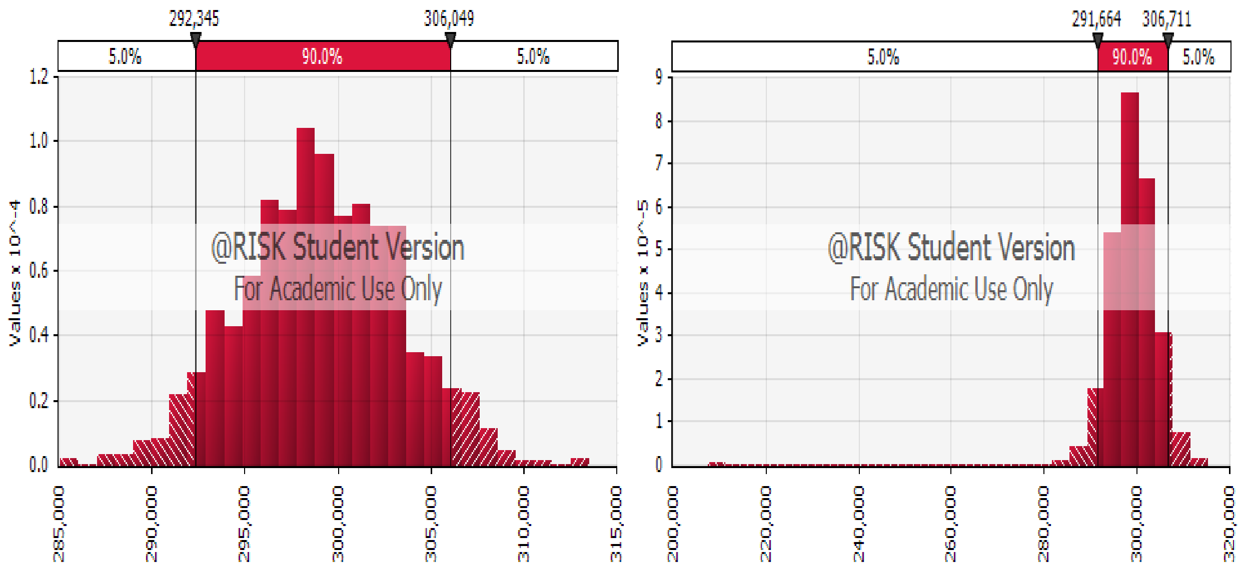



*Figure 10: Profit distribution trading with futures contracts and options with 5% price volatility and no trend*

### 5.1.3 High Price Variability with an Increasing Trend

This section covers the results obtained for a risk averse manufacturer facing a price volatility of 30% with an increasing trend.

Figure 11 presents the mean, VaR, and CVaR for each strategy:

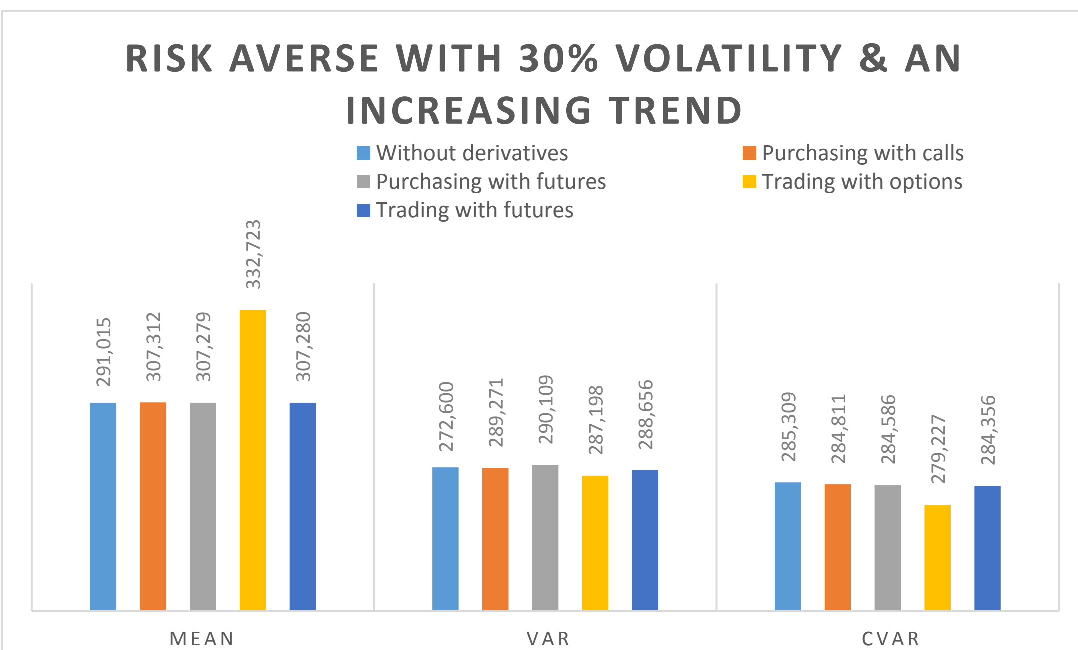



*Figure 11: Summary of risk averse approach with 30% volatility and an increasing trend*

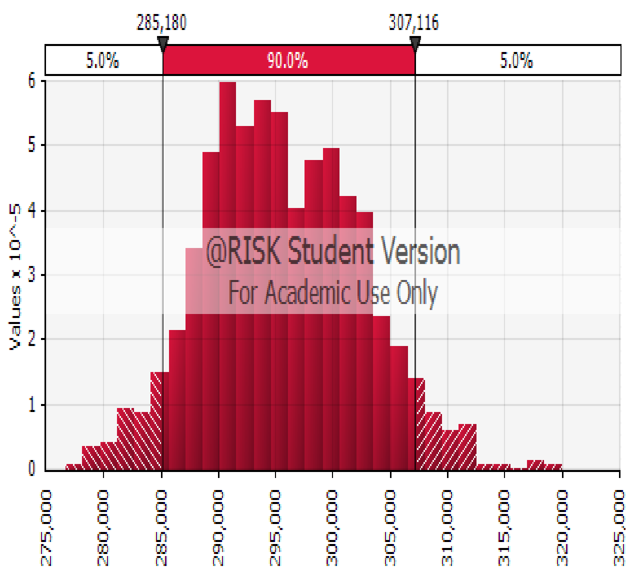
Standard deviation for each strategy is presented in table 9.

*Table 9: Standard deviations of risk averse approach with 30% volatility and an increasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 10,967 | 7,207 | 6,787 | 8,253 | 5,101 |

In this scenario the manufacturer's profits figures drop on all fronts from the previous case, as its purchasing costs rise due to the increasing prices. The manufacturer faces higher costs, while its income remains fixed since the selling price does not change from before and therefore incurs lower profit margins. Another observation that should be noted is that when derivatives are used in any way here, there is a raise the manufacturer's average profits, which was not the case when the prices were random and without any trends.

Using call options or futures contracts in this situation does not really differ, as both raise the VaR and CVaR by nearly 5% and reduce the standard deviation by nearly 35%. The only difference is that the use of call options raise average profits by 2%, while the futures contracts raise it by 1.5% and futures contracts lead to a slightly higher CVaR. Figure 12 shows the profit distributions obtained when purchasing with derivatives.



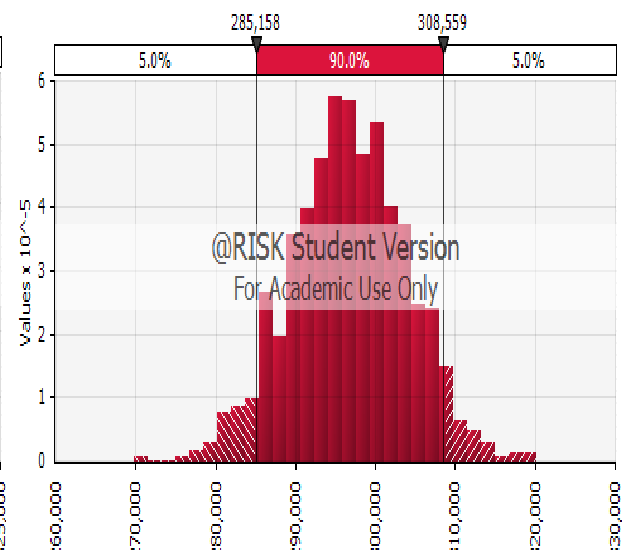




*Figure 12: Profit distribution purchasing with futures contracts and call options with 30% price volatility and an increasing trend*

Trading with options and derivatives improve the manufacturer's profit VaR by 7% and 7.5% respectively. Both tools perform well in this case, but it seems the secured prices provided by futures contracts make them the more attractive alternative here. Figure 13 shows the profit distributions obtained using the trading strategy.

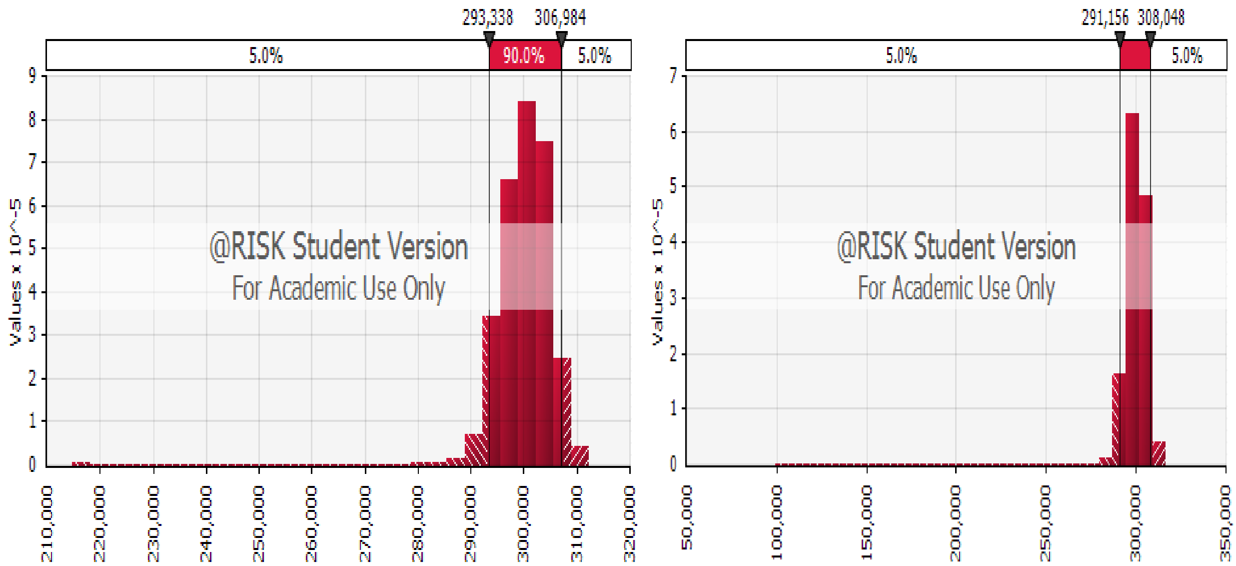



*Figure 13: Profit distribution trading with futures contracts and options with 30% price volatility and an increasing trend*

Although the profit distribution is not symmetrical as more data points concentrated on left tail of the distribution (low level of skenwness), but the narrow spread (lower standard deviation or high level of kurtosis) around the mean still provide better results in terms of the risk metrics (VaR and CVaR).

### 5.1.4 Low Price Variability with an Increasing Trend

This section covers the results obtained for a risk averse manufacturer facing a price volatility of 5% with an increasing trend.

Figure 14 presents the mean, VaR, and CVaR for each strategy:

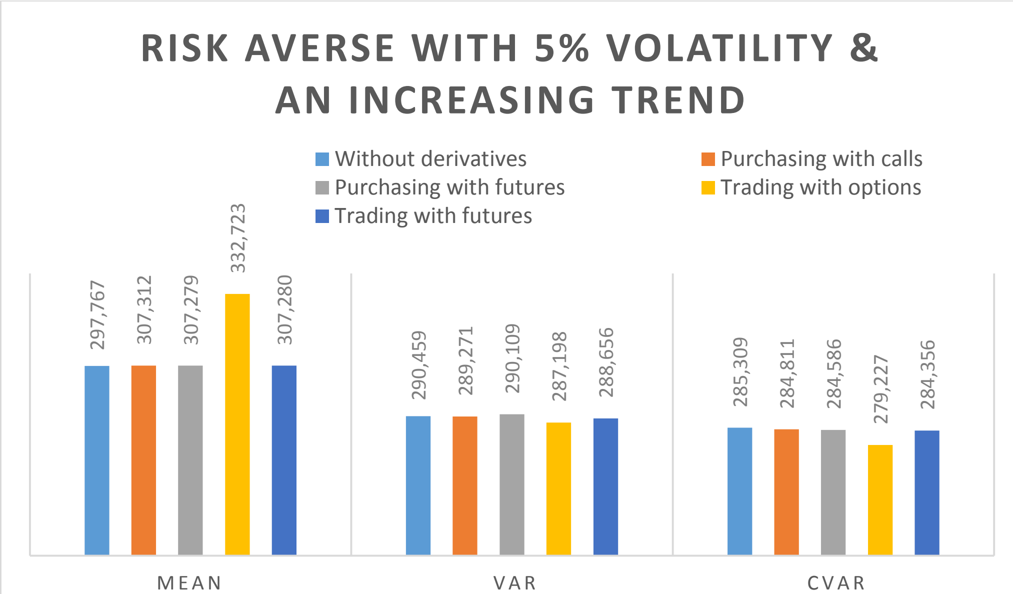


*Figure 14: Summary of risk averse approach with 5% volatility and an increasing trend*

Standard deviation for each strategy is presented in table 10.

*Table 10: Standard deviations of risk averse approach with 5% volatility and an increasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 4,461 | 4,286 | 4,222 | 4,646 | 4,408 |

As was the case before when there was no trend; the low variability leads the hedge-free model to better results on all fronts than the high variability one.

Purchasing with call options improves the VaR by nearly 3% at a slightly lower level of variability than the hedge-free model, in addition to a slightly higher average profit. Call options surpass futures contracts in terms of the benefits provided in this scenario.

Figure 15 shows the profit distribution obtained from the purchasing strategy.

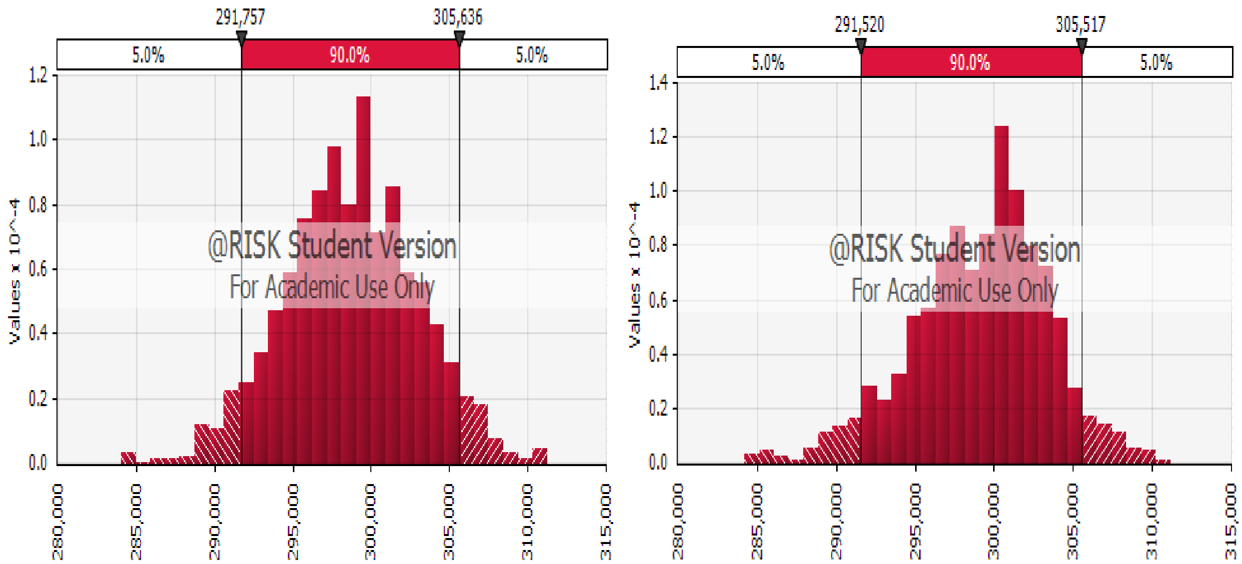



*Figure 15: Profit distribution purchasing with futures contracts and call options with 5% price volatility and an increasing trend*

Trading with derivatives under this scenario deliver limited improvements, as the low price variability offers very small price movements, providing limited opportunities for buying and then selling derivatives, especially when the alternative is a risk free project who has a similar return rate in this case.

The graphs for the use of derivatives in trading are shown in figure 16.

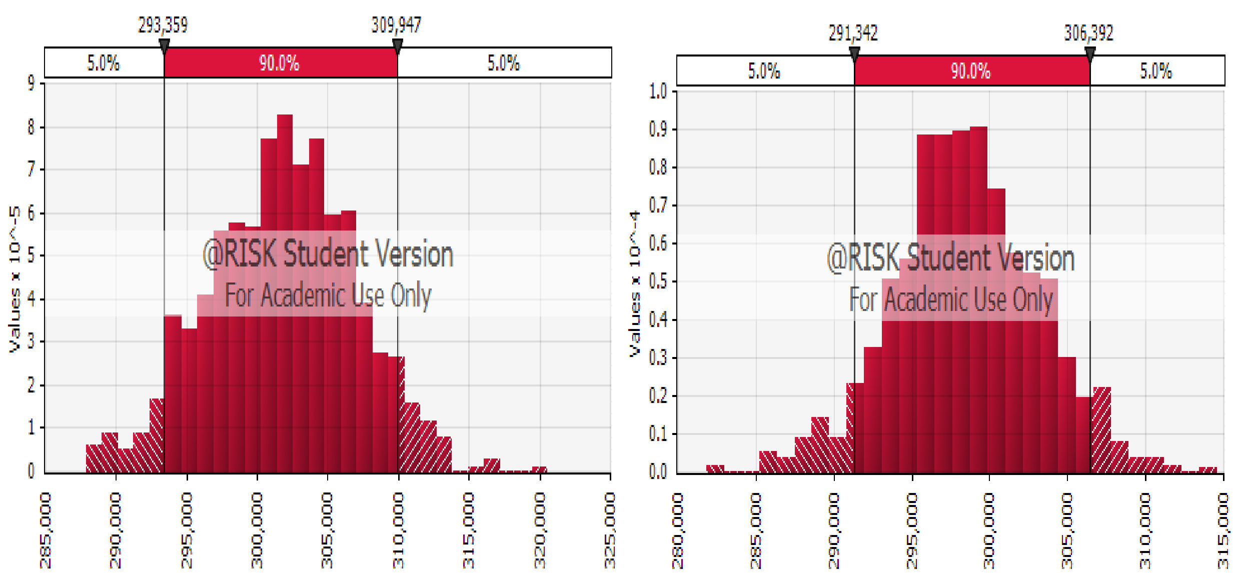



*Figure 16: Profit distribution with futures contracts and options with 5% price volatility and an increasing trend*

### 5.1.5 High Price Variability with a Decreasing Trend

This section covers the results obtained for a risk averse manufacturer facing a price volatility of 30% with a decreasing trend.

Figure 17 presents the mean, VaR, and CVaR for each strategy:

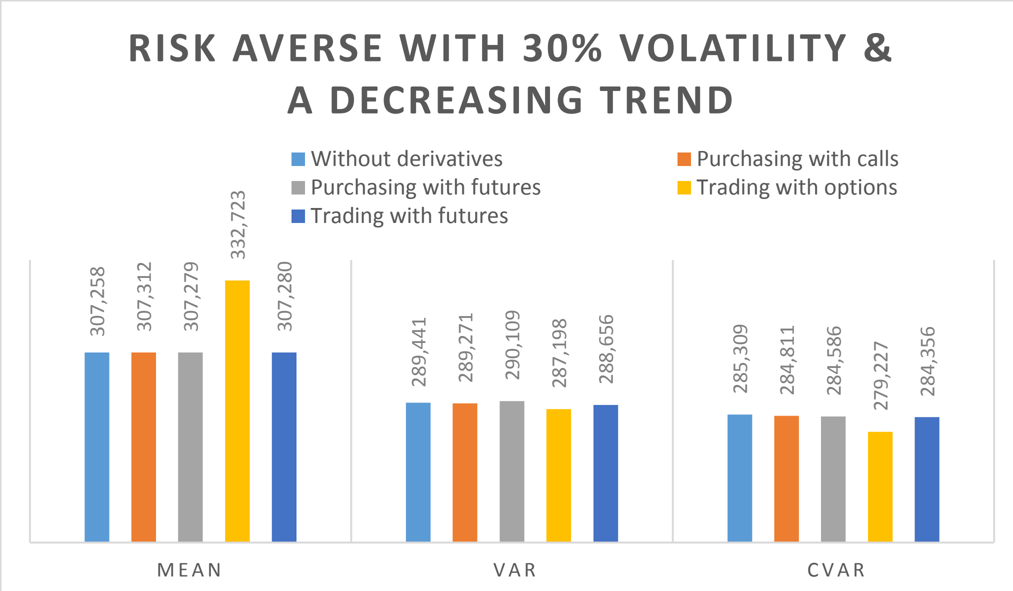



*Figure 17: Summary of risk averse approach with 30% volatility and a decreasing trend*

Standard deviation for each strategy is presented in table 11.

*Table 11: Standard deviations of risk averse approach with 30% volatility and a decreasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 11,284 | 7,867 | 8,029 | 6,528 | 4,950 |

With prices dropping each period, the manufacturer is able to purchase inventory cheaper and therefore more capable to generate higher profits, with better "risk measures" evident in the higher VaR and CVaR figures.

The use of derivatives for purchasing or trading under this scenario yielded better results in terms of the VaR, CVaR and the profit standard deviation, but this takes place at the expense of a slightly lower average profit. Since this is a risk averse manufacturer that is being looked at however, the benefits provided outweigh this single disadvantage, as a risk averse manufacturer would be more concerned with the risk of its operations rather than the average profits.

Purchasing inventory with call options and futures contracts result in similar improvements in terms of the profit VaR, CVaR and standard deviations, no one derivative seems to have the upper hand in this situation.

It might seem a bit counter-intuitive to use call options or futures contracts when purchasing inventory in this case, since both rely on prices going up to provide benefit, but the fact that the manufacturer is risk averse, and prices have a high level of volatility, means that these derivatives have a role to play here, albeit limited, as a backup deterrent should prices go up.

Trading with options and futures contracts also produce similar results (mean, VaR and CVaR), but futures contracts do have a better standard deviation at the same mean level, as it is reduced by more than a half.

Figures 18 and 19 show the graphs plotting the profit distributions obtained when derivatives are in use for purchasing and trading respectively:

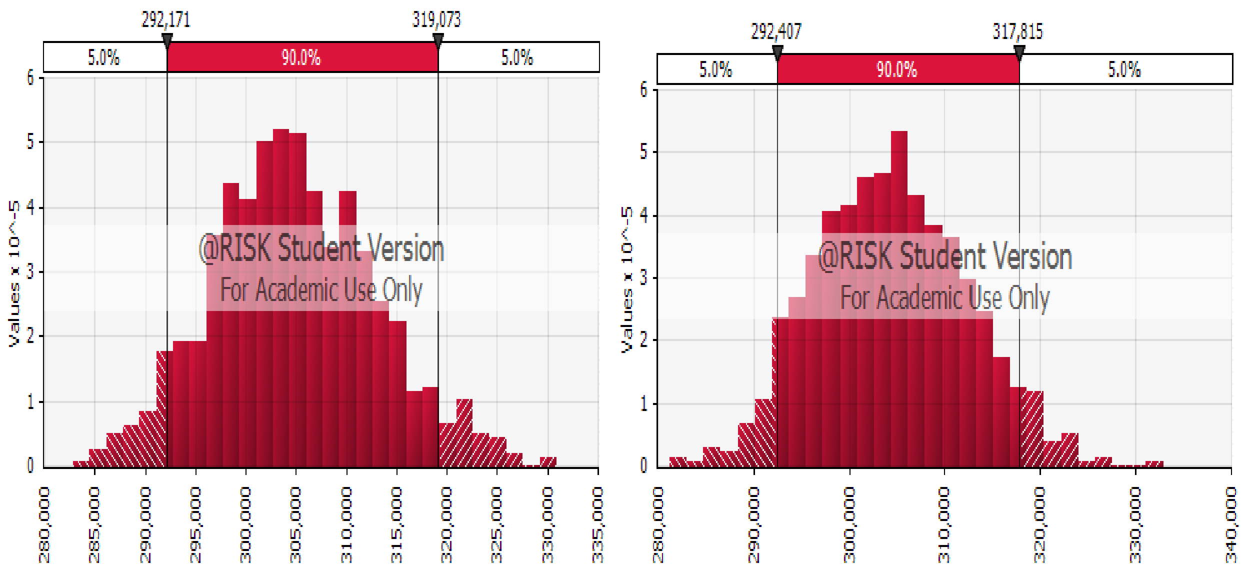
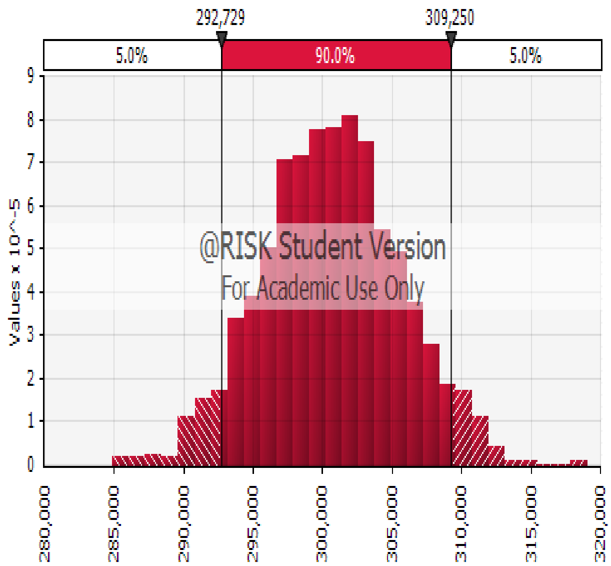



*Figure 18: Profit distribution purchasing with futures contracts and call options with 30% price volatility and a decreasing trend*



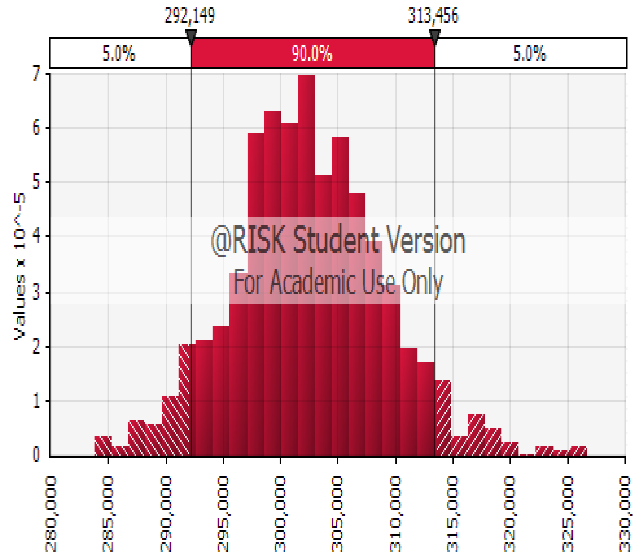




*Figure 19: Profit distribution trading with futures contracts and options with 30% price volatility and a decreasing trend*

### 5.1.6 Low Price Variability with a Decreasing Trend

This section covers the results obtained for a risk averse manufacturer facing a price volatility of 5% with a decreasing trend.

Figure 20 presents the mean, VaR, and CVaR for each strategy:

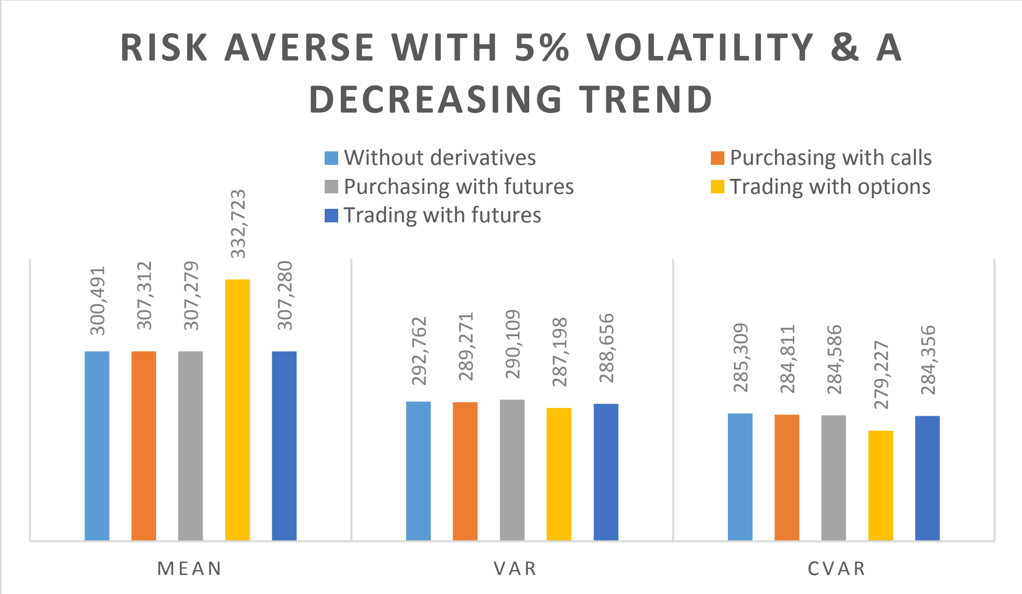



*Figure 20: Summary of risk averse approach with 5% volatility and a decreasing trend*

Standard deviation for each strategy is presented in table 12.

*Table 12: Standard deviations of risk averse approach with 5% volatility and a decreasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 4,774 | 4,845 | 4,733 | 10,543 | 4,474 |

In terms of risk, this is the best case scenario for the hedge-free manufacturer, as it receives the highest VaR and CVaR among all price scenarios.

As opposed to the previous case with high volatility and decreasing prices, purchasing inventory with calls or futures have no role in this case, as the low volatility price movement do not provide any sudden significant price sparks, hence no need for any deterrent.

The same situation arises with the use of futures contracts as a trading tool, as futures also depend on prices going up to provide a profit. But since prices are going down without much variation, the risk free investment will provide a guaranteed return in this situation, hence no need for the limited income that most probably will not arrive with futures trading.

On the other hand, using call and put options for trading purposes provide some extra profits for the manufacturer. This makes sense since put options benefit from prices going down, meaning the manufacturer does not have to have missed opportunities when prices go down as the put options will make up for these lost potential savings the manufacturer could have made.

Trading with options provide a slightly higher VaR and CVaR with a higher level of average profits (3.6% higher). Even though this is achieved with nearly twice the level of volatility of the hedge-free model, it is still better because as shown in the graphs of figures 21 and 22, there is a shift in the mean of the hedged model towards the right side, the more profitable side and more of the results are on the rights side of the graph, indicating that the distribution does not follow a perfect normal bell curve and that more of the variability goes towards the profitable side. It can also be viewed upon as that higher profits are achieved when trading with options, with a VaR and CVaR which are slightly higher than the hedge-free model.

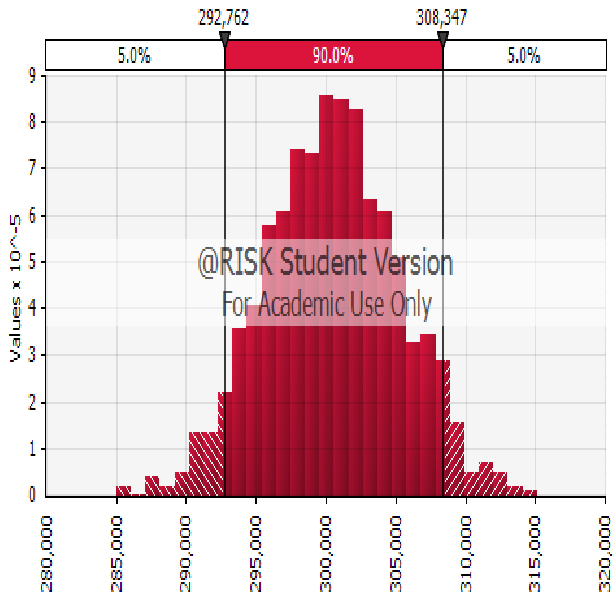



*Figure 21: Profit distribution without hedging with 30% price volatility and a decreasing trend*

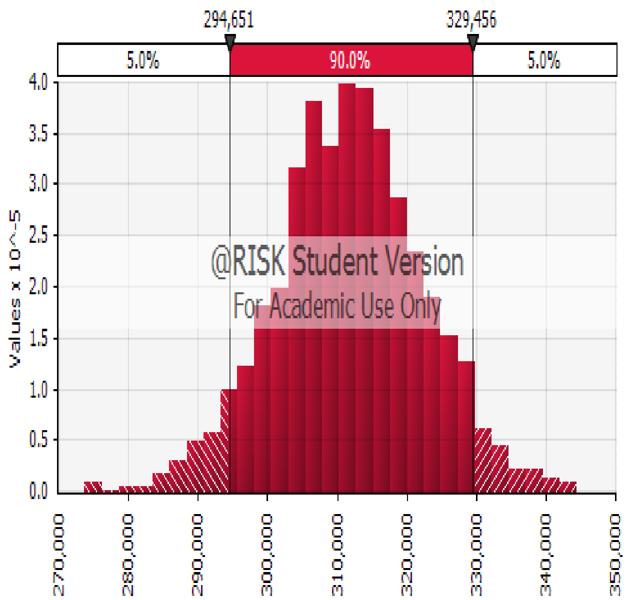



*Figure 22: Profit distribution trading with options with 5% price volatility and a decreasing trend*

### 5.2 Risk Neutral Manufacturer

This section covers the results recorded for a risk neutral manufacturer, who is attempting to optimize the expected profit, while not going below the corresponding Value at Risk of the non-hedged model.

This is done by modifying the objective through @Risk from maximizing the 5th percentile of profit to the average (i.e. 50th percentile), as well as adding a constraint to each model, which prevents the VaR from going beneath a certain limit.

Table 13 displays the minimum allowed VaR the hedged models had.

*Table 13: VaR constraints used for risk neutral approach*

| Price Pattern | Minimum Value-at-Risk (VaR) |
|---|---|
| **30% volatility with no trend** | 280,000 |
| **5% volatility with no trend** | 290,000 |
| **30% volatility with an increasing trend** | 272,000 |
| **5% volatility with an increasing trend** | 290,000 |
| **30% volatility with a decreasing trend** | 287,000 |
| **5% volatility with a decreasing trend** | 292,000 |

### 5.2.1 High Price Variability without a Trend

This section covers the results obtained for a risk neutral manufacturer facing a price volatility of 30% without any trends.

Figure 23 presents the mean, VaR, and CVaR for each strategy:

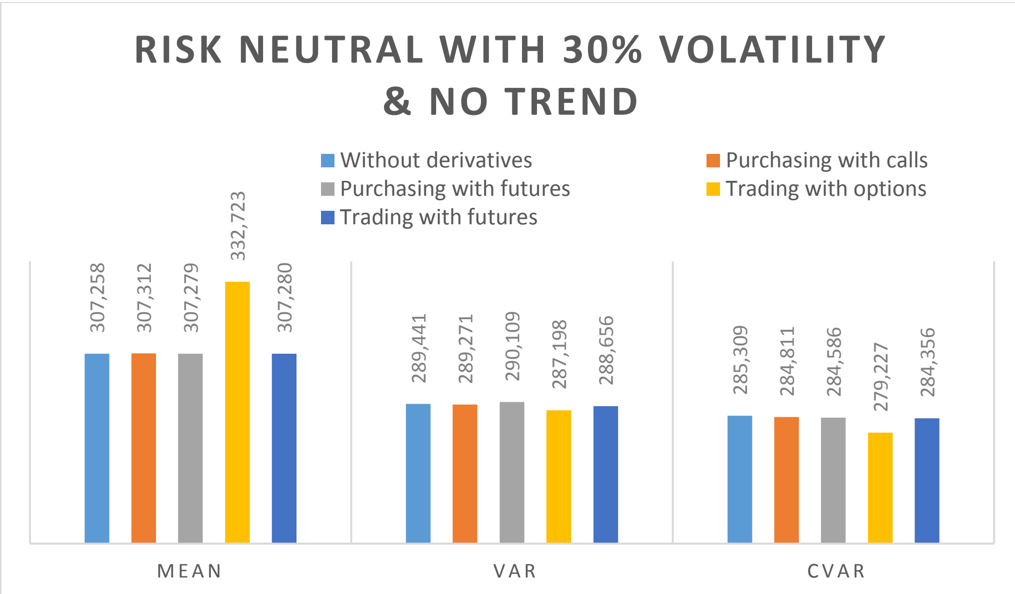



*Figure 23: Summary of risk neutral approach with 30% volatility and no trend*

Standard deviation for each strategy is presented in table 14.

*Table 14: Standard deviations of risk neutral approach with 30% volatility and no trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 11,112 | 11,041 | 11,115 | 57,300 | 11,343 |

With this risk approach it seems that the purchasing strategy has no role to play, as neither call options nor futures contracts are recommended to be used by the model under this approach. So the results indicate that neither tool can further improve the average, despite having more 'leverage' to reduce the VaR to its lower limit under this approach.

Trading with options seems to be more beneficial than with futures in this case, as the model recommends not using any futures. Options provide nearly 2% higher average profits than the hedge free model. It should be noted however, the drop of its CVaR as it becomes slightly lower than the hedge-free model, which makes sense since the VaR dropped to its lower constraint. There is also a sharp increase in the standard deviation which is roughly 6 times as much as the unhedged figure. However, options still retain a relatively high CVaR when considering the amount of variability experienced, this indicates that the normality of the profit distribution is a bit a skewed as compared to before, indicating there are more results on the right side of the bell curve and that most of the variability goes towards the profitable side of the manufacturer's profit distribution, as shown in the graph. All of this can be seen in figure 24 below.

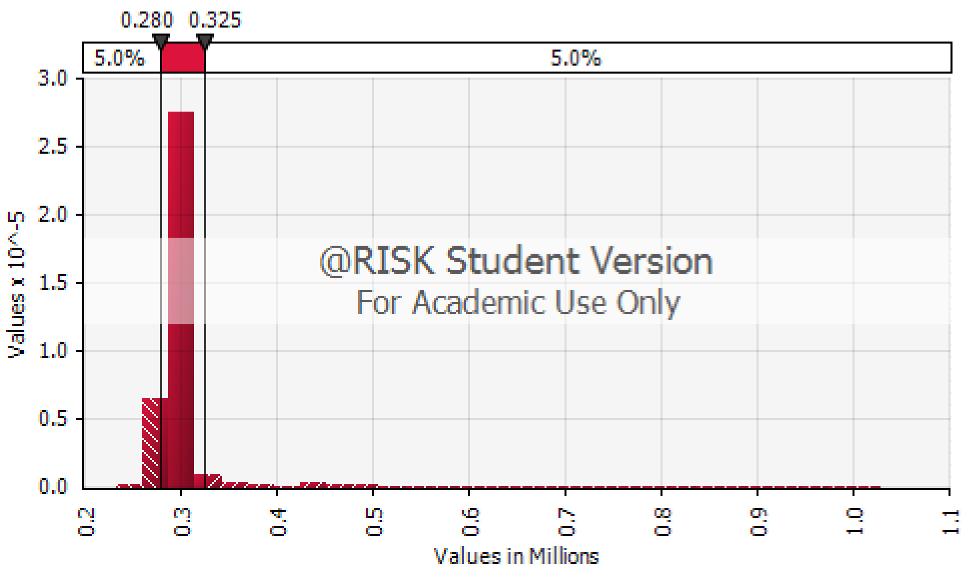



*Figure 24: Profit distribution with options with 30% price volatility and no trend*

### 5.2.2 Low Price Variability without a Trend

This section covers the results obtained for a risk neutral manufacturer facing a price volatility of 5% without any trends.

Figure 25 presents the mean, VaR, and CVaR for each strategy:

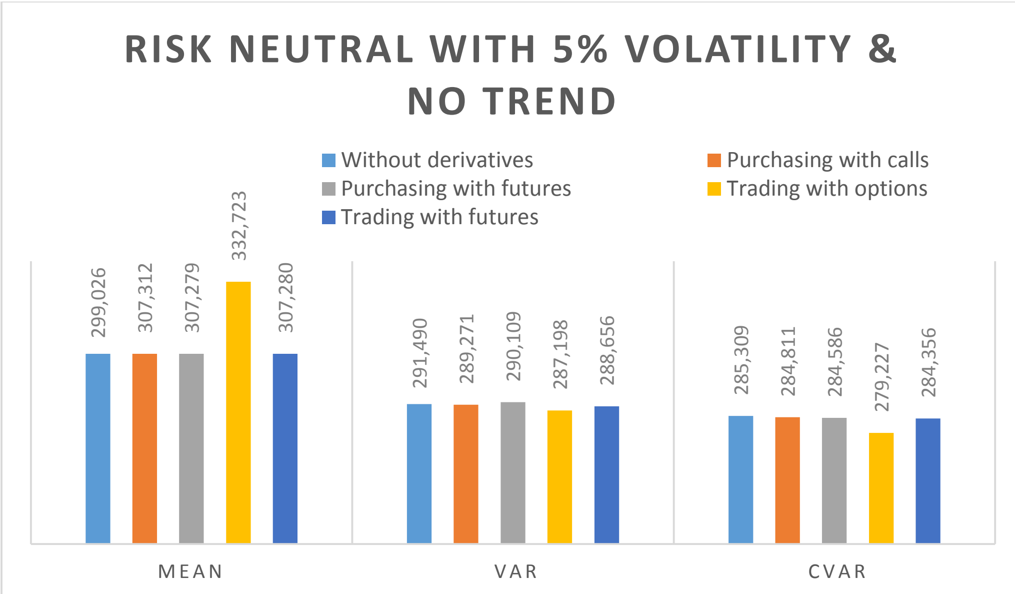



*Figure 25: Summary of risk neutral approach with 5% volatility and no trend*

Standard deviation for each strategy is presented in table 15.

*Table 15: Standard deviations of risk neutral approach with 5% volatility and no trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 4,887 | 4,469 | 4,507 | 4,568 | 4,713 |

As was the case with the high volatility scenario, purchasing derivatives are not required in this case and can't provide anything extra to the manufacturer. The same can be said about the use of futures contracts as a trading tool.

Trading with options raises average profits by 0.6%, not really making any use of the VaR allowance while dropping to the same VaR as the unhedged version.

### 5.2.3 High Price Variability with an Increasing Trend

This section covers the results obtained for a risk neutral manufacturer facing a price volatility of 30% with an increasing trend.

Figure 26 presents the mean, VaR, and CVaR for each strategy:

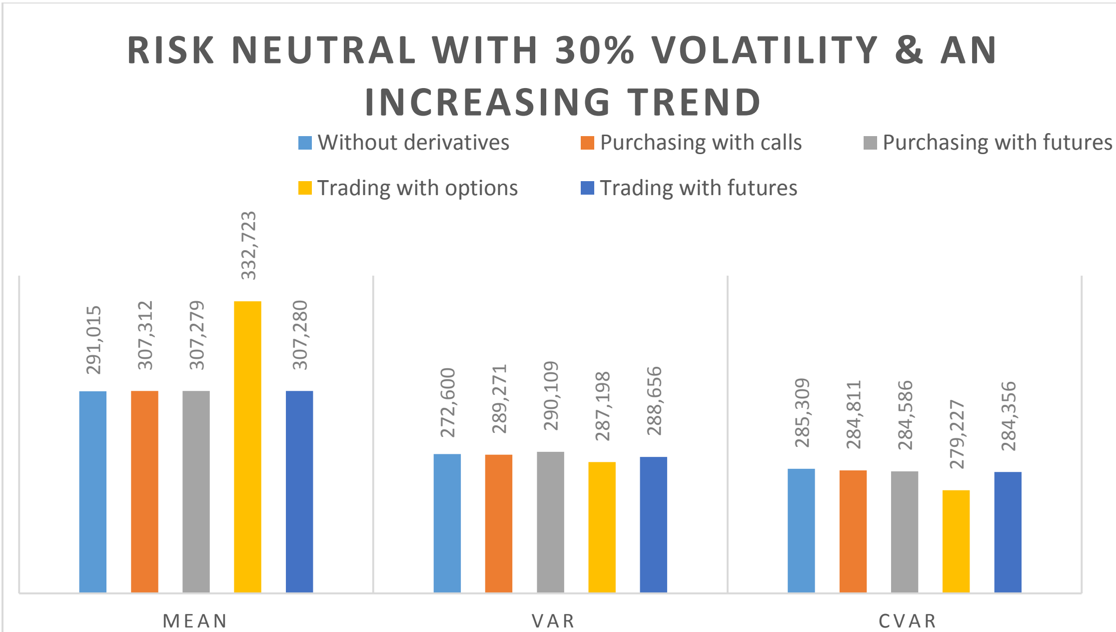



*Figure 26: Summary of risk neutral approach with 30% volatility and an increasing trend*

Standard deviation for each strategy is presented in table 16.

*Table 16: Standard deviations of risk neutral approach with 30% volatility and an increasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 10,967 | 8,444 | 8,158 | 31,963 | 36,417 |

Using derivatives for purchasing inventory raises average profits by 2%, in the case of call options, and 2.3% in the case of futures contracts. This takes place while reducing the standard deviation by 20% and 24% respectively. The CVaR goes up by 4% and 7% as well. It is worth noting though, that the VaR for both models does not drop to the lowest allowed value, it just drops by 1 to 2% from the risk averse figure when the VaR was being maximized. Figure 27 displays the profit distributions produced by the purchasing strategy.

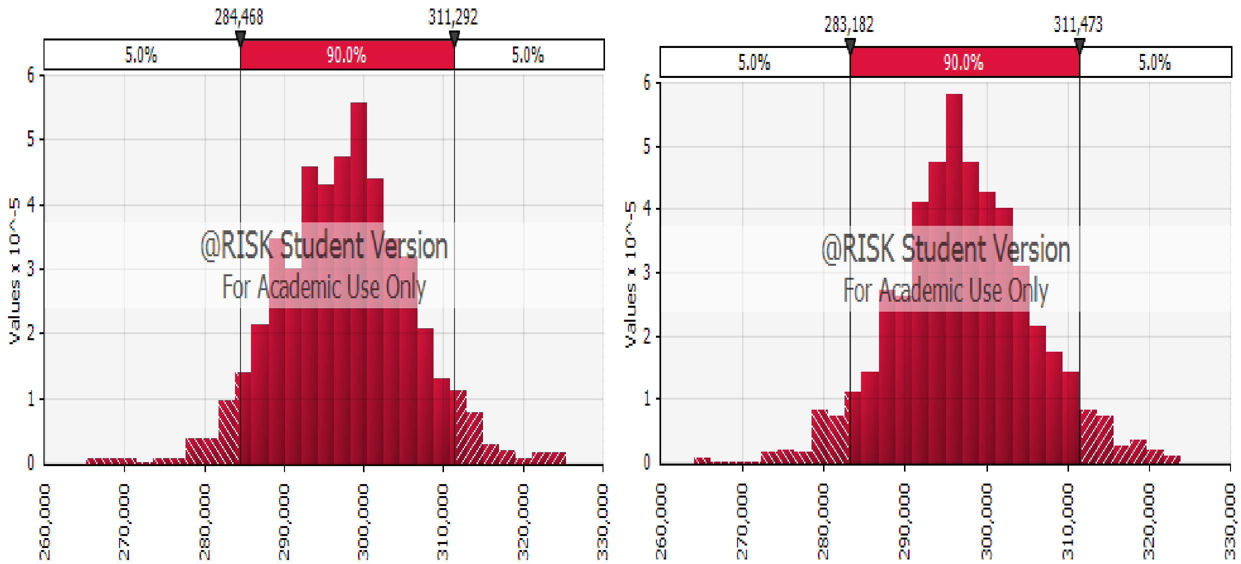



*Figure 27: Profit distribution purchasing with futures contracts and call options with 30% price volatility and an increasing trend*

With the trading strategy, futures contracts produce a higher level of average profits with a 13% increase over the hedge free model, despite having the same VaR. Trading with options on the other hand yielded 10% higher average profits, also with the same level of VaR.

Both approaches utilize the allowed drop in the profit "risk" to the fullest, by reducing the VaR to the constrained limits in order to raise the average profits. However, this is accompanied by having a standard deviation which is 3 times higher than the hedge-free model at a similar mean. Despite the high variability, the hedged models still keep the same VaR level because of the much higher average profits, which shift the results more to the profitable side of the distribution.

But options under this scenario do have the advantage of not reducing the CVaR as much as futures. Options retain the same CVaR as the hedge-free model. Since the objective is to maximize the average profits, futures would have the upper hand but the manufacturer could sacrifice a small portion of that average, and still achieve a decent improvement, in order to secure the profit CVaR. Figure 28 plots the trading strategy's profit distributions.

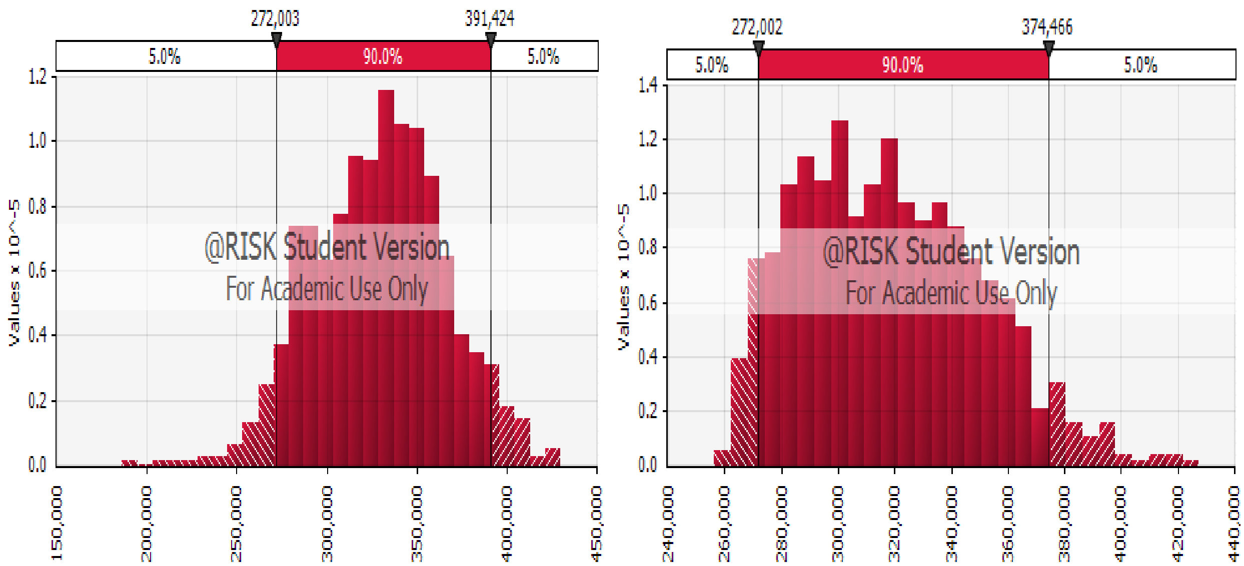



*Figure 28: Profit distribution with futures contracts and options with 30% price volatility and an increasing trend*

**5.2.4 Low Price Variability with an Increasing Trend**

This section covers the results obtained for a risk neutral manufacturer facing a price volatility of 5% with an increasing trend.

Figure 29 presents the mean, VaR, and CVaR for each strategy:

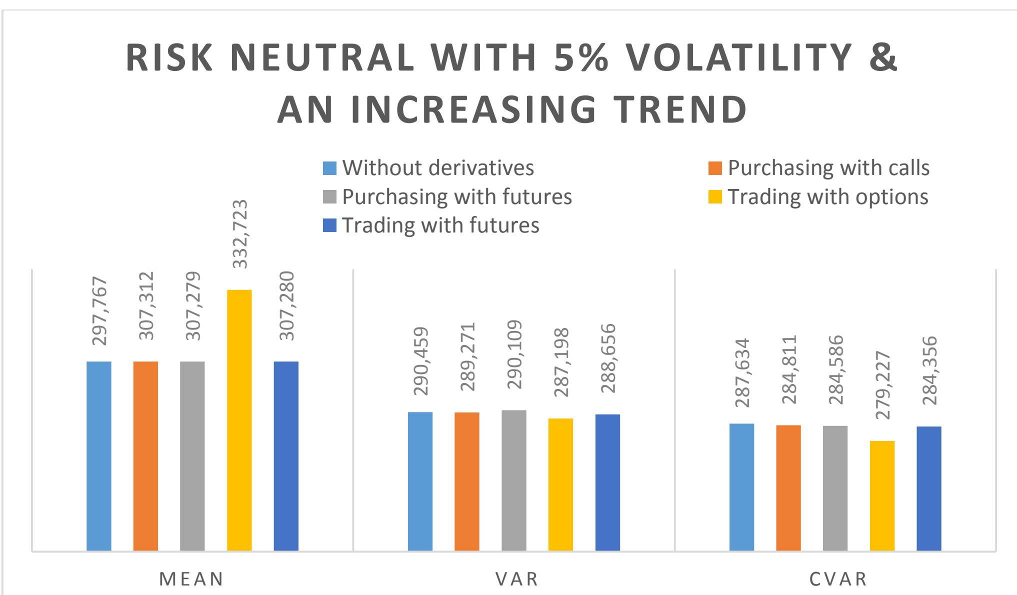



*Figure 29: Summary of risk neutral approach with 5% volatility and an increasing trend*

Standard deviation for each strategy is presented in table 17.

*Table 17: Standard deviations of risk neutral approach with 5% volatility and an increasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 4,461 | 4,268 | 6,191 | 5,586 | 10,629 |

Using futures contracts to purchase inventory for production with the risk neutral approach does not really differ from the risk averse one as similar results are achieved. Call options on the other hand, take advantage of the lower VaR figure reached, and reduce the standard deviation of the profits from the hedge-free model by nearly 20%, while achieving a 0.5% higher average profit and a 3% higher CVaR. Call options therefore clearly perform better under this scenario than futures contracts, as was the case with the risk averse approach. Shown below in figure 30, are the two graphs plotting the hedged profits' distributions.

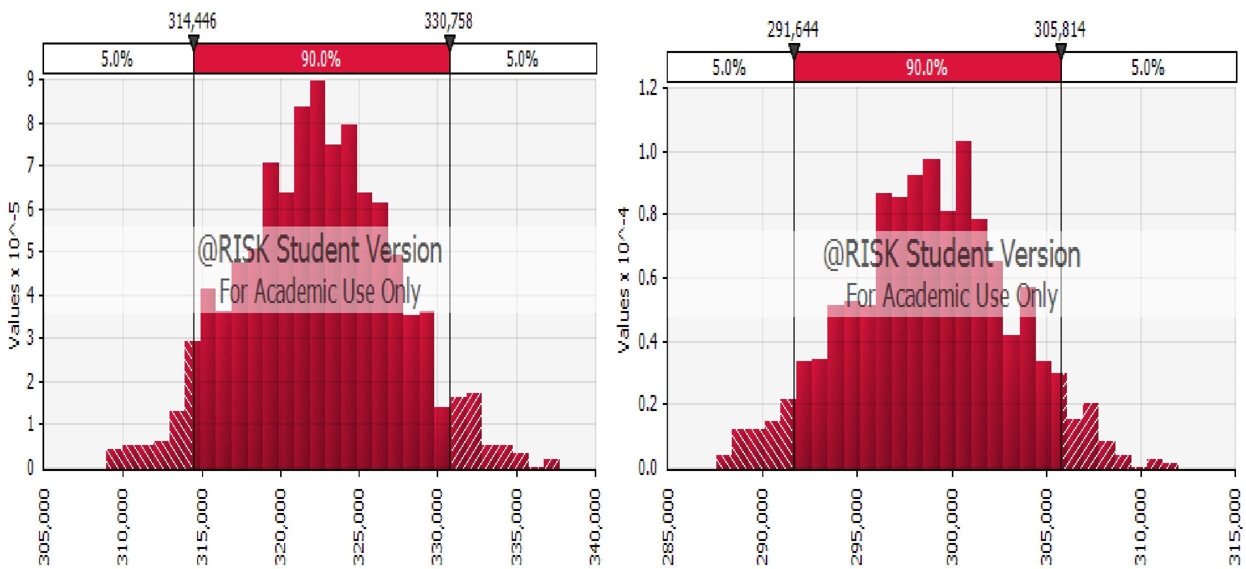



*Figure 30: Profit distribution purchasing with futures contracts and call options with 5% price volatility and an increasing trend*

With regards to derivatives trading, the low variability does not provide enough opportunities for options to have any significant impact on the profits figures, they raise the average profit figure by under 1%. Futures contracts are not affected as much by the low variability and can still raise the average profits by nearly 3%, but just like before, this is achieved with a standard deviation that is twice as big as the hedge-free model. Figure 31 shows the profit distributions obtained from the trading strategy.

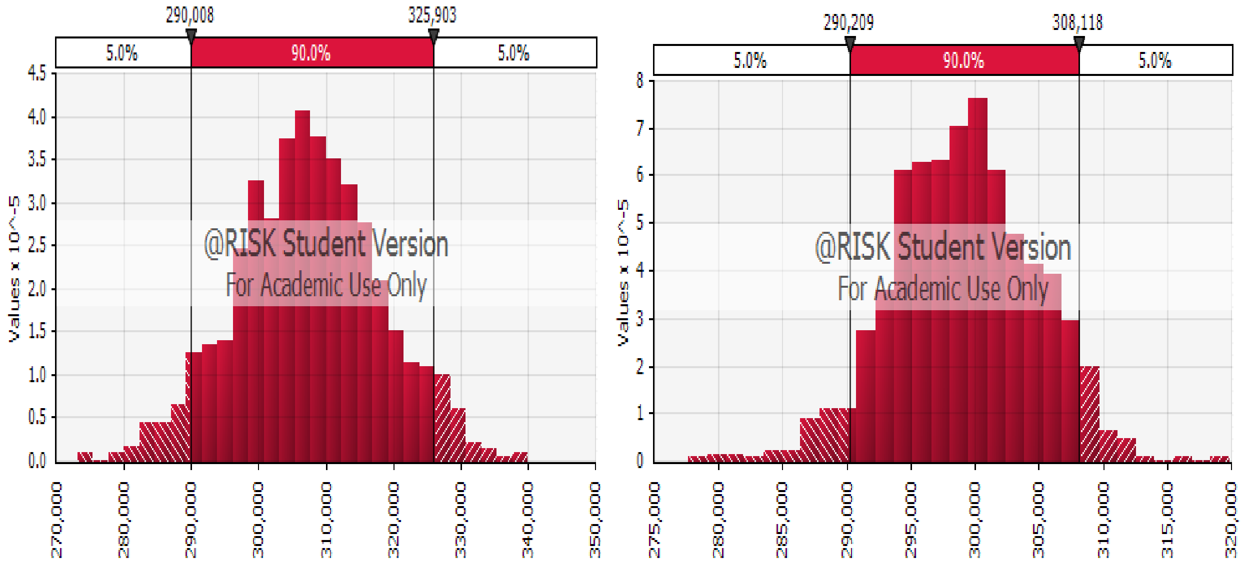



*Figure 31: Profit distribution trading with futures contracts and options with 5% price volatility and an increasing trend*

### 5.2.5 High Price Variability with a Decreasing Trend

This section covers the results obtained for a risk neutral manufacturer facing a price volatility of 30% with a downward trend.

Figure 32 presents the mean, VaR, and CVaR for each strategy:

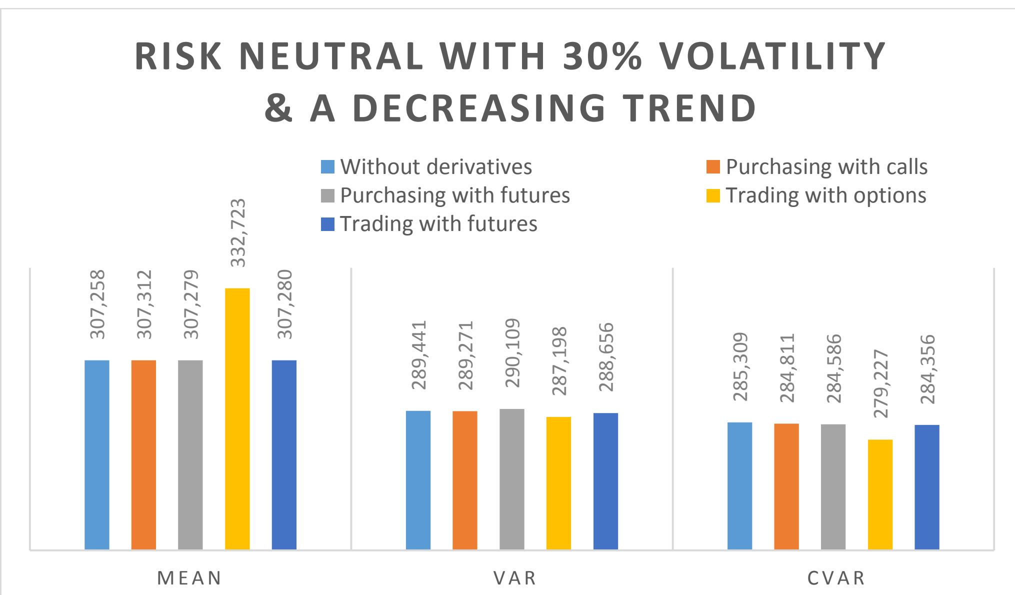



*Figure 32: Summary of risk neutral approach with 30% volatility and a decreasing trend*

Standard deviation for each strategy is presented in table 18.

*Table 18: Standard deviations of risk neutral approach with 30% volatility and a decreasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 11,219 | 11,068 | 11,145 | 109,484 | 11,127 |

Unlike the risk averse manufacturer, derivatives are not recommended at all for purchasing inventory when facing a large volatile decreasing price scheme.

Futures contacts are also recommended not to be used by the model in this scenario. This makes sense, since a portion of the average profits had to be sacrificed in order to slightly raise the VaR with the risk averse manufacturer. When prices are going down, and the objective is to raise the average, futures aren't able to raise profits except when prices unexpectedly go up, which is why risk averse manufacturer was able to use futures as a buffer, but won't be able to be relied on for prices regularly going down with the concern being the average.

But just like before, the use of call and put options yield a positive performance, as pull options are able to capitalize on prices going down and make it up for the manufacturer who purchased inventory at a higher cost earlier and make up for the lost investment opportunity costs. Shown in figure 33 is the profit distribution obtained from the trading strategy.

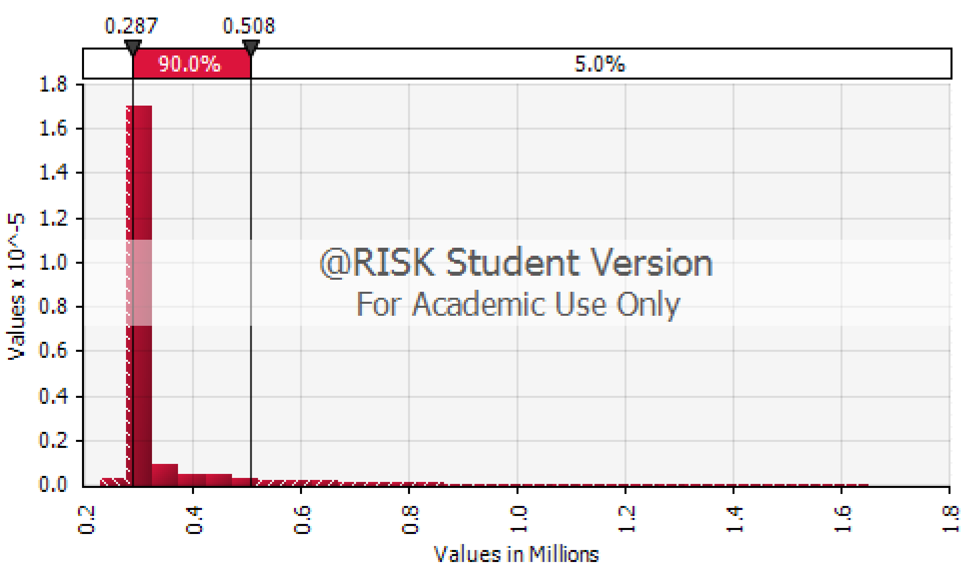



*Figure 33: Profit distribution trading with options with 30% price volatility and a decreasing trend*

Trading with options raise the average profit by nearly 8%, which comes at the cost of a standard deviation that is 10 times as big as the hedge-free model's one. But as shown in the graph, the profit distribution isn't perfectly symmetric, with a great deal of results located towards the right tail of the profit distribution, the profitable side, indicating a low level of skewness and that most of the variability that comes is of a more profitable nature.

### 5.2.6 Low Price Variability with a Decreasing Trend

This section covers the results obtained for a risk neutral manufacturer facing a price volatility of 5% with a downward trend.

Figure 34 presents the mean, VaR, and CVaR for each strategy:

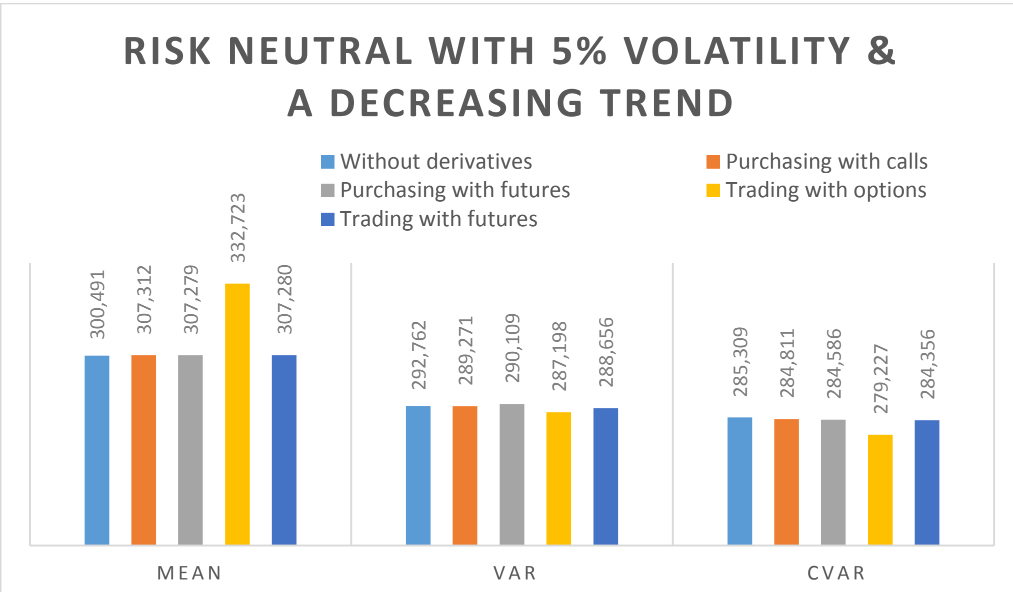



*Figure 34: Summary of risk neutral approach with 5% volatility and a decreasing trend*

Standard deviation for each strategy is presented in table 19.

*Table 19: Standard deviations of risk neutral approach with 5% volatility and a decreasing trend*

| Strategy | Without derivatives | Purchasing with calls | Purchasing with futures | Hedging with calls & puts | Hedging with futures |
|---|---|---|---|---|---|
| σ | 4,774 | 4,663 | 4,592 | 28,660 | 4,605 |

As was the case with the high volatility price scheme, purchasing with call options or futures contracts can’t improve the manufacturer’s profit figures. Futures contracts used in trading are not required either.

Options can be used in trading and raise profits by 3.4% at the same VaR as the hedge-free model. Looking at the high variability level and the profit distribution, the same argument exists from before, where that all the variability comes at the more profitable side of the distribution as shown in figure 35.

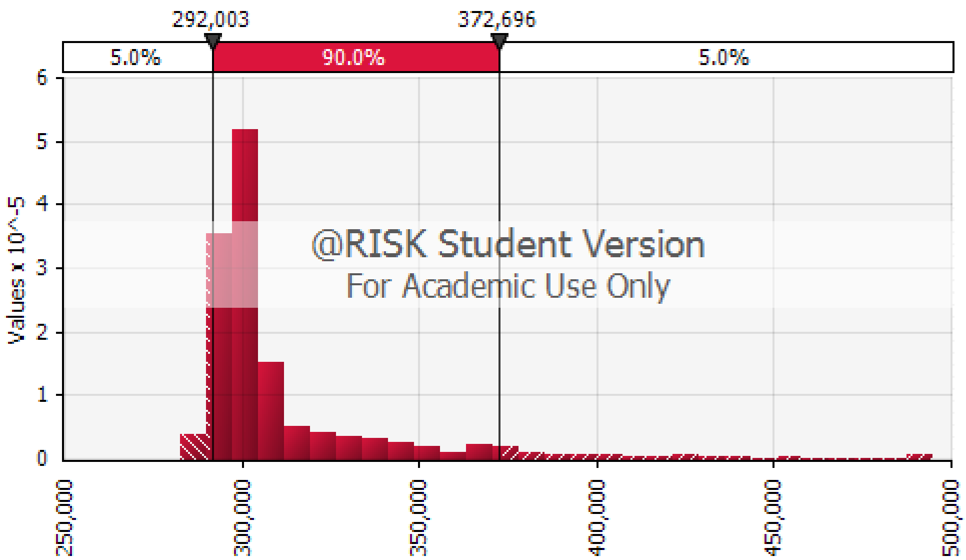


*Figure 35: Profit distribution trading with options with 5% price volatility and a decreasing trend*

### 5.3 Results and Discussion

Table 20 summarizes which tool the manufacturer should use to hedge in all the different scenarios covered based on the simulations results. For the risk averse manufacturer, the VaR is the deciding factor and for the risk neutral manufacturer, it is the average profits. In case of a tie, the other discussed factors are considered. If the tools produce similar results on all fronts, it is recorded as "either". If the tool provides a small improvement from the non-hedged model, it is noted as "limited" in between brackets. If the model recommended that no hedging take place, it is noted as "none".

"Purchasing" refers to the strategy when call options or futures contracts are used to purchase inventory for the commodity, to be used in production. "Trading" refers to the strategy when extra funds are used to trade with futures or call and put options.

*Table 20: Summary of recommended tool for each strategy under each scenario*

| Scenario (Price variability and trend) | Risk Averse (Maximize VaR) | | Risk Neutral (Maximize Mean) | |
|---|---|---|---|---|
| | Purchasing | Trading | Purchasing | Trading |
| High volatility with no trend | Futures | Futures | None | Options (limited) |
| Low volatility with no trend | None | Futures (limited) | None | Options (limited) |

| | | | | |
|---|---|---|---|---|
| High volatility with an increasing trend | Either | Futures | Either | Futures |
| Low volatility with an increasing trend | Call options | Futures | Call options (limited) | Options |
| High volatility with a decreasing trend | Call options | Futures | None | Options |
| Low volatility with a decreasing trend | None | Options | None | Options |

### 5.3.1 Price Scenarios

The first observation that can be noted from the model results, is that financial hedging always performed better when the prices were facing a high level of volatility, than when facing a low one. This coincides with the literature review performed and with the objective of these tools in the first place, which is to hedge against large price movements which deter the manufacturer from its target profits. High volatility levels indicate that the commodity price moves away from the average or expected value more often, providing less confidence in purchasing based on the expected value and providing more price gaps and opportunities for financial derivatives to capitalize on.

The results also revealed that purchasing inventory, through futures contracts or call options, and trading with futures still have a role to play when prices have a decreasing trend in a highly volatile manor, despite being tools that rely on prices going up. Despite the modelling of a trend indicating that the average commodity price would go down, the random nature of price fluctuations accompanied with the high level of volatility means that there would be some occasional significant increases in the price of the commodity, which implies that these tools can be used as backup in case prices unexpectedly go up, when they should be going down.

### 5.3.2 Risk Approach

After simulating financial hedging with both the risk averse and risk neutral approaches, it was observed that better results were achieved with the risk averse approach under the modeled circumstances. Under the risk neutral approach, the only price scenarios that were boosted by purchasing inventory with derivatives or trading with futures were when there was a tendency for prices to increase. As pointed out in the previous section, these improvements did not fully utilize the allowed drop in VaR to raise the average, indicating that these derivatives seem to fare better as risk averse tools and hence the limited ability to raise average profits. Using call and put options in trading on the other hand, managed to maintain the good performance encountered under the risk neutral approach.

### 5.3.3 Trading Strategy

Trading with call and put options was the most consistent strategy in producing good results under most scenarios, and this was expected since it involved using 2 financial derivatives that are inversely proportional; call options which benefit when prices go up and put options which benefit when prices go down. This meant that even when prices went down, the put options would make up for the opportunities the manufacturer lost for purchasing inventory when the prices were previously higher.

Despite this wide coverage of scenarios offered when using 2 derivatives, trading with futures contracts seemed to trump options in nearly all the risk averse price scenarios. According to the Black Scholes Merton model, options contracts become more expensive to attain when the underlying asset has a high level of variability, this would explain why futures provided better results. This coincides with futures faring better than options as shown in some papers [28] [29].

But the results also showed that if there was a risk scale with a risk averse investor, who is just concerned with the risk and profit VaR, on one side and a risk seeking investor, who wants to maximize profits regardless of risk, on the other side that the further the target is towards the risk averse side, the better the ability of futures contract to meet those targets and the closer the target is towards the "risky" side, the better the ability of options to come in to play. This is also confirmed by looking at the numbers of the risk neutral approach for options trading, where there was a significant increase in the average profits while having the profit VaR at the allowed limit, indicating the lower the bar for the VaR is set, the higher the average can be. Options trading did well with the risk averse approach, just not as good as futures, whose ability to use a locked-in price seemed to be better able to stabilize the price and reduce the risk. This was also evident in the fact that futures outperformed call options when it came to the purchasing strategy in the highly volatile rising and no trend price scenarios, where they achieved similar profits but with different standard deviations.

### 5.3.4 Profit Variability

Despite not being the objective of any approach, the profit standard deviation was drastically improved when derivatives came into play especially when the prices had a high level of volatility, sometimes being cut down by two thirds. With low volatility levels, the standard deviations provided by derivatives were equal to the hedge-free model.

The cases that saw higher volatility with the hedged models were those under the trading strategy. However that seems a bit misleading. As shown in the previous sections' graphs, futures contracts which led to highly variable profits, had significantly higher average profits and maintained similar risk measures as the hedge free model, which means that futures contracts led to a low level of skewness, i.e. the shift of the center of the bell curve towards the more profitable side, while keeping the same 5$^{th}$ percentile of profits as the hedge free model made the profit distribution curve more flat than it is steep.

Trading with options also had high profit standard deviations, which are attributed to the same reason as futures contracts, as well as having most of the variability goings towards the right side, the more profitable side, of the profit distribution indicating a low level skewness (non-symmetry of the profit distribution curve).

# 6. CONCLUSIONS

This chapter concludes and summarizes the report. The chapter identifies the contributions and the insight gained from this thesis in the first section. Section 2 then points out the limitations of this report, as well as areas for future research.

## 6.1 Contributions

This thesis provided a review of the different strategies and research done on how companies can mitigate risk through the use of operational, financial and integrated hedging techniques. Then a simulation-based optimization model was developed that provides a practical guide for managers who use a commodity in their production process on how to make the decision of which financial tool to use, based on the nature of the price behavior of the commodity they use, the risk approach they prefer and their financial abilities (purchasing and trading). The simulations also shed light on the potentials gained when using financial hedging tools and their behaviors. This thesis helps to fill a void in the literature, which is to provide non-financial practitioners with more educational material to be able to properly use these tools [29] [27] [7].

Besides noting the performance of the different financial derivatives under the various scenarios, the results showed that financial hedging is much more beneficial when there is a high level of price uncertainty, due to the wider price movements leading to bigger price gaps that derivatives capitalize on. The results also showed that the financial derivatives considered, fared much better when used under the risk averse approach rather than the risk neutral one, this was evident in the fact that the risk neutral's results were only improved from the hedge-free figures when there was a tendency for the prices to increase. The only strategy that performed consistently well throughout all the scenarios was the call and put options trading one, which makes sense since it involved the use of two derivatives that are inversely proportional to each other and therefore could benefit from the prices moving up or down. However, the results showed that the futures trading strategy outperformed the options trading one when used with a risk averse mindset, which might suggest that futures are the more appropriate risk averse tools and options are the more appropriate risk seeking tools. Finally the results demonstrated that, despite not being the objective, the hedged profits' standard deviations were less variable than the unhedged versions at a similar average level. This means that financial hedging can bring in a great deal of stability to profit figures in a highly unstable pricing environment. The only cases that saw hedged models have higher levels of profit variability were those that a much higher average not making the comparison very straightforward.

### 6.2 Limitations and Areas for Future Research

It should be noted that the obtained results, the subsequent observations and discussions were all based on how the different factors considered were modelled under a specific set of circumstances. The selection of these factors and methods were based on the findings of a literature review of existing recognized material. Using different modelling methods and techniques, or hedging strategies might have led to different results.

Some of the extensions or alternatives for the approach used in this report are covered in this section.

a) In this model, it was assumed that the commodity price and the manufacturer's demand volatility aren't related, that neither affects the other. It can be looked at to link one's behavior to the other's so that for example, if the demand rises for the product sold, this would mean there would be a greater need for the commodity used as well, which would raise the price the manufacturer purchases it for, and vice versa, similar to the work of Sakong [29]. This extension could also include a strategy of changing the manufacturer's selling price as well.
b) Different pricing models could be used for establishing the costs of futures and options, similar to the work performed in Xu [37].
c) In this model, only one strike price for options was used throughout the entire modeling period, this could be adjusted so that the manufacturer is able to buy options at different strike prices at different times to take advantage of the price trends. The model could also be extended to allow the manufacturer to purchase futures and options at different prices at the same time using different financial strategies such as spreads (bull, butterfly, etc…) and combinations [12].
d) Some analytical research is in need that integrates financial and operational hedging methods similar to what Hommel [23]and Chowdhry [34] did with exchange rates.
e) We were limited to classical financial tools but classical advanced tools such as swaps and stocks, or even consider the case of a manufacturer using a resource that doesn't have

financial derivatives and the manufacturer has to hedge with a resource that does have such tools and behaves similarly to the resource they do use.

f) In our work we considered one product that used one commodity, this could be extended to several customers or suppliers and this could be considered an operational hedging strategy similar to the ones covered in Chapter 3.

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# 8. APPENDIX

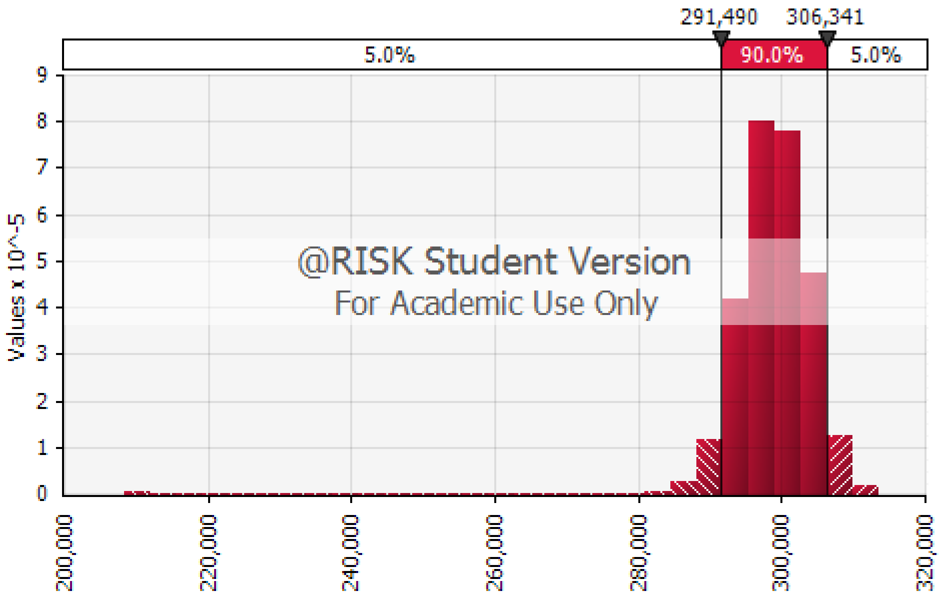


*Figure 36: Profit distribution without hedging with 5% price volatility and no trend*

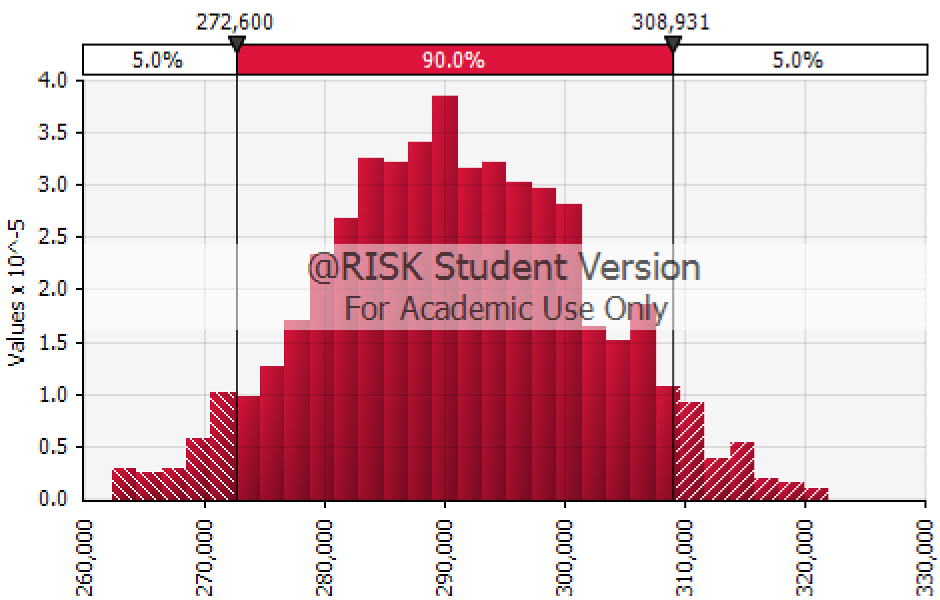


*Figure 37: Profit distribution without hedging with 30% price volatility and an increasing trend*

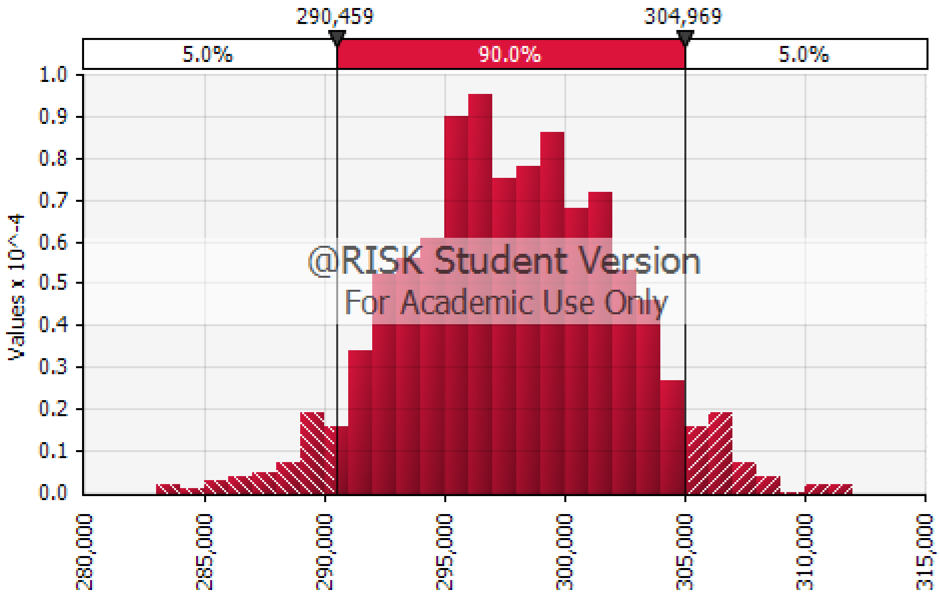


*Figure 38: Profit distribution without hedging with 5% price volatility and an increasing trend*

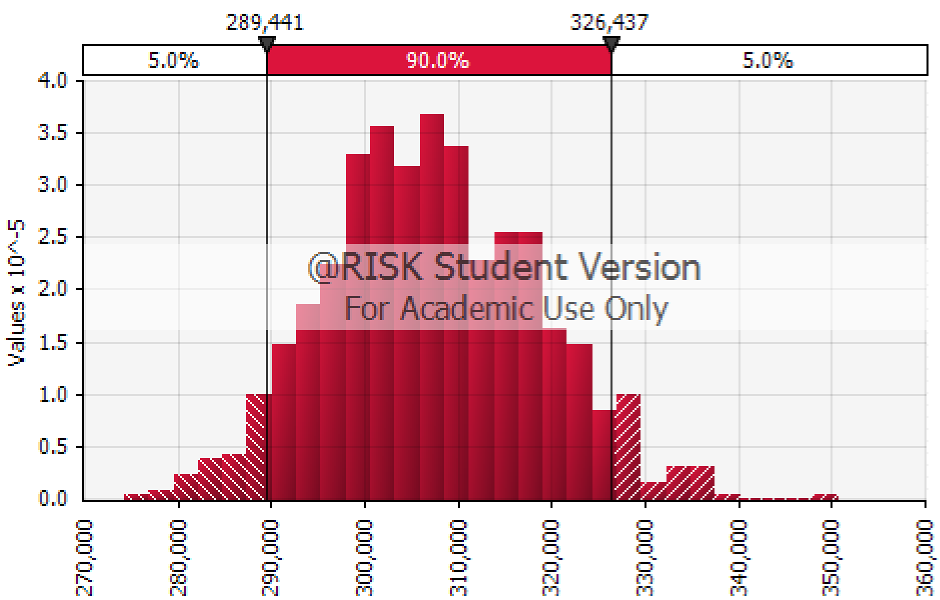


*Figure 39: Profit distribution without hedging with 30% price volatility and a decreasing trend*

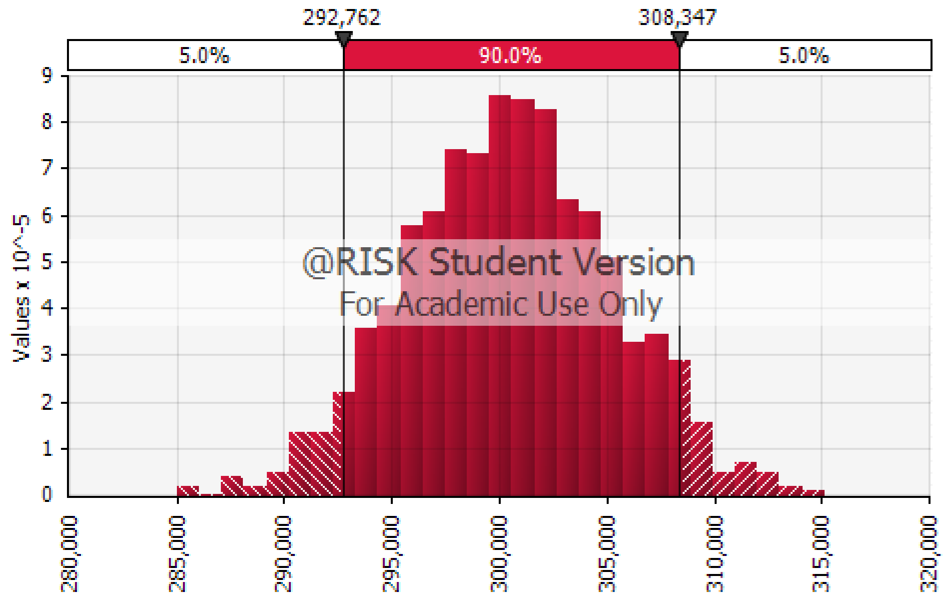


*Figure 40: Profit distribution without hedging with 5% price volatility and a decreasing trend*