Risk Analysis and Modelling

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November 2021

Abstract

Firms are exposed to the uncertainty of both internal and external factors to their operation, which could adversely affect their future results. Nevertheless, they could reduce this uncertainty and create value by managing their risk exposure, according with their risk preferences and objectives. Therefore, this research seeks to provide a methodology to study the companies' risk exposure, applied to a codfish processing company case study. The methodology implemented follows some of the ISO 31000 framework steps, which include defining the context of the company, assessing the risks and treating them. For a clearer understanding of the future results uncertainty, the company's future net incomes were modelled using Monte Carlo Simulation. Additionally, the company's risk profile was defined by using an exponential utility function. Even though the future net incomes model has resulted in a wide range with some limitations, possible prevention and mitigation strategies could be modelled and their added utility to the company was measured. The results of this investigation have shown that the price fluctuation of codfish is crucial for the company under study, being the mitigation of this risk very recommended.

Keywords: Enterprise risk management, Risk profile, Risk modelling, Monte Carlo simulation, Codfish industry

1. Introduction

Changes in the surrounding conditions might trigger unexpected consequences for the companies, and these possible changes constitute risks. Risk definition has not been consensual between different authors [18], but there is always a general agreement that a risk is the impact of an uncertain event on a certain objective of an organization [9].

Therefore, companies can benefit from managing risks [16], adopting different approaches and measures to deal with several types of risks, depending on the company's tolerance to losses.

Risk management provides a strong basis for planning and decision-making, contributing to an increase in the processes' efficiency and compliance of regulation [7] and allows companies to protect themselves from undesirable future positions.

However, despite the fact that companies should manage risk to prevent having bad results, Atluntas et al. [2] show that companies are generally more likely to adopt or improve their risk management practices only after having the bad results.

The available literature already presents many risk management frameworks. However, the authors usually agree that the risk management practices must be unique and perfectly adapted to each company and situation [8]. Therefore, this research will have a positive impact on the existing literature, providing a clear methodology on how to implement some of the most common risk management steps and how to adapt different techniques in a particular case study.

One of the most accepted standards for managing risk is ISO 31000, which contains guidelines regarding the principles, framework and process to manage risk. In particular, the process is composed by the phases of establishing the context, assessing risk (or, in other words, identifying, analysing and evaluating it) and treating risk, together with continual communication, monitoring and reporting [11].

Additionally, the objectives of the organizations must be determined in accordance with their risk preferences and tolerance. As a result, utility functions can be used to measure and compare the utility supplied by various options. In particular, the exponential utility function leads to accurate results in different situations and with low levels of error associated [12]. The exponential utility function is defined by:

$$u_x = 1 - e^{-x/\rho} \tag{1}$$

Where u is the utility associated to the gain x, ρ is the risk tolerance coefficient and $\mathrm{sgn}(\rho)$ corresponds to the sign of ρ. Several authors propose different approaches to estimate the risk tolerance coefficient of this function, and 4 of those approaches will be studied in this research. The first one is setting the

the coefficient to about 6% of the total sales of the company, which should be approximately the same of around one sixth of the total equity [10].

Another way to calculate this coefficient is calculating the largest value of X a decision-maker is interested in betting in a gamble with 50% probability of gaining X and 50% probability of losing $X/2$. The chosen value corresponds to the risk tolerance coefficient.

The third method consists is finding the maximum acceptable loss (L) a decision-maker would be willing to take, in order to accept a gamble with a certain probability (p) of gaining an arbitrarily large amount of money [6]. The coefficient is then calculated by:

$$\rho = -\frac{L}{ln(p)} \tag{2}$$

Lastly, the fourth method corresponds to a more complex technique to calculate, which consists in performing a survey to the managers of the company. The survey presents a certain number of investment opportunities with independent outcomes, similar to the decisions that the managers usually face in the industry in which they operate. Each opportunity has 2 different outcomes — success or failure, and the correspondent probabilities and results (gain and loss values). For each of these opportunities the managers should decide on their level of participation in that investment, in percentage. After, the computation is made by calculating the certainty equivalents:

$$C_X = -\rho \cdot \ln\left(\sum_{i=1}^{n} P_i \cdot e^{-X_i/\rho}\right) \tag{3}$$

Where C_X is the equivalent cash value of a decision with probability P_i of having an outcome X_i for a manager with a risk tolerance coefficient of ρ. The computation consists in calculating C_X for each participation level and for different values of ρ, and choosing the value (or range of values) of ρ that provides a greater C_X for the participation level specifically chosen by the managers, when compared to the other participation levels. This makes sense because the managers will choose the best option for them, with the greatest C_X, given their ρ. So, if any other participation level would lead to a greater value of C_X for the same ρ, the manager would choose that option [17].

To estimate the future results of a company, it is adequate to calculate their Value at Risk (VaR) [1] and to use Monte Carlo Simulation (MCS) [5], which is a method that allows the definition of each variable with uncertainty and provides a good basis for decision-making. However, MCS has the disadvantage of the subjectivity associated with the distribution definition.

Finally, the risks may be managed differently, depending on the risk and its impact in the business. The strategy to deal with a risk may vary from accepting it to completely eliminating it [3], with the implementation of mitigation strategies, as, for example, having an insurance.

Having said this, the present research seeks to study risk management, applying the techniques to the case study of a Portuguese codfish processing company. Despite the recent good performance of the company under study, they are vulnerable to a number of potential risks. They have solely concentrated on credit risk so far, even though they are exposed to other risks. For example, laws and regulations may change, prompting the payment of fines or requiring a significant change in the way the business runs. Furthermore, there are other uncertain variables, such as fluctuations on the tax rates in the countries where they operate, changes in the demand for codfish, changes in the price of the codfish, among others. Thus, the company's future results are uncertain in a broad range of values. Besides, the level of risk the company is exposed to might not match their risk preferences, stressing the importance of studying the strategies that should be ensuring their strategic goals.

The past results of a company are not a guarantee of their future success [4]. Hence, it would be important to understand and simulate the company's future results under a variety of scenarios and their respective probabilities, taking into account the external threats and opportunities.

Therefor, the objectives of this study are:

1. The determination of the company's risk profile, which relates to their willingness to take risks.

2. Modelling their future net incomes, combining the different possible values of revenues and costs, that will depend on several factors, including the probability and impact of the most relevant risks their are exposed to. The final result of this model will consist in a Value at Risk curve, representing the probability of the company achieving certain results in the future.

3. Suggestion of the most adequate risk management practices and mitigation strategies to improve the company's future results, considering their risk profile and the impact of the strategies in the developed future results model.

2. Methods

The methods to develop the future net incomes model are now going to be detailed, revealing the steps to construct a risk register and a mitigation strategies register. Additionally, the other variables modelled are detailed, and the risk profile of the company defined, by resorting to the exponential utility function.

2.1. Risk Management Process

The process of the ISO framework process was followed, containing the steps of the scope, context and criteria definition; the risk assessment and the risk treatment.

First, it was necessary to define the context of the company. For that, a Five Forces of Porter and a SWOT analysis were held, revealing key aspects that triggered the identification of the risks to create a risk register, as well as the identification of the mitigation strategies that were studied.

After the context and capabilities characterization, the risks were identified based on the company's external environment and current operation. The objective of this step, was the creation of a risk register, including the explanation of the possible impacts and risk factors associated with each risk, to enable the identification of the most relevant ones, with the highest impact and probability. Thus, two scales were used to attribute values from 1 to 5 to each risk, characterizing their probability and impact. The probability scale was defined according with the happening frequency of the risk factors, whereas the financial impact corresponds to the loss that the company would face if the risky situations took place. The last one is adapted to the company's results in the past 10 years. The classification of the risks was made by resorting to the company's managers expertise to assign a value of the scale to each risk. The available values are:

1. Very Low — probability of occurrence once in periods over 15 years or possible losses below 100K €
2. Low — probability of occurrence once in every 5 to 15 years or possible losses between 100K € and 500k €
3. Medium — probability of occurrence once in every 3 to 5 years or possible losses between 500K € and 1M €
4. High — probability of occurrence once in every 1 to 3 years or possible losses between 1M € and 5M €
5. Very high — probability of occurrence at least once a year or possible losses above 5M €

Following the risk identification and analysis, the evaluation phase consists in selecting the risks which can jeopardize the company's results the most, between the ones available at the risk register previously developed.

Thus, the risks were ranked according with their risk level. To calculate this level, Mitchell's [13] interpretation of risk was used:

$$Risk_n = P(Loss_n) \times I(Loss_n) \tag{4}$$

Where P represents the probability of a certain loss, whereas I represents the impact of that loss. After calculating the risk level ($Risk_n$) associated with each of the n identified risks, the ones with a higher level associated were chosen for further analysis and modelling.

2.2. Future Net Incomes Model

The model was developed in Microsoft Excel, using the @Risk add-in from Palisade Decision Tools. This model contains a simulation of the company's net incomes depending on the simultaneous uncertainty of the risky events, quantities sold, buying and selling prices, and other relevant components that impact their results. To develop the model, first it was necessary to define its inputs. In other words, the variables that affect the company's results and their respective probabilistic distributions.

The final output of the model is the net income, in accordance with the investigation objectives previously described. So, the estimated variables are related with the interest and taxes paid, the depreciation and amortizations, operating revenues, material costs, cost of employees and other operating costs.

Some of these variables depend on other external variables. For example, the operating revenues depend on the quantity and price at which they sell. In turn, these might depend on the codfish price fluctuations, macroeconomic factors, and so on.

For that reason, the software IBM SPSS statistics was used to search for multiple linear regressions that predict the value of some variables, the dependent variables, based on the values of some inputs, the independent variables. This was performed using the method stepwise, which adds variables to the regression model according with their statistical significance. To better estimate the **operating revenue**, its relation with the following variables was studied: **(a)** gross domestic product per capita in Portugal, **(b)** inflation in Portugal, **(c)** number of employees of the company, **(d)** market share and **(e)** quantity of frozen codfish produced in Portugal. In addition, to estimate the **material costs**, the considered variables were: **(a)** inflation in Iceland, **(b)** inflation in Norway, **(c)** average importation price of dry cod in Portugal, **(d)** average importation price of fresh cod in Portugal, **(e)** market share and **(f)** quantity of frozen codfish produced in Portugal. The last two mentioned variables were chosen to try to predict the quantity with which the company in study operates. This quantity may relate both to the material costs, since it depends on the quantity of raw material they buy, and to the operating revenue, affecting in particular the quantity they sell. The other variables mentioned are supposed to explain the variation of the prices at which they buy and sell. Finally, the **cost of employees** might depend on the: **(a)** average salary in Portugal, **(b)** minimum salary in Portugal, **(c)** unemployment rate in Portugal, **(d)** gross domestic product per capita in Portugal, **(e)** inflation in Portugal and **(f)** the company's number of employees.

The result of this step, consists in three regressions, one for each of the explained variables. The found relations were implemented in the model.

Lastly, to investigate the reliability of the results and validate the regressions, the following conditions were verified [14]:

1. Near linear relationship between the dependent variable and the independent variables.

2. Variance inflation factors (VIF) values below 10 units to ensure there is no multicollinearity.

3. Uncorrelated and normally distributed errors, with mean equal to 0.

Regarding the data collected to develop the model and the multiple linear regressions, several sources were consulted. First, the company's past results were reviewed in their financial reports, gathering the values from 2010 to 2019 of all the variables previously mentioned and the number of employees the company had each year. Also, the sales of their five main competitors were extracted from the financial reports of those companies, to calculate the market share of the company in study. The remaining variables were consulted in statistics and data bases from different web-sites, noting that the inflation variables correspond to consumer price indexes.

Having the multiple linear regressions defined, the next step is to predict the values of each input variable for the next 10 years, which is the time frame on which this investigation is focused. The prediction of some of the variables was made using the expertise of the company's managers, whereas the remaining input variables were forecast by resorting to statistics of banks and other entities.

The model was developed using the most predictable course of the variables. For example, the demand for codfish is not expected to decrease suddenly and the inflation rates are not likely to change more that 2% in a year. Nevertheless, some of these variables might have unexpected abrupt changes. This way, the importance of modelling extreme events arises. For that, the top identified risks of the register previously developed were implemented in the model, considering the opinion of the company's experts, who had participated in the evaluation of the probability and impact of the risks, assigning values from 1 to 5 of the scales.

First, some distributions were defined to model the number of occurrences of the possible losses per year, associated with each risk. For simplification purposes, most of the levels of the scale are modelled considering the average period of the range and the Bernoulli distribution. For example, for an event that occurs once in every 5 to 15 years, it was considered a probability of occurrence once every 10 years, resulting in a yearly probability of $p = \frac{1}{10}$. Regarding the number of occurrences in a very high probability case, there is at least one event per year. So, considering that the occurrence of many events is less probable than the occurrence of a smaller amount of events, a Poisson distribution was used to model the remaining number of events that might happen beyond the one already predicted.

Additionally, the distributions to model the impact of the risks for each classification of the scale were defined. Most categories were modelled with an uniform distribution, since it was assumed that the probability of losing each of the values inside the range was the same. The only exception is for the losses above $5M€$, where it was assumed a Pareto distribution, that will allow a higher probability for losses closer to $5M€$, and increasingly lower probabilities of much higher losses. Choosing a shape parameter of 2, the average loss is set to $10M€$, which was considered an acceptable value.

Lastly, the risks were integrated in the model by multiplying the impact by the number of occurrences and implementing it in the company's final results.

2.3. Mitigation Strategies

After analysing the main risks the company is exposed to, six possible mitigation strategies were defined by resorting to strategies presented in the case studies of the existing literature. Based on these, a mitigation register was developed, containing the identified mitigation strategies and a brief description of their implementation and impact.

To implement the mitigation strategies in the model, it is necessary to estimate its the implementation costs and impact in the company's results. The cost of the strategies was estimated by reviewing additional literature and available statistical sources. Relating the impact of the chosen strategies, it can be defined as a variation in the sales, costs or changing a specific risk. In particular, the strategies might contribute to reduce the impact, the probability or completely eliminating a previously modelled risk.

2.4. Utility Function

Having defined all the elements of the model, the net profit estimation is achieved. Nevertheless, to compare the utility that the expected results provide to the company, it is important to define their utility function $u(x)$.

Regarding the function calculation, the company's risk profile was estimated using the exponential utility function, as mentioned in the introduction. The four methods introduced were explored. The first one by directly calculating the risk tolerance:

$$\rho \approx 0.06 \times Total\,Sales \approx \frac{Total\,Equity}{6} \tag{5}$$

Additionally, to calculate the coefficient by resorting to the other 3 methods, a survey was developed. Later, the answers of the company's managers were collected. The survey is divided in 3 sections. The first one corresponds to Neapolitan and Jiang's [15] method, where the decision-makers are asked to decide on the maximum value of X they would accept in a 50-50 gamble of winning X or losing $X/2$. The second one is the method suggested by Delquie [6], where the decision-makers have to indicate the maximum value of money they are willing to lose to have a chance of wining an arbitrary large amount of money. In this case, let us consider the large amount of 10^{100}€ and probability $p = 0.5$, which corresponds to an equal chance of gaining 10^{100}€ or losing the maximum acceptable loss (L). The risk tolerance coefficient is then computed by:

$$\rho = -\frac{L}{ln(0.5)} \tag{6}$$

Regarding the third section of the survey, Walls's [17] method was used. For that, typical decisions faced by the managers of the company in study were identified. In the codfish processing industry, managers have to decide on what quantities to buy at a determined price. Therefore, 5 scenarios were created, where the company has the opportunity to buy a determined quantity of codfish at a certain price that, after being processed and sold, will result in a known gain or loss, whose probabilities are also known. In each scenario, the decision-makers have to decide the percentage of the available quantity they would buy, knowing that selecting 100% corresponds to buying the totality of the codfish, exposing themselves to the totality of the presented results, and selecting 0% means they would not buy any codfish, if the expected results of that transaction are not desirable.

The computation of the risk tolerance coefficient in this method is performed by using Microsoft Excel and calculating certainty equivalent for several values of risk tolerance coefficient, using the equation:

$$C_X(\rho, PoC) = -\,\rho \ln\left(P_{success} \times e^{\frac{X_{success} \cdot PoC}{\rho}} + P_{failure} \times e^{\frac{X_{failure} \cdot PoC}{\rho}}\right) \tag{7}$$

Where ρ is a possible risk tolerance coefficient, PoC the percentage of codfish chosen by the manager, $P_{success}$, $X_{success}$, $\mathrm{P}_{failure}$ and $X_{failure}$ are the probability and outcome values of the decision, for both success and failure in selling the codfish. The computation was made in the same way as the author's computation, which was briefly explained in the introduction.

2.5. Value at Risk Curves Comparison

Now, the the company's net income can be simulated. For that, a determined number of iterations needs to be run. For a largest number of iterations, the model will provide more accurate results. On the other hand, the more iterations the more time is required to run the simulation. So, this number was set to 5000, being high enough to provide precise results during an acceptable simulation time.

During each iteration the utility of the simulated net income is calculated:

$$u(Net\,Income) = 1 - e^{-\frac{Net\,Income}{\rho}} \tag{8}$$

Where ρ corresponds to the risk tolerance coefficient calculated by the methods explained in the previous section, and $Net\,Income$ corresponds to the calculated income in the present iteration. In the end of a simulation, 5000 iterations were run, enabling the results of two different curves — the net income curve, having the different net income values that occurred during the simulation associated with their happening frequencies, and the utility curve, having the different utilities calculated during the simulation and respective frequencies.

In this case, as the risk tolerance coefficient calculation results correspond to a range of values, instead of a single one, the utility output just mentioned was calculated twice, using two values of risk tolerance — the lower and the upper values of the uncertain risk tolerance range. This way, it is possible to analyse the two extreme scenarios, and understand how the decision results would vary depending on a higher or lower risk tolerance inside the identified range.

First, 9 simulations were run, calculating the expected and most probable net income for each year from 2021 to 2029. Together with this results, the 5% VaR was calculated. This value consists in the possible loss the company may have in each year, considering a 5% probability, corresponding to an unlikely, but possible, loss.

Later, the utility curves were calculated for the years of 2021 and 2029. The year of 2021 provides more accurate results, as the risk tolerance coefficient was calculated with the survey answers given in this year (2021), revealing the risk tolerance the company has now, or, in particular, when answering the survey. Moreover, the results for the year of 2029 will add a long term perspective for the decision-making. For each of these two years (2021 and 2029), two utility distributions were also outputs of the model, using the lower and the upper values of the identified risk tolerance range. Additionally, 7 other simulations were run for each of the two years, corresponding to different scenarios — one representing the scenario where the company would adopt all the identified mitigation strategies, and the others, corresponding to the situations where the company would adopt each of the six identified mitigation strategies. The objective is to study the impact that each mitigation strategy has on the company's utility. This way, the strategies must be simulated separately, so it is possible to understand which strategies contribute to increase the utility and which strategies will deteriorate it.

The expected value of the utility is calculated by the @Risk software, corresponding to the mean value of the obtained utility distribution:

$$E[u] = \frac{\sum_{i=1}^{5000} u_i}{5000} \tag{9}$$

Where u_i corresponds to the simulated utility value in the iteration i. The 5000 utility values are summed, and then divided by the total number of iterations to result in the expected value. As a result, the advantageous mitigation strategies are concluded by comparing the expected utility provided by the utility curve of each scenario.

3. Results and Discussion

3.1. Risk Register

The risk register was developed and the risks were sorted by the highest impact times probability to the lowest. The 5 top risks identified were the following:

1. Sales decrease($Probability \times Impact = 15$): Increased competition or changes in consumer preferences and trends might lead to a decrease in the company's sales.

2. Codfish price ($Probability \times Impact = 15$): The company works mainly with one type of product, which is the codfish, and its price is dependent on the quotas defined by the governments of the fishing countries. This quotas are very volatile and, even though the company is able to pass the price changes to their customers, a significant change in the price can trigger a high reduction of the quantity demanded.

3. Reduced margins ($Probability \times Impact = 15$): Having low margins, periods of less favourable conditions can more easily lead their profitability to zero, or even to negative results.

4. Lack of new products ($Probability \times Impact = 12$): The continuous success of the company under study is subjected to their ability to forecast new trends, to innovate accordingly to those trends, and develop or adopt the necessary technology to launch new products.

5. Increase of the client's power ($Probability \times Impact = 12$): They sell their products to some retailers that may have increased power, resulting in lower margins to the company in study.

In fact, a broad research and context characterization has contributed very positively for the risk identification, as suggested by Gjerdum [8].

Let us note that the identified risks may be subjective, depending on the available information and brainstorming capacity. Therefore, other risks probably exist, and must be continually identified as the company's operation changes and evolves. Additionally, the expected probability and impact may also be subjective, relying on the expertise of the company's managers.

These 5 risks were modelled and implemented in the MCS model. To do that, as the 5 first risks in the ranking had the same value of 3 in the probability scale, the probability of all these risks was modelled with a Bernoulli distribution with a annual probability of 0.25. Regarding the impact, the first three risks in the ranking had a classification of 5 in the impact scale, resulting in a Pareto distribution, while the next two risks in the ranking had an impact classification of 4, correspondent to an uniform distribution varying between 1 and 5 million euros.

3.2. Multiple Linear Regressions

The results for the multiple linear regressions (MLRs) have presented some constrains, including the very short number of observations and variables involved. The available data allowed the regressions to be estimated based on the data from the past 10 years and, the more observations there were, the more accurate the results would be. Nevertheless, the regressions were successfully calculated for the 3 variables. From now on, let us denote the regressions of the variables operating revenue, material costs and cost of employees by regression 1, regression 2 and regression 3; respectively.

Regarding regression 1, according with the stepwise method, the operating revenues depend on the consumer price index in Portugal and on the quantity of frozen codfish produced in Portugal each year. Relating to regression 2, the material costs are related with the consumer price index in Iceland and with the quantity of codfish produced by the Portuguese companies. Finally, regression 3 is a simple linear regression, only depending on the number of employees of the company.

Table 1 summarizes the characteristics of the found regressions, containing the information regarding the residuals, which are normal distributed and have a mean of zero.

Table 1: Summary of the MLRs.

MLR	R	R^2	Mean	Std. dev.
1	0.96	0.92	0.00	4.45E6
2	0.89	0.80	0.00	5.68E6
3	0.88	0.78	0.00	9.95E5

The obtained regressions depend on less variables than what would be expected. For example, the quantity of codfish produced by all the Portuguese companies is not enough to accurately estimate the quantity the company buys and sells. Also, the prices at which they buy and sell depend on several factors besides the inflation. Hence, it would make sense that the regressions incorporated the average price of codfish and the company's market share, for example. A possible reason for the market share to not be correlated with their sales and quantities they buy, is that it was not calculated correctly. In this case, it was calculated by using the sales of the company in study and its five main competitors. So, a possible explanation is that the market was not well defined, existing other relevant players, and, as a result, the market share values are not correct.

Now it is important to verify the accuracy of the results by the requirements previously set. For the first one, medium correlations were observed between the dependent variable and each independent variable, which does not correspond to the ideal solution, where all these correlations would be high. For the second condition, all the obtained VIF values are much below 10 units and the correlations between the independent variables are low, meaning that there is no multicollinearity. Regarding the last condition, the errors are approximately following a normal distribution. However, the errors should be uncorrelated, which is not verified in same cases, where the errors seem to have a linear relationship.

Nonetheless, the obtained regressions were implemented in the model, by using the coefficients provided by the software. Additionally, despite the limitations found during the estimation of the material costs and the operating revenue, the simulation of the operating costs and revenues led to very plausible results. The average of the simulated operating revenue in 2021 is 176 million euros, whereas the operating costs have an average value of 168 million euros.

3.3. Mitigation Strategies Register

Moving on to the mitigation register, the six identified mitigation strategies were the following:

1. Marketing campaig: Marketing campaigns may contribute to product differentiation and increase the consumers purchase intention, increasing the quantities sold and, as a result, the company's sales.

2. Investing in R&D: Investing in R&D is another way of differentiating the products and innovating, increasing the sales of the company, and automatizing and improving the processes, decreasing the company's costs.

3. Hedging: Hedging contributes to reduce the impact of commodities' price volatility.

4. Supplier contracts negotiation: Setting prices and quantities in contracts with the suppliers may be beneficial for both parties, since the buyer locks in a favourable price and the seller guarantees future sales.

5. Export to new countries: Expanding to new countries reduces the macroeconomic risks specific to a country or a group of countries. Also, it increases the number of costumers of the company, contributing to a possible sales' increase.

6. Selling directly to consumers: This strategy reduces the risk associated with the company's clients, which are not the final consumers. A way of selling directly to the end consumers is online sales.

To model these strategies, several assumptions had to be made, by consulting various sources. These assumptions are subjective and, when using this model for decision-making, the company should study in detail the impact of the different decisions they want analyse. The result of this step was the definition of the implementation cost for each of the strategies and the impact of the strategy. For example, both the strategies of hedging and negotiating prices with the suppliers are modelled by eliminating the codfish price risk, that was previously modelled.

3.4. Risk Tolerance

Regarding the risk tolerance results, the different methods provided very different results regarding the risk tolerance of the company in study, between 8 and 21M€.

The first method is very simple to implement, not requiring any subjective view of the company's managers for specific decisions or gambles. The formulas assume a constant proportion between the sales and the equity of the company, which corresponds to a limitation. Nevertheless, in this case, that proportion was roughly reached in 2015. Using this method, two conclusions could be took straight away. The first one is that the risk tolerance of the company has been increasing over the past years. This makes sense, since they have been expanding their business, increasing their costs, revenues and profits. So, their tolerance to lose money is expected to grow together, since the same amount of money starts representing a smaller and smaller percentage of their traded volume. As a result, one may assume that the coefficient is currently slightly greater than it was in 2019 and that it will likely continue to rise in the coming years. The second conclusion is that, even though the two formulas to calculate the risk tolerance provide very different results in some years, the risk tolerance coefficient was around 9M€ in 2019.

Moving to the second method, the company's managers have answered that they would accept a gamble with a 50% chance of wining X and 50% chance of losing $X/2$ for values of X equal or bellow 8M€, risking to lose a maximum of 4M€. In this method, this value of 8M€ corresponds to the risk tolerance coefficient. The results of this gamble seem to provide more conservative results, when comparing with any of the other methodologies.

On the other hand, the third method results in higher risk tolerance values. In this gamble, the company's decision-makers claim to be willing to bet 10M€ for a 50% chance of wining $10^{100}M$€. The computation of the risk tolerance will lead to a result of 14.43M€ for the coefficient. One may conclude that when gambling to win an arbitrary amount of money, the willingness to lose money increases more than the expected, compared with a situation of winning twice the bet amount. Considering that the company's risk tolerance is in the range between the values reached through this gambles, it is possible to conclude that the simpler approach of the first method, that was initially tested for oil and chemicals companies [10], also applies to the codfish processing industry.

The last method used, developed by Walls [17], suggests an higher risk tolerance coefficient than the other methods. Considering only four of the decisions of this method, the result for the coefficient would be between 13 and 21 million euros, including lower values consistent with the previous method analysed. Nevertheless, one of the decisions has changed this results since the company's managers have shown a 100% willingness to lose 100K€ with a 90% probability, for the 10% chance to win 100M€. This way, this methodology added a valuable insight to the equation, exposing a much higher tolerance to risk than the initially predicted. The determined risk tolerance through this method corresponds to a range between 19 and 21 million euros.

For the next steps, it makes sense to consider two scenarios of risk tolerance coefficient values and compare the results provided by each scenario. If both coefficients provide the same decision it is not important to specify the value of the coefficient within the range to conclude weather the mitigation strategy is recommended or not. Given the results, let us assume a risk tolerance range between 8 and 21 million euros.

3.5. Net Income and Value at Risk

The simulation was run for the 9 years, from 2021 to 2029, and the net income results are bell shaped curves, similar to the normal distribution. Table 2 presents the minimum, maximum and mean values of the simulated net incomes. As can be verified, the obtained ranges are very wide, with low precision. As a result, the company's future results will very likely be included in the range. Nonetheless, this range is not acceptable, when using the results to help in decision-making, being too wide to enable any conclusion.

Table 2: Simulated net income for the years from 2021 to 2029.

Year	Simulated Net Income (€)			
	Min.	Max.	Mean	5%VaR
2021	-3.67E7	1.80E7	-3.38E6	1.66E7
2022	-3.46E7	2.27E7	-2.71E6	1.60E7
2023	-3.56E7	2.36E7	-1.78E6	1.56E7
2024	-3.78E7	2.19E7	-8.97E5	1.45E7
2025	-2.95E7	2.48E7	3.44E4	1.37E7
2026	-3.27E7	2.36E7	9.26E5	1.30E7
2027	-3.26E7	2.53E7	1.85E6	1.26E7
2028	-3.10E7	2.58E7	2.92E6	1.09E7
2029	-2.94E7	2.73E7	3.95E6	1.03E7

Furthermore, the average net income of the years between 2021 and 2024 is negative, which is not consistent with the positive results the company has had in the past years. Possibly, during the modelling of the top 5 risks in the register, the risks' probability was overestimated, lowering the average results more than the reasonable. This overestimation is due to the subjectivity associated with the risks modelling, and consistent with the limitations of MCS found by Crum and Rayhorn [5], since these authors have also verified the same limitation during their simulations. Nonetheless, the net income simulations have captured the growing tendency of the company's results, estimating a net income increase of 7 million euros in 8 years, when comparing 2029 results with 2021 ones.

Additionally, Table 2 also contains the 5% VaR information. In 2021, the company is risking a 5% chance of losing almost 17 million euros, which may correspond to a low probability, but is a very significant loss, that would very likely completely destroy the business of the company under study. In 2029, the model predicts a decrease in this value to roughly 10 million euros, which is still higher than what would be acceptable in a healthy business.

3.6. Utility Results

Moving to the utility results, two utility outputs were calculated in the model, using the two extreme values of the possible risk tolerance coefficient range:

$$u_8 = 1 - e^{-\frac{Net\,Income}{8E6}} \tag{10}$$

$$u_{21} = 1 - e^{-\frac{Net\,Income}{2.1E7}} \tag{11}$$

Where u_ρ is the utility provided using the risk tolerance coefficient ρ and $Net\,Income$ is the simulated net income in each iteration. In the end of the simulation, the expected value (average value of all iterations) was considered, and will be presented.

The model was run for the two risk tolerance coefficients and the 8 mitigation scenarios. Let us denote the first simulation by simulation 1, corresponding to the current operation scenario. The 6 simulations corresponding to individually implementing each of the 6 identified mitigation strategies will be noted by simulations 2 to 7 and, lastly, simulation 8 corresponds to simultaneously implementing all the mitigation strategies. Table 3 summarizes the expected utility resultant from the simulation of these scenarios in the years of 2021 and 2029.

Analysing Table 3, similar conclusions can be took for the two years and the two risk tolerance coefficients. The mitigation strategies that provide a greater utility to the company when put in practice are hedging (simulation 4) and the supplier contracts negotiation (simulation 5). Additionally, investing in R&D (simulation 3) and expanding to new countries (simulation 6) decrease the expected utility. The results have shown that the added benefit of these strategies do not compensate for their costs, resulting in less utility for the company. Lastly, the marketing campaign (simulation 2) and selling directing to the consumers (simulation 7) do not significantly change the utility value, when compared with simulation 1.

Table 3: Expected utility using the two risk tolerance coefficient for different scenarios for 2021 and 2029.

	2021		2029	
Sim. \ RT	8$M€$	21$M€$	8$M€$	21$M€$
1	-1.52	-0.26	-0.06	0.11
2	-1.45	-0.25	-0.05	0.11
3	-1.70	-0.29	-0.14	0.08
4	-1.19	-0.22	0.08	0.14
5	-0.80	-0.14	0.23	0.19
6	-2.03	-0.37	-0.26	0.03
7	-1.56	-0.26	-0.08	0.11
8	-1.327	-0.27	0.04	0.10

The last line of the table contains the results when all the mitigation strategies were simulated simultaneously. If the company has a risk tolerance value closer to 8 million euros, they would benefit from applying all the mitigation strategies at the same time. On the other hand, if having a higher tolerance to risk, they are more willing to take risks, and less in need to apply the mitigation strategies. As a result, when considering a risk tolerance of 21 million euros, applying all the strategies is not beneficial anymore, contributing to a decrease in the provided utility. Hence, a more risk averse company must benefit more from managing risk than a more tolerant one.

Let us note that the utility values are likely incorrect for 2021, since these depend on the expected net income, which is also very likely incorrect. Nevertheless, the negative values could be compared and it could be concluded that the implementation of some decisions is more beneficial than the implementation of the others, providing greater values of utility.

4. Conclusions

Risk management practices were applied to a codfish processing company, which have had positive results so far, but is exposed to a variety of uncertainties related with their operation, such as the relationship with their customers, decrease in the demand for codfish and abrupt increases in the codfish price.

Regarding the developed MCS model, its reliability has been questioned, since the risks, mitigation strategies and forecast of the variables were made by resorting to the expertise of several entities, which may be subjective. A very significant limitation of the model, is the MLRs found. In this case study, the available information was restricted to the total values of sales and material costs, without the quantities bought and sold specification, neither the prices at which they buy and sell each year. It was concluded that the macroeconomic, market prices and quantities variables are not accurate in predicting the dependent variables. Possibly, better regressions could be found to explain the variables: (a) codfish annual buying price, (b) annual quantity sold per product and (c) tonnes of codfish bought annually.

As a result, the net income forecast result is a very wide range of values, with a negative average for some of the years. These results were not consistent with the company's positive results of the past years. As expected, the negative incomes provide negative utility to the company in study. Thus, the utility values are likely incorrect. Nonetheless, the utility analysis allows a comparison between different scenarios. Therefore, it has proved to be a great approach for decision-making. The results have also shown that a more risk averse decision-maker benefits more from mitigating risks than a more risk tolerant one.

The utility analysis was made through the use of an exponential utility function, using the risk tolerance coefficient. The coefficient calculation methods have provided different results. In particular, the methods proposed by Howard [10] and Neapolitan and Jiang [15] lead to similar and conservative results. Conversely, the methods suggested by Delquie [6] and Walls [17] have resulted in higher risk tolerance values.

To conclude, this research has contributed to study the adaptability of the different risk management frameworks for the codfish processing industry and to verify the accuracy of the used methods.

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