INTRODUCING RISK ANALYSIS AND CALCULATION OF PROFITABILITY UNDER UNCERTAINTY IN ENGINEERING DESIGN

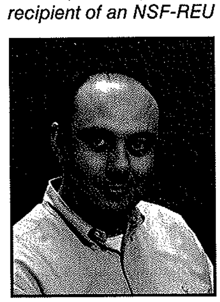
Georgia Kosmopoulou, Margaret Freeman, and Dimitrios V. Papavassiliou
The University of Oklahoma • Norman, OK 73019

Engineering economics is typically taught in chemical engineering design courses. Such courses are focused on cost estimation for equipment and processes, on the calculation of product cost and profit, and the calculation of profitability criteria in order to determine whether a process can be economically sustainable and profitable for a corporation or not. Even though these economic calculations incorporate the time value of money, effects of inflation, amortization costs, etc., they usually do not emphasize the fact that all cost or profit factors are not deterministic, but are subject to financial uncertainty. In fact, the prices of raw materials and products, the cost of energy and labor, and the financial landscape during the time period that a process will be in operation are likely to depend on factors that are outside of an engineer's control (*e.g.*, natural disasters, international conditions). At the same time, the literature in management and in industrial economics is rich in the presentation of models that can handle and quantify uncertainty and risk (see, for example, Reference 1). Corporations that employ chemical engineers have, of course, utilized such models for planning and pricing policies and for taking decisions for many years. Risk analysis has received attention on and off in the last 30 to 40 years, as evidenced with sections on decision making and risk in textbooks.[2,3] The undergraduate curriculum in chemical engineering needs to remain updated in this area, and this updating can be done without extensive additional work on the part of the instructors.

Recently, renewed effort has been placed on the introduction of risk analysis in chemical engineering design.[4] At the most recent Annual AIChE Meeting, in Salt Lake City (November

***Georgia Kosmopoulou** is the Edith Kinney Gaylord Presidential Professor at the Department of Economics at the University of Oklahoma. She has received a B.S. from the University of Piraeus and her M.S. and Ph.D. from the University of Illinois at Urbana-Champaign. Her research interests are in industrial organization, auction theory, and mechanism design.*

***Margaret Freeman** is a senior student in the accelerated M.S./B.S. program in chemical engineering at the University of Oklahoma. She is also pursuing a minor in entrepreneurship for engineering majors and is the recipient of an NSF-REU fellowship.*



***Dimitrios Papavassiliou** is a Presidential Professor at the School of Chemical, Biological, and Materials Engineering at the University of Oklahoma. He has received a Diploma from the Aristotle University of Thessaloniki, and M.S. and Ph.D. degrees from the University of Illinois at Urbana-Champaign. His research interests are in turbulent transport, transport in porous media, microfluidics, and computational transport. He has been teaching Design I for more than 10 years.*

2010), in addition to our presentation,[5] there was one more presentation describing a new one-credit-hour course at the University of Michigan on risk analysis with expected profit.[6] Note that most modern textbooks in chemical engineering design and in engineering economics used within other engineering disciplines offer a "risk free" content—calculations of profitability criteria do not account for financial risk. (An exception among recently published books is the third edition of Turton, et al.,[7] which includes a section on risk analysis).

Lately, through collaboration between chemical engineers and economists, we have developed classroom material that introduces the concepts of financial risk and decision making under uncertainty in Design I, a course that introduces engineering economics to chemical engineers who lack an extensive economics background. In a prior *Chemical Engineering Education* paper,[8] we discussed decision making based on expected profit and on expected utility, the use of decision-tree analysis, and also the development of classroom games (or class experiments, as they would be called in the economics literature) that demonstrate the concept of the utility function and strategic decision making. In addition to discussing the educational objectives of each game, we discussed the mechanics of carrying out such experiments in the classroom. The concepts that were explored with those games can be used to quantify risk and facilitate decision making under uncertainty by modifying the way profitability is calculated. In the present work we demonstrate first the use of assignments and examples from everyday life to introduce the idea of financial uncertainty. Then we discuss how to quantify risk with Monte Carlo methods and how to take it into account in profitability calculations depending on the attitude of the decision maker towards risk. Such an approach, based on indifference curves and the notion of certainty equivalence, incorporates the subjective character of handling risk into the decision process and takes the students beyond the simple calculation of expected values. We also discuss the use of software that is readily available in assignments for the class.

TABLE 1
Historic Data for the Price of Oil and Natural Gas

Date	Oil Price (West Texas Intermediate, $/bbl)	Natural Gas Price ($/MMBTU)
01/09/1999	9.50	1.95
03/01/2000	25.60	2.33
09/01/2000	33.25	4.79
08/24/2001	23.25	3.00
08/26/2002	25.50	3.50
08/27/2003	28.75	5.25
08/23/2004	44.00	5.50
08/18/2005	59.75	9.6
08/18/2006	66.75	6.7
08/18/2007	69.00	6.2
08/27/2008	114.65	8.7
08/25/2009	72.54	3.2
08/25/2010	68.15	4.9

The dollar values are not adjusted for inflation. The price of oil has been obtained on the dates indicated from <*http://octane.nmt.edu/gotech/Main.aspx*>, and the price of natural gas has been obtained on the same dates from <*http://tfc-charts.w2d.com/chart/NG/M*>.

INTRODUCING THE CONCEPT OF FINANCIAL UNCERTAINTY

In our course, we try to illustrate financial uncertainty quite early in the semester. As part of the first assignment that the students receive, they are asked to establish a fictitious consulting company and then to recommend to their first client a production policy based on data and on forecasting of energy prices. Specifically, the students are asked to propose whether a small independent hydrocarbon producer in Oklahoma should stop production in a well and, instead, use the well to re-inject all or parts of the gas that another well is producing, thus boosting hydrocarbon production from that second well. The details of the assignment are not important for our current discussion. What is important is that in order to respond to this problem, the students need to forecast the price of natural gas and the price of oil two years into the future. Data related to the price of oil and gas during the past decade are also offered as part of the assignment (see Table 1).

There is some implicit but useful information in Table 1: the prices shown are for "West Texas Intermediate" (as opposed to crude from other origins), and there is a peculiarity in the oil industry to use the roman symbols "M" to indicate 10^3 and the roman symbol "MM" (thousand)(thousand) to indicate 10^6. Other than that, the price prediction task initially appears trivial; maybe a plot of the values followed by a linear or polynomial fit can do the job (easy tasks for seniors having access to Excel). As the students plot the data and start thinking about how to extrapolate the prices into the future, however, they realize that this is not as trivial as it might seem. The more inquisitive students find even more historical data, and that can complicate things further, since energy prices dropped significantly in the late '90s, but have been on the rise for a considerable part of this past decade, only recently dropping back.[1] There are local minima and maxima, there is no clear direction, and the ratio of the oil to gas price is not constant. Neither does a periodic pattern emerge. In fact, one student in Fall 2010 told the instructor "This is impossible—I asked my mom who is an economist!" Some student groups end up

1 As can be seen in Table 1, in the middle of 2008 the price of oil increased to a level that was nearly 4 times higher than that of 2003.

using the price of futures for oil and gas that are available in the NYMEX (New York Mercantile Exchange).

Even though time-series analysis and calculation of seasonal and cyclical variations can be used to forecast in a reasonable way future prices of most commodities (see for example Chapter 6 in Reference 1, or Chapter 8 in Reference 2), the price of oil and gas is fluctuating in rather unpredictable ways. The prices are affected not only by inflation in the United States, but also by factors that are independent of the engineer's control, and have to do for example with international events (like the first and second Gulf Wars), with natural disasters (like Hurricanes Katrina and Rita that affected production in the Gulf of Mexico in 2005), and with random events that occur in this market sector (like the BP leak in the Gulf of Mexico in summer 2010). As the assignment is discussed in class, it becomes clear to the students that it is not only them (seniors in a chemical engineering design class), but others more experienced and with more training in forecasting who cannot predict the future. We use examples of such expert failures in class to demonstrate the real-world implications of financial uncertainty. For example, we present in class a short clip from the UpFront section of the journal *Business Week* (issue of Oct. 2, 2006) with the title "Bad Bets: Cheaper Oil But Not for Most Airlines," by Michael Arndt. This clip describes how major airlines forecasted that the price of oil was going to top $100/bbl in the fourth quarter of 2006, since there was a price maximum in July 2006. Leading companies (Continental, U.S. Airways, Northwest) hedged their fourth-quarter fuel contracts at prices in the range of $71.39/bbl to $79.40/bbl. The actual price was around $65/bbl, however, leading to major losses. Only one company (Southwest) managed to lock 73% of its fourth quarter fuel needs at $36/bbl. A second related example that is discussed in class is taken from the Money Section of *USA Today* (published March 15, 2008), where a risk analysis table was offered for airlines (see Table 2). The table provides the loss or gain that 12 airlines were going to have in 2008 as a function of the price of oil, ranging from $75/bbl to $110/bbl.

This example clearly shows that detailed predictions made by professional forecasters can be wrong, and different companies, based on their expert information, might be led to wrong decisions. If that happens, then real money is lost and those who make the worst predictions can go out of business. Furthermore, both of these examples indicate that there is competition in a business sector, and it is not only enough to manage risk, but manage it in consideration of the competitive environment. In the fourth quarter of 2006, Southwest could start a price war in which the rest of the airlines could not compete, even if they estimated that they would be profitable buying fuel at $79.40/bbl.

At the end of this discussion, the question arises of how to account for uncertainties like this in order to calculate profitability.

TABLE 2
Scenarios of Airline Gains/Losses as a Function of Possible Oil Prices

Airline	$75	$95	$100	$110
Alaska	104	14	-9	-54
American	797	-538	-872	-1,539
Continental	444	-12	-126	-354
Delta	538	-100	-260	-579
Northwest	488	43	-69	-291
United	540	-116	-280	-609
Total majors	**2,913**	**-709**	**-1,615**	**-3,426**
AirTran	87	-27	-56	0
Allegiant	47	22	15	3
Frontier	9	-48	-63	-91
JetBlue	66	-45	-72	-91
Southwest	495	467	460	445
US Airways	259	19	-41	-160
Total Industry	**3,877**	**-322**	**-1,371**	**-3,321**

These are estimates of airlines' net income or loss in millions if the price of oil averaged the values on the first row during 2008 (the values of this table were taken from the March 15, 2008, issue of *USA Today*, and they were attributed to Merrill Lynch).

RISK QUANTIFICATION—MONTE CARLO SIMULATIONS

One way to take uncertainty into account for making business decisions is to *maximize expected profits* or to *maximize expected utility* (see Reference 8 for ways to introduce these concepts in class with examples and class games). Expected profit can be calculated based on a probability density function (pdf) for specific profits to occur. This pdf is generated from experts within a company, or from a consulting firm, and it is a pdf that describes the likelihood of potential discrete outcomes (each one associated with a profit or a loss) that may arise following each decision made by the company. This type of pdf is based on opinion and on tools such as market research and surveys, since one cannot repeat the same economic experiment under the same business conditions. A business situation occurs once; thus, one cannot generate a sample of outcomes given the decisions made and develop a rigorous statistical pdf.

One can also generate a pdf for each component that affects the profit function (*e.g.*, equipment costs, inflation, raw material prices, labor costs, transportation costs, product prices, market share). These pdfs can be continuous, since there might be historical data available that can allow a reasonable guess about the form of the pdf. The expected value in the statistical sense (*i.e.*, the average value) of costs, prices, etc., is then used to calculate expected profit or expected Net Present Worth (NPW).

Generating the pdf for profit or for NPW can lead to the quantification of risk. A measure of risk is either the standard deviation, σ, of a pdf, or the coefficient of variation, V, which can be defined as follows:

$$V = \frac{\sigma}{\mu} \tag{1}$$

where μ is the mean of the variable. The coefficient of variation is a normalized risk, since it designates uncertainty as a fraction of the mean. How can the coefficient of variation be calculated, however? For example, the NPW is a function of several variables, like equipment cost, operating cost, the economic life of the process, the firm market share, the product price, the price of raw materials, inflation, etc. O'Donnell, et al.,[4] presented two techniques. One is the propagation of error, in which the assumption is made that the pdfs followed by the variables that comprise NPW are statistically independent. The second is a Monte Carlo technique, in which a great many scenarios are generated. Each one of these scenarios is based on a set of randomly selected values of the independent variables. The random selection is made so that the random variables take values from the specific pdfs that describe each one of them. The NPW is calculated for each randomly selected case, and a pdf for NPW can then be generated. The process stops when the mean and the standard deviation of the pdf that NPW follows do not change significantly. Specifically, the Monte Carlo technique includes the following six steps:

i) Decide on the probability type for each independent variable.

ii) Estimate the minimum, maximum, and most likely value.

iii) Generate random numbers for these variables based on their probability functions.

iv) Calculate NPW for each set of variables.

v) Repeat as many times as necessary, i.e., *until the probability distribution of NPW does not change significantly. This may require hundreds or even thousands of repetitions.*

vi) Calculate the mean and the standard deviation of the pdf that NPW follows.

A student with knowledge of Excel® can generate random numbers that follow a uniform pdf, or a normal pdf (see also Reference 4). Monte Carlo calculations, however, can be done quickly with Crystal Ball® by Oracle—an Excel add-in that is designed specifically for risk analysis applications and forecasting. Figure 1 is a typical pdf for NPW that was generated using Crystal Ball by a student group in Fall 2010. Such software allows the user to simply click on a spreadsheet cell, opening up a menu of pdf choices (*e.g.*, uniform, normal, log-normal, triangular), followed by the input of the parameters that characterize the pdf (*e.g.*, mean and standard deviation). When the variable of interest (NPW) is written as a function of values in that spreadsheet cell, the generation of Monte Carlo realizations is started. The pdf appearing in Figure 1 is the result of 3,000,000 different calculations of NPW. The software reports not only the pdf, but also the cumulative pdf, the most common value, the median, and the skewness and kurtosis of the pdf, and in general all the details that characterize the pdf. It can even perform a goodness-of-fit test to determine whether the NPW pdf can be described analytically.

Class Problems. The introduction to Monte Carlo methods and risk quantification is done after the discussion of conventional profitability criteria. The following is an example of a sequence of assignment problems used in class. A process (cyclohexane production from benzene) is described, and data are provided related to the operation of this process. In the first problem of the sequence, the students need to apply conventional methods to calculate profitability based on cost, price, inflation, and other data, some of which are provided and some that need to be found by the students. The following are the questions asked related to profitability:

Problem 1

- *Report on profitability based on Return on Investment (ROI), rate of return based on discounted cash flow, Net Present Worth (NPW), and pay-out time.*
- *What would your NPW be, if your products were sold at five times the price that you estimated*

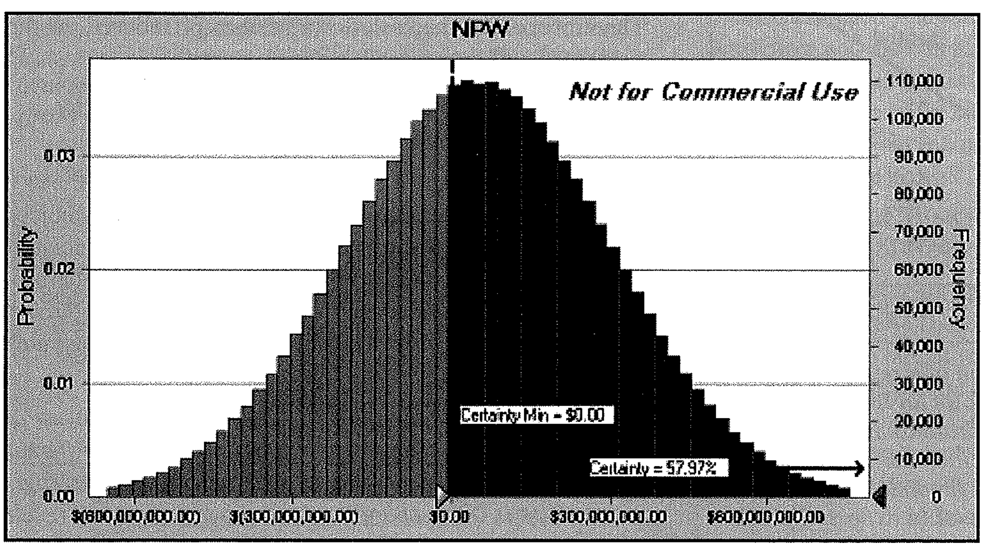


Figure 1. *Typical pdf generated with Crystal Ball®. The NPW in this case is for a cyclohexane production process where the prices of cyclohexane, hydrogen, and benzene are randomly selected from normal pdfs.*

from your calculations above? What would your NPW be, if your products were sold at half the price you estimated above?

The second part of this problem reveals the possibility of changes in the financial circumstances during the economic lifetime of this process, and allows the follow-up problem, which is given to the students after our discussion in class about risk and Monte Carlo methods. The related questions in the follow-up problem are:

Problem 2

• *Perform sensitivity analysis for the quantification of risk,* i.e., *show Strauss plots of the NPW as a function of fixed capital investment, product cost, and product price (variables for which a probability density function is provided).*

• *Calculate the risk associated with NPW using the error propagation method discussed in class.*

• *What should the minimum price difference between your product and the raw material be, in order to have positive expected NPW?*

• *Use Crystal Ball® to estimate the NPW distribution when the price of hydrogen is uniformly distributed between $200/ton and $400/ton and the price of benzene takes values from a normal distribution with a mean of $2/gallon and standard deviation of $1/gallon.*

This second problem requires a full-scale risk characterization and quantification for the process. The Strauss plots are sensitivity analysis graphs that present the dependent variable (NPW) as a function of one of the independent variables (*e.g.*, fixed capital investment) while the rest of the variables are set as constants (see References 4 and 7 for details). We have used Crystal Ball® only in Fall 2010, the most recent semester

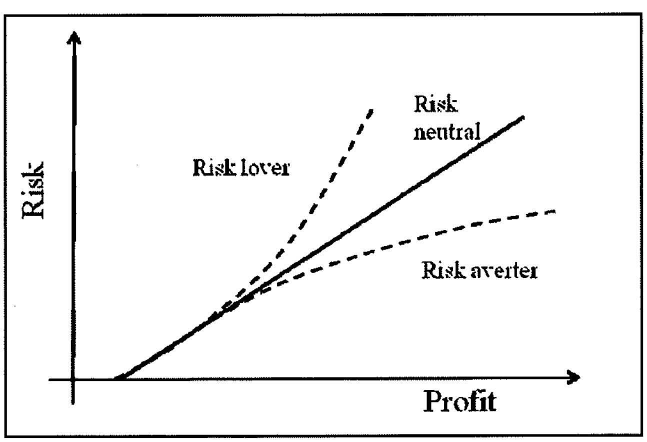


Figure 2. *Graphical representation of a person's attitude towards risk. The risk averter allows an increase in risk only when the profit increases dramatically, the risk-neutral decision maker allows an increase in risk proportional to the expected profit, and the risk lover can take more risk even with small increases in expected profit.*

that our Design class was taught. The students learned the software very quickly and produced quality reports without a need to conduct a training session.

TAKING FINANCIAL UNCERTAINTY AND ATTITUDE TOWARDS RISK INTO ACCOUNT FOR PROFITABILITY CALCULATIONS

The question that arises now is how to involve the calculations of risk into the decision-making process and the determination of whether a process that has a particular pdf for NPW is worth pursuing or not. It is natural that different people or different corporations have different attitudes towards risk. There are three types of people: (a) Those that are risk-averse, *i.e.*, they would assume more risk only when the expected profit is much higher; (b) Those that are risk-loving, *i.e.*, they are willing to assume more risk even when the increase in the expected profit is not large; and (c) Those that are risk-neutral, *i.e.*, they are willing to take risk proportional to the expected profit. Figure 2 is a graphical representation of risk behavior. Most people, corporations, and especially small businesses owners are risk-averse and are willing to assume more risk only when the expected profit increases.

The formula that is used to calculate NPW is as follows:

$$NPW = \sum_{k=1}^{n} \frac{CF_k}{(1+i)^k} + \frac{V_s + WC}{(1+i)^n} - TCI \qquad (2)$$

where n is the economic lifetime of the project, CF_k is the cash flow at year k, i is the minimum acceptable rate of return, V_s is the salvage value, WC is the working capital, and TCI is the total capital investment. The working capital and the salvage value are usually not the source of risk. Risk mostly stems from the cash flow. Looking at Eq. (2), the way to incorporate risk is to change the first term of the right-hand side of the equation. One can either change the numerator (the cash flows) or the denominator (the minimum acceptable rate for return) in a way that makes the profitability criterion stricter. Therefore, either the cash flows need to be reduced, or the riskless rate of return needs to be increased.

Use of the Notion of 'Certainty Equivalence' to Modify Cash Flows in the NPW Equation

Let us first introduce the concept of *indifference curves*. These are 2-D curves that represent combinations of choices that leave the decision maker indifferent. The decision maker (*e.g.*, the boss) may be indifferent between undertaking a specific amount of risk for a high profit and obtaining a lower profit risk-free. The following example illustrates the concept.

Example 1. *A company wants to decide whether to invest in a new automation system that will also result in a different type of by-product. According to the company's expert engineers, there is 0.3 probability that such a system will result* *in a $1,600,000 profit, a 0.2 probability that it will result in a $700,000 profit, 0.1 probability that it will result in a $300,000 profit, and a 0.4 probability that it will result in a $800,000 loss.*

The expected profit, in $\$10^3$, for this case is given as
Expected Profit= $0.3 \times 1{,}600 + 0.2 \times 700 + 0.1 \times 300 - 0.4 \times 800 = \$330$

The standard deviation is given as
$\sigma = [0.3x(1{,}600\text{-}330)^2 + 0.2x(700\text{-}330)^2 + 0.1x(300\text{-}330)^2 + 0.4x(800\text{-}330)^2]^{1/2} = \$1{,}011$

and the coefficient of variation is $V = \sigma$ / (Expected Profit) = 3.06.

Figure 3 is an example of an indifference curve where a manager is indifferent between venturing on this process, with risk expressed as V = 3.06 and an expected profit of $330,000, and receiving a certain profit of $200,000 from a risk-free alternative action. The exact curve would be generated using additional (profit, risk) points, for which the decision maker is indifferent when asked to choose between ventures with those profit/risk combinations or a zero-risk venture with profit of $200K. The indifference curve presented in Figure 3 is that of a typical risk-averter, since this decision maker is willing to take a higher risk than 3.06 only when the expected profit is much higher than $330,000. Mathematically, the curve is concave (the second derivative is negative as one is willing to take marginally more risk for a lot more profit). This zero-risk value that corresponds to the indifference curve is called the *certainty equivalent*. We say, therefore, that the decision maker is indifferent between taking any risk along the indifference line with the corresponding expected profit and making a profit equal to the certainty equivalent with no risk.

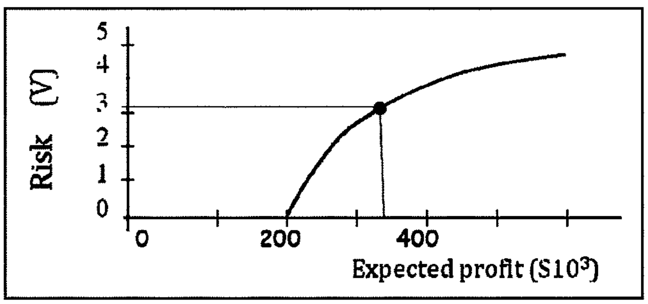


Figure 3. *Indifference curve for a certainty equivalent (i.e., zero risk option) of $200,000. A curve like this can be generated by surveying decision makers to obtain expected profit and corresponding risk points that make them indifferent relative to the $200,000 and zero-risk option.*

The exact shape of indifference curves, like the one presented in Figure 3, describes the attitude of a particular individual. In business, this individual is the person who will make the decision whether to invest in a process or not. There are innumerous indifference curves for the decision maker, one for each certainty equivalent. In the example discussed above, there are other indifference curves that have certainty equivalents of $100K, $300K, $400K, etc. These curves are not intersecting each other (one can ask the students why that is, stimulating class discussion about indifference curves). One can obtain such indifference curves by presenting the decision maker with two options. Option A: a certainty of a specific profit, say P_1, and Option B: a gamble that has a higher expected profit, say P_2, but carries a certain risk V_2. Starting with a high V_2, the choice should be option A. Then, one can decrease V_2 to the point where the option chosen becomes option B. The values P_2 and V_2 where this switch occurs designate a point on the indifference curve that has a certainty equivalent P_1. (The interested reader can find a description of Excel-based classroom games that we have developed in the context of introducing the utility function to students.[8] These games place the students in the decision maker's position and illustrate how one switches options when faced with such choices.)

In order, therefore, to take risk into account for the expected cash flows appearing in Eq. (2), one can use their certainty equivalents, as follows:

$$\text{NPW} = \sum_{k=1}^{n} \frac{\text{CF}_k^{\circ}}{(1+i)^k} + \frac{V_s + \text{WC}}{(1+i)^n} - \text{TCI} \qquad (3)$$

where CF_k° is the certainty equivalent of the cash flow for year k. For each year one needs to estimate both the expected cash flow and the risk associated with it, use the indifference curves to obtain the certainty equivalent for each cash flow, and then do the NPW calculation. If the NPW remains positive, then the process will be considered profitable even with risk.

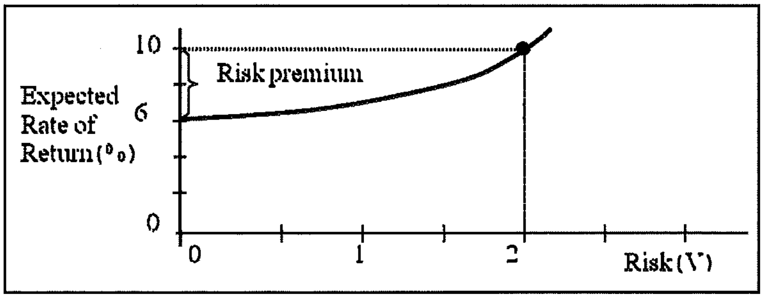


Figure 4. *Indifference curve for an expected rate of return indicating a risk premium of 4% at risk of V = 2.*

Use of 'Risk Premium' to Modify Acceptable Rate of Return in the NPW Equation

In this case, the minimum acceptable rate of return is modified based on an indifference curve that relates risk to rate of return. Figure 4 is an example of such a curve for the case where the minimum acceptable rate of return is 6% (for zero risk). This curve is again for a risk-averse decision maker, since it indicates that this person expects a marginally higher rate of return in order to accept marginally higher risk. The additional expected rate of return in order to assume risk is called *risk premium*, i_p. Therefore, a modified rate of return, i_r, needs to be used in Eq. (2) in this case, that is given as $i_r = i + i_p$. Eq. (2) then becomes

$$NPW = \sum_{k=1}^{n} \frac{CF_k}{(1+i_r)^k} + \frac{V_s + WC}{(1+i)^n} - TCI \qquad (4)$$

where the discount factor for salvage value and working capital is not modified (because these amounts are not at risk). Eq. (4) can also be used with different risk premiums for each year k. If the new NPW is still positive, then the process will be considered profitable.

Example of a Homework/Test Problem

The following is the type of problem that we give to the students in a test. It only uses n = 2, in order to be doable in a few minutes in class, but it makes the students produce indifference curves, it allows them to calculate profitability and then to incorporate risk into their calculations. One can generate problems like this that would involve more extensive calculations rather easily.

Problem 3

The total capital investment is given at $750,000, the working capital is assumed to be 10% of the total capital investment, the salvage value is zero, and n is 2 years. The acceptable return on investment for your company is 8%. Consider the following data that describe the decision maker's attitude towards risk. They provide combinations of risk and expected profit levels for which the decision maker is indifferent.[2]

Risk (V)	Expected Profit (EP_1)	Expected Profit (EP_2)
0	100,000	200,000
0.5	125,000	250,000
1	175,000	330,000
1.5	250,000	430,000
2	340,000	600,000
2.5	550,000	

and the following data are provided for your investment:

Year	Expected Cash Flow	Risk (V)
1	$400,000	2
2	$500,000	0.75

(a) Calculate the NPW for this project without risk. Is the process profitable?

(b) Draw a plot of the indifference curves for this situation.

(c) Calculate the NPW for this project incorporating risk into your calculations. Is this process considered profitable now?

(d) What risk premium would be needed in order for the process to be profitable when risk is taken into account? (Assume that the risk premium would be the same for both years of operation, irrespective of risk.)

This process is profitable without risk [Eq. (2) gives NPW = $113,340]. For part (b), when the two indifference curves for this problem are drawn (one for certainty equivalent of $100,000 and one for $200,000, see Figure 5) the students realize that they need to draw two additional lines that would

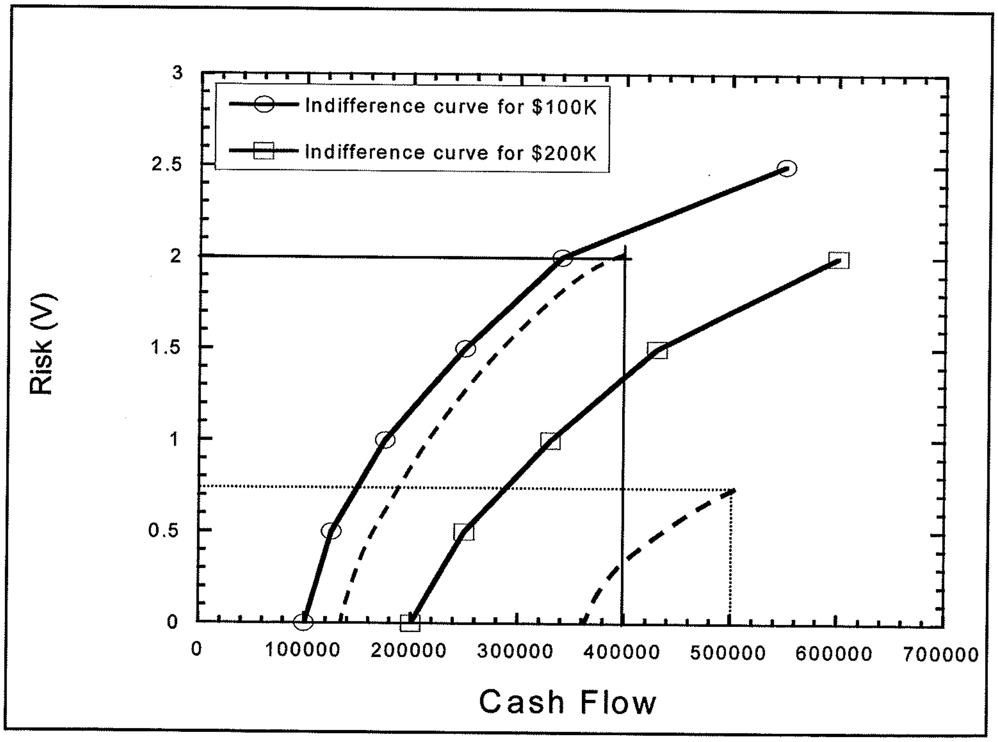


***Figure 5.** Indifference curves corresponding to the data for Problem 3. The dashed lines indicate the two indifference curves corresponding to CF = $400,000 and V = 2, and to CF = $500,000 and V = 0.75*

2 *Notice that there is a different riskless rate of return associated with EP_1 and EP_2.*

be used to estimate the certainty equivalents of the cash flows for years 1 and 2. Knowing that indifference lines do not intersect, one can draw the dashed lines appearing in Figure 5 and estimate the certainty equivalent of $400K and estimated risk parameter V=2 to be about $140K and the certainty equivalent of $500K and estimated risk parameter V=0.75 to be $360K. Using these adjusted values in Eq. (3), it is found that the process is no longer profitable with the given risk and the given attitude towards risk.

CONCLUDING DISCUSSION

Modern developments in economics and management include techniques that address uncertainty and risk in a systematic and quantitative way. Deterministic models for the calculation of NPW can be used to introduce the concept of NPW, but further analysis that incorporates financial uncertainty should be offered. Uncertainty can be discussed in class using examples from the real world, such as the forecast of energy prices discussed herein. The financial implications of uncertainty can also be discussed with relevant examples or assignments. Uncertainty can be quantified by applying well-designed Monte Carlo methods, which have lately become easy to implement in a Design course due to the availability of commercial software that students can use with little or no training. In addition to quantifying risk and presenting options based on expected profit or expected NPW, the attitude towards risk can be taken into account in profitability calculations using indifference curves. Incorporating risk analysis in the teaching of Engineering Economics is not taxing in terms of class time (it usually takes one week to discuss in class the ideas presented here and conduct the class games described in Reference 8), and it offers the students an updated and relevant perspective on profitability.

ACKNOWLEDGMENTS

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