Including changes in security of supply in cost benefit analysis – an application to oil prices in the transport sector

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Abstract
This paper contains a tentative suggestion of how to take into account changes in security of supply in real world cost-benefit analysis. Assuming that consumers are risk avers, security of supply can be viewed as a matter of avoiding oscillations in consumption originating from volatile prices of for instance oil. When the government makes transport related choices on behalf of the consumers, the effect on oscillations in general consumption should be included in the policy assessment taking into account the most significant correlations between prices on alternative fuels and between fuel prices and consumption in general. In the paper, a method of valuing changes in security of supply based on portfolio theory is applied to some very simple transport related examples. They indicate that including the value of changes in security of supply often makes very little difference to the results of cost benefit analysis, but more work has to be done on quantifying, among other things, consumers' risk aversion and the background standard deviation in total consumption before firm conclusions can be drawn.

Introduction
Is it more valuable to save oil than to save coal? It is often claimed that society's dependency on oil produced in political unstable regions means that for security of supply reasons more value should be put on saving oil than saving other energy carriers. Because of their positive impact on the security of energy supply projects and policies saving oil – typically in the transport sector – might be more valuable than reflected in ordinary cost benefit analysis. But how can we appraise this extra value? This study presents an attempt to answer this question using projects from the transport sector as simple examples.

The study is confined to a narrow definition of changes in the security of supply since it is simply regarded as a matter of a change in the volatility of general consumption as a consequence of changes in the society's sensitivity to fuel price changes. Real physical shortness is assumed to be limited to either very short periods or states of war and can hardly be handled in economic analysis. *High* oil prices can be handled within standard cost benefit calculations but *volatile* prices is a major difficulty for cost benefit analyses.

The starting point for the study is that consumers are assumed to be risk avers and tend to avoid dependency on goods with volatile prices because they mean volatile real income and thus volatile consumption. When the consumers on their own hand are confronted with a choice, they presumably take this risk into account, but when the government makes choices on behalf of the consumers, the effect on the volatility of general consumption is normally not taken into consideration. But it should be because for a risk averse consumer a change in the volatility of consumption - that is a change in the security of supply - means a change in utility or welfare.

By means of a *risk premium* a change in the volatility of consumption can be evaluated and standard cost benefit analysis may be adjusted by adding the value of this change to the net present value of the projects. In the study, a correction based on the measure of the consumers' *relative risk aversion* is applied to evaluate the change in total consumption volatility caused by the project in case. This measure reflects the consumers' degree of risk aversion which depends on the concavity of the consumers' utility functions. The change in volatility or risk is measured as the change in the standard deviation in real consumption. The standard deviation isn't solely affected by the standard deviation of the project at hand, but it also depends on the correlation with the existing standard deviation of consumption stemming from the volatility of prices of goods in general. If for instance the consumers switch from oil whose price is negatively correlated with consumption in general, to another fuel with the same price standard deviation (say biofuels), but without correlation with general consumption, total standard deviation of the real consumption and hence total risk will be reduced.

Thus, it will not be correct just to add a risk premium to the volatile oil price when making cost benefit analyses. The volatility of the prices of other goods and their correlations with the oil price and consumption in general should also be included in the calculations.

The suggested method for valuing changes in the security of supply is here applied to four very simple examples of transport energy related projects and typically the value of a change in the security of supply turns out to be small compared to the annual net benefits, but there is a high degree of uncertainty. A Monte Carlo simulation shows that in 95% of the cases the value of a change in the security of supply as a percentage of the project's other net benefit lies within the interval from 0.3% to 15%.

The outline of this paper is as follows: First, previous research is described shortly. Second, risk aversion and risk premium as a measure of the value of security of supply is introduced and linked to oil consumption and the application in cost benefit analysis is discussed. Finally, the approach is applied to simple synthetic projects to get an impression of the potential influence of the value of changes in the security of supply to the net benefits of the projects.

Previous research

There is a comprehensive literature on the security of supply of oil. The problem is approached from several different angles. One approach – mainly taken in the USA – focuses on market failures and externalities. Theses studies often try to estimate the cost for oil importing countries stemming from the monopoly profits in the exporting countries (market power), but they also include the loss in potential output due to high price levels of an important production factor and the macroeconomic adaptation costs when oil prices are changing dramatically. There seems to be consensus that the asymmetry in the observed effects of oil prices (decreases have less impact than increases) stems from the nature and timing of the two last effects. Greene and Ahmad (2005) and Leiby (2007) are examples of this approach.

There is a discussion whether it is the level of oil prices or their volatility that are costly for the economy and to what extend. Ferderer (1996) finds that volatility is more important than the price level. Hamilton (2003) has introduced a transformation of the oil price called NOPI (Net Oil Pice Index). He and others (Cuñado and de Gracia, 2003; Guo and Kliesen, 2005) find that this index which extracts surprising oil price increases (increases that are not following decreases) is the best in explaining changes in GDP. Cuñado and de Garcia (2003) among others use NOPI in VAR (vector auto regressive) analyses for a number of countries. The VAR analyses find much larger effects from oil price changes than is predicted by macroeconomic models. The difference is explained (i.a. by Greene and Ahmad, 2005) by the lack of disaggregation in the macroeconomic models.

Another approach to value the security of supply is focussing on the risk issue. To be dependent on oil means running the risk of a volatile economy – in other words high standard deviation in real consumption. The risk aversion of the consumers is the key concept here. The approach is standard in financial portfolio theory, but may also be applied in cost benefit analyses. The view is taken that there is a trade-off between relatively cheap oil with a volatile price on the one hand and more expensive fuels with a stable price on the other. Walls (2004) suggests using portfolio theory and a risk premium when optimizing project selection in the oil extraction industry. Referring to Walls, Stæhr (2006) suggests using the same concept to take into account risk in general in cost benefit analysis. As far as we know portfolio theory hasn't yet been applied to the assessment of security of supply as we propose to do it here.

Expected utility, risk aversion and risk premium

It is the risk-approach to valuing security of supply that is taken here. We apply the method to projects within the transport sector, but it can be used generally. For instance when assessing which is the most efficient: to decrease CO_2 emissions in the oil consuming transport sector or in the coal consuming power sector, including the higher volatility of oil prices in the analysis may in principle tip the outcome. In general, volatility of general consumption stemming from all types of sources should be included, but here we will concentrate on cases where only one or two goods are the source of this risk.

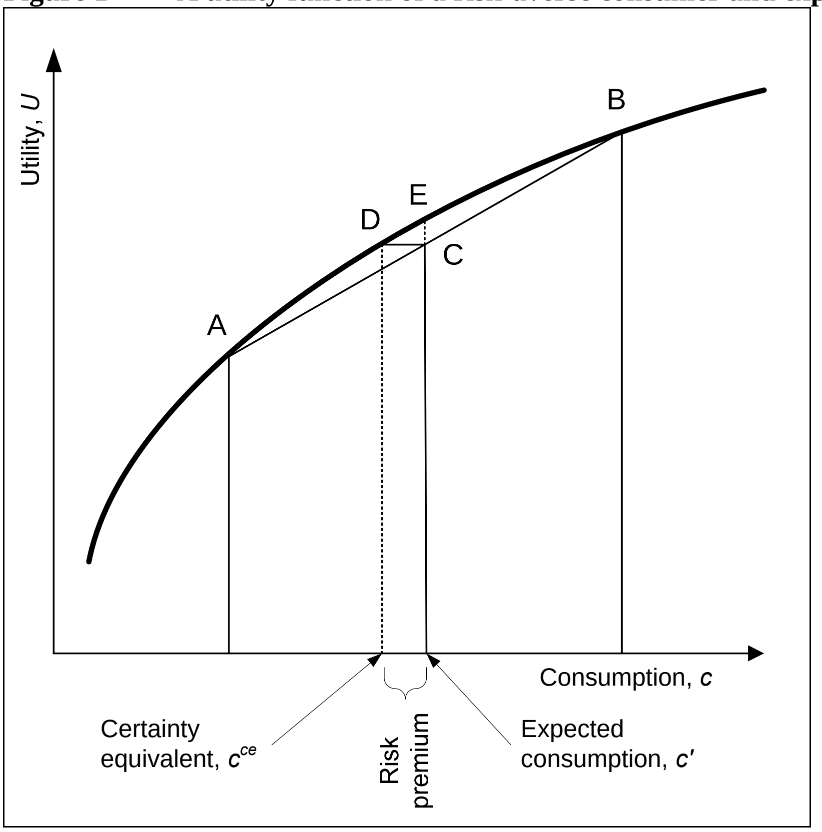
In some respects the choice of transport fuel or transport technology can bee seen as a choice between assets with different expected net benefits and different effects on the variability of general consumption. For instance, there could be a choice between an oil based system and a system based on biofuels. The oil based system is by a majority expected to be less costly, but as the oil price.is expected to be more volatile than the biofuel price the oil based system will also add more to the volatility of the whole economy and to the variability of real consumption. This means a decrease in security of supply and thereby an increase in the risk for the consumers. If the consumers are risk averse, this change can be counted as a cost to the society in welfare economic cost benefit analysis

Von Neumann and Morgenstern (1944) have introduced the notion of *expected utility*. They assume that given a utility function *u*(*c*) the utility *U* from a set of possible consumption possibilities $c' = (c_1, c_2, \dots)$ with the corresponding probabilities $(p_1, p_2, \dots)$ can be described as

$$U(c') = \sum_i u(c_i) p_i$$

In other words, the expected utility of a set of possible consumption outcomes known only by a probability distribution can be measured as the weighted average of the utility of each outcome using the probabilities of the outcomes as weights.

Figure 1 A utility function of a risk-averse consumer and expected utility



Normally the utility function $u(c_i)$ is assumed to be concave. A concave utility function means that the consumer has decreasing marginal utility of consumption - i.e. if consumption is increased from 100 to101 it increases utility less than an increase from 10 to 11 would do. This is the main argument for consumers to be *risk averse*. If a consumer has risk aversion, his utility of the distribution of possible consumption outcomes will be less than the utility of having the expected consumption level with certainty. This is demonstrated in figure 1

The consumer's consumption level might either be as in point A or B each with probability 0.5. The expected utility is found in C as the probability-weighted average of the utility in A and B. This utility lies below the utility in E of receiving the corresponding expected consumption level c' without risk. The utility in C is the same as in point D if the consumer receives the consumption level c^{ce} with certainty. The consumption level c^{ce} is called the *certainty equivalent* to receiving the uncertain expected consumption level c'. The consumer is willing to accept a loss of consumption equal to the difference between c' and c^{ce} in return for not having any risk. This difference is called the *risk premium*. Thus there is a trade-off between risk and consumption and each extra unit of risk requires an increase in consumption to compensate the consumer.

Usually, risk in a variable is measured by considering it to be a stochastic variable and calculation it's variance, σ^2. If the risk is not to big compared to the consumption level and if the utility function is concave, the risk premium *RP* can be computed using a second order Taylor approximation through the formula

$$RP = ½ \cdot \sigma^2 \cdot \left(-\frac{u''(c)}{u'(c)} \right)$$

Where $u'(c)$ and $u''(c)$ are the 1st and 2nd derivatives of the utility function, σ^2 is the variance of the stochastic part of consumption, and the expression in square brackets is the so-called Arrow-Pratt measure of **absolute** risk aversion. The derivation can be seen in Luís (2001). The formula is independent of the probability distribution for *c*.

Thus, the more concave the utility function is (the numerically higher *u''* is), the higher the risk aversion and the risk premium *RP* will be. Furthermore, low consumption level means high marginal utility and this decreases the risk aversion.

In the literature the **relative** risk aversion parameter, *A*, is considered to be more robust than the absolute and often the risk aversion estimates found in the literature relate to *A*. The relative measure is equal to the absolute multiplied by the consumption level. The square bracket may thus be replaced by *A*/*c*– the relative risk aversion divided by consumption. The risk premium can now be written:

$$RP = ½ \cdot \sigma^2 \cdot \frac{A}{c}$$

Empirically, there is clear evidence of risk aversion with most persons. Thus in the empirical literature a variety of values for the relative risk aversion measure has been found. According to Meyer & Meyer (2005) values between 10 and 20 are typically found in studies when it is measured in relation to income. In the examples below we have applied a value of 15.

However, empirical studies also show that there seems to be a clear asymmetry between the value of possible losses and gains (Kahneman and Tversky, 1979). A possibility of a loss of a certain amount is often valued much higher than the same possibility of a gain of the same amount. This contradicts with the notion of constant relative risk aversion. In fact this notion puts a narrow limit to the choice of utility function. Only the following specification has the property of constant relative risk aversion:

$$u = \frac{c^{1-A}}{1-A} \quad \text{when } A \neq 1 \quad \text{and} \quad u = ln(c) \quad \text{when } A = 1$$

When we consider small changes in risk and consumption, the relative risk aversion might be considered to be approximately constant.

Portfolio theory
From portfolio theory we know that by diversification - i.e. combining a set of assets - the risk can be reduced as long as the returns *r* of the assets are not perfectly correlated. The expected return $E(r)$ of combining two assets *a* and *b* with the expected returns $E(r_a)$ and $E(r_b)$ can be calculated as

$$E(r) = w_a \cdot E(r_a) + w_b \cdot E(r_b)$$

where the *w*'s are the shares of the two assets in the portfolio.

The risk of holding each asset can be measured by the standard deviations of the returns σ_a and σ_b and the standard deviation σ of the expected return from the mix of the two assets can be computed by the standard formula

$$\sigma = \sqrt{w_a^2\sigma_a^2 + w_b^2\sigma_b^2 + 2\rho_{ab}w_a w_b \sigma_a \sigma_b}$$

where ρ_{ab} is the correlation coefficient between the returns from the two assets. By definition the following inequality holds: $-1 \le \rho_{ab} \le 1$. If the returns are perfectly positively correlated ($\rho_{ab} = 1$) there will be no gain from diversifying - i.e. the standard deviation of the mixed portfolio σ cannot be reduced by diversifying. In all other cases, risk can be reduced by diversifying without loss of expected return.

In the analogy to transport systems the expected return can be regarded as the expected negative cost of operating the systems. Using the example of oil versus biofuels, this means that often it will be better to choose a system based on both oil and biofuel than sticking to only one of these options.

However, the portfolio approach emphasizes that the correlation between the fuel costs is important. It is of very little use creating a flexible system if the price of biofuel is highly correlated with the oil price. This argument may be more obvious if the alternative to oil is natural gas because in Europe the gas price is closely linked to the oil price. The optimal choice is to find an alternative energy source that is negatively correlated to the oil price. This is probably not realistic, but it may be worth the investment to select a fuel with a price exhibiting very low positive correlation with the price of oil.

Another analogy would be if we interpret return as change in consumption for the society. When we use cost-benefit analysis to calculate the NPV of the project's net benefits, we estimate the expected contribution to total consumption by implementing the project. But the implementation also changes the standard deviation (risk) of the total consumption. If we know the (risk averse) utility function of the society we can decide if a project adding to expected consumption does not increase the standard deviation of the total consumption so much that total welfare decreases, and moreover, projects reducing expected consumption might increase welfare if they decrease total risk.

Quasi option value
The described simple version of the portfolio theory is static, and it doesn't tell us that it is probably not optimal to choose a system with fixed shares of oil and biofuels. There is a so called *quasi option value* if we in the future get more certain information about the fuel prices and are able to switch fuel accordingly. The quasi option value is the value of postponing the decision until we have more certain information. The value might both be positive and negative – see Pearce et al. (2006).

If the future price of a product is only known as following a given probability distribution there may be a value in postponing the investment and see what the price turns out to be. If the price turns out to be high, it may be profitable to invest, if it is low, the investor has the opportunity to cancel or postpone the investment again.

In the context of transport fuels or transport systems, the analogy to this example could be that it may be profitable to invest in a system where switching fuel according to the current prices is possible. In other words the investor or society can buy the option to switch fuel at any moment and this option has a positive value if in the reference situation the investor is tied up on one specific fuel. The value of this option depends on which future prices are in fact realized, but it may be larger than the investment. In the case of transport fuels it is possible to invest in a flex-fuel fleet and a diversified distribution system and the expenditure for this investment may be less than the value of the option to switch between the different fuels.

In our study we have not taken the quasi option value into account as it is difficult to calculate ex ante. The value of postponing a decision depends on what the fuel prices in fact will be and this we don't know ex ante.

A suggestion for including de value of changes in the security of supply in CBA
We suggest including the value of changes in the security of supply in CBA by calculating the change in the risk premium ΔRP for the affected persons using the formula below.

$$\Delta RP = ½ \cdot \Delta\sigma^2 \cdot \frac{A}{c}$$

where $\Delta\sigma^2$ is the change in the variance of general consumption caused by the project considered. Thus, projects increasing overall risk $\Delta RP > 0$ will have their NPV reduced while projects decreasing risk $\Delta RP < 0$ will have their NPV increased.

This will in principle imply comprehensive calculations using the correlation between all costs, benefits and consumption for each time period for all persons involved to calculate $\Delta\sigma^2$ - cf. the portfolio formula for σ - but we suggest confining the analysis to include only correlation with very risky and consumption-correlated components such as the oil price.

In the following we apply this method of valuing changes in the security of supply on a number of simple examples related to transport and energy.

Examples
In this section the results from four examples of including changes in the security of supply in CBA on transport projects are presented. The examples take a starting point in the standard variation of the oil price and include correlation with the prices of other energy carriers (biofuels) and general income/consumption possibilities. In one of the examples investment in flexibility (flex-fuel cars) is analysed. The basic assumptions used in the examples are shown in table 1:

Table 1 General assumptions

	Unit	Mean	Standard deviation	correlation with consumption
Oil price	$/GJ	10	5	-0.1
Price of biofuels	$/GJ	16	2	-0.05
Pr. cap. consumption	$/capita	50,000	1,000	
Risk aversion parameter		15		
Correlation between the prices of oil and biofuels		0.5		

Note: In the calculations we assume that the distribution of the oil price is log-normal and the distribution of the price of biofuels is normal.

Investment in a road or a bridge

In this example a bridge crossing an inlet is constructed reducing the distance between to cities. Each year 100 persons crosses the bridge and this means a reduction in fuel consumption of 0.1 GJ oil per capita (say from 20 GJ to 19.9 GJ). The expected value of the annual oil savings is total fuel consumption times the expected oil price 100 · 0.1 GJ · 10 $/GJ = 100 $. We ignore the value of time saving and the traffic is assumed to be unaffected. The standard deviation of the expenses for fuel is accordingly decreased from 5 · 20 to 5 · 19.9 $ – that is from 100 to 99.5 $.

Instead of oil the consumption of other goods increases. The other goods have a much lower price standard deviation and therefore the variability of total consumption is reduced. The security of supply increases. This we take into account by assuming that the correlation between oil price and general consumption is -0.1. When the oil price goes up consumption opportunities go down a little.

Using the assumptions from table 1 and the formula from page 5, the standard deviation of total oil and other consumption per capita is reduced from 1014.89 to 1014.79 when the consumption of oil is reduced:

Standard deviation before: $\sqrt{100^2 + 1000^2 - 2 \cdot (-0.1) \cdot 100 \cdot 1000} = 1014.89$

Standard deviation after: $\sqrt{99.5^2 + 1000^2 - 2 \cdot (-0.1) \cdot 99.5 \cdot 1000} = 1014.79$

Here we have used the portfolio formula for the standard deviation of the sum of two correlated variables. With a per capita consumption of 50,000 and a relative risk aversion parameter A of 15 this means a reduction in the risk premium of 0.030 $ per capita or 3.0 $ for the 100 persons crossing the bridge. The calculation goes like this:

$$\Delta RP = ½ \cdot \Delta\sigma^2 \cdot \frac{A}{c} = ½ \cdot (1{,}014.89^2 - 1{,}014.79^2) \cdot \frac{15}{50{,}000} = 0.030\$$$

The value of the increase in security of supply (the reduced risk premium) is added to the value of the fuel savings and we obtain a security of supply corrected annual benefit of 103 $. In other words, the benefits are increased by 3% if we correct for the increase in security of supply.

The investment and maintenance costs of the bridge, its lifetime and the discount rate will then decide whether the investment is profitable.

Biofuels

This example is in principle very much like the one above. Instead of reducing fuel consumption we replace 5% of the oil consumption by biofuels having a higher price than oil (16 $/GJ instead of 10 $/GJ) but a lower price variation (a standard variation of 2 instead of 5) and a price correlation with oil of 0.5. We still assume a per capita consumption of 20 GJ and a population of 100 persons. The correlation between oil price and general consumption is again -0.1, and we further assume that the correlation between the price of biofuels and consumption is half the size compared to that of the oil price (-0.05 compared to -0.1).

Replacing oil by biofuels means an expected increase in costs of 100 · 5% · 20 GJ · (16-10) $/GJ = 600 $. Total variability in consumption is now reduced both because the standard deviation of the biofuel price is less than that of the oil price and because the correlation with total consumption is smaller. Therefore, we have a reduction in the overall risk premium of 31 $. This means that the costs are reduced by approximately 5% if we adjust for the increase in security of supply.

Flex-fuels
In this example we ignore correlations and just force the population to replace gasoline driven cars by flex-fuel cars. The owners are now able to use the cheaper of the two fuels at any moment and the cost per gallon will be minimal of the two prices. If there is no correlation between the two prices, the result is that the mean value and the standard deviation of the composite fuel price are reduced from 10 and 5 $/GJ when using oil to 9.05 and 3.62 $/GJ. The calculations are more comprehensive than above because the distribution has to be evaluated using repeated calculations for each possible price. In each calculation the formula for the distribution of the minimum of two stochastic variables is used. If the two density and distribution functions are f/F and g/G, the distribution for the minimum of the two is f·(1-G)+g·(1-F). If the annual consumption per car is 20 GJ the average costs are reduced by 19.05 $, but the decrease in risk premium is worth 0.72 $ or approximately 4% of the average cost reduction. In total the improvement including the value of the increase in the security of supply is 19.77 $ and this may compared with the extra cost of a flex-fuel car.

If the oil price and the biofuel price are positively correlated, both the reduction in the expected fuel costs and the reduction in the risk premium will be reduced. In the case where the correlation is perfect, they are both reduced to almost nothing since the likelihood that the oil price will exceed the biofuel price is almost zero with the chosen assumptions. Thus, the above results can be seen as a maximum.

The results are very sensitive to the assumptions. If the annual consumption per car is 50 GJ instead of 20 GJ, the reduction in the risk premium or increase in the security of supply will account for 9% of the total cost reduction. Thus, the change in the total standard deviation as a share of total consumption is crucial for the risk premiums importance.

Fuel savings
This example is covering the case were for some technical reason (say better tyres) fuel consumption can be reduced by 5% with no investment. It is on the one hand very simple because there is only one fuel, but on the other hand we include a short term price elasticity that may dampen the oscillations of total consumption and thereby the risk premium a little. The long term price elasticity should be included in standard cost benefit analysis, but a short term elasticity means that it is simple and cheap for the consumer to adjust to short term movement in the oil price by switching to other fuel types or other consumption goods (say bus or bicycle). This flexibility means that real consumption fluctuates less and the risk premium is reduced. In this example we have chosen a short term price elasticity of -0.1.

Using the basic assumptions, a 5% fuel reduction means saving 1.000 $ a year at the mean. The reduction in consumption variability yields a reduction in the risk premium of 25 $ or 2.5 % of the annual cost savings. Without the short term price elasticity the risk premium would be reduced by 30 $ or 3%.

These basic calculations can be supplemented with a sensitivity analysis. In table 2 below, we have collected rough guesses on the most likely interval of some of the main assumptions behind the calculations.

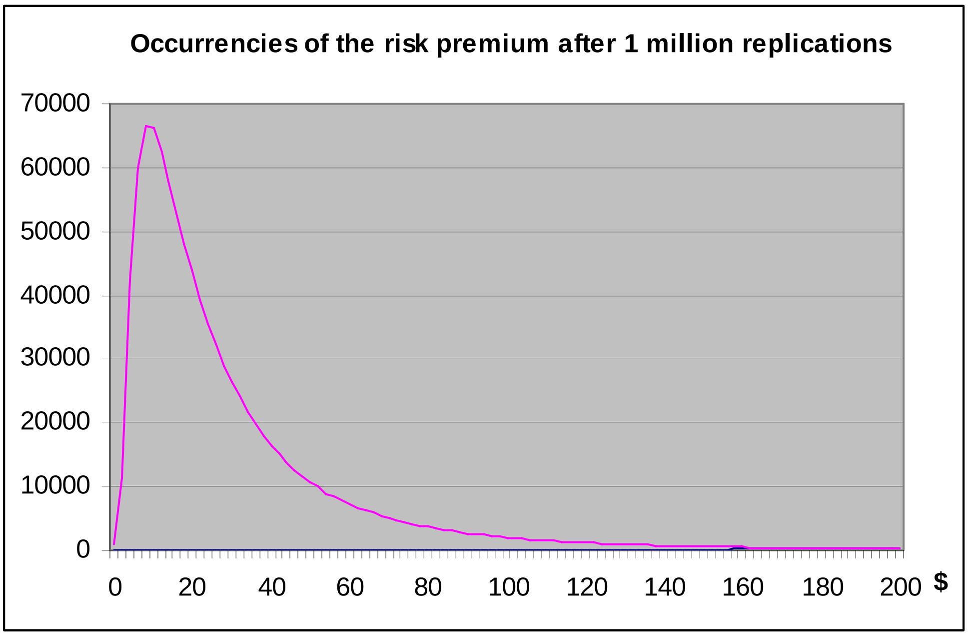
Table 2 Assumptions for the sensitivity analysis

	Mean	Interval	Distribution
Oil price	10	5 – 20	Log normal
Oil price standard deviation	5	2 – 10	Log normal
Per capita consumption	50,000	30,000 – 100,000	Log normal
Consumption standard deviation	1,000	400 – 3,000	Log normal
Correlation between oil price and consumption	-0.1	-0.2 – 0.0	Normal
Short term price elasticity	-0.1	-0.2 – 0.0	Normal
Relative risk aversion parameter	15	5 – 40	Log normal

Using theses intervals and distribution assumptions the specific distributions can be set up such that the chosen intervals approximately cover the central 95% confidence intervals. Using these seven distributions we have carried through 1 million replications in a Monte Carlo simulation and reach a change in risk premium as displayed in figure 2.

95% of the estimates of the change in risk premium fall within the interval between 2 $ and 126 $ with 2.5% of the outcomes on each side. The mean value is 30 $. Taking into account that also the fuel savings varies with the oil price this means that the change in risk premium lies between 0.3 and 15% of the annual cost savings with a mean of 3.5% of the fuel savings. This is a little more than the one found above of 2.5% in the non-stochastic calculation. The difference is due to the highly non-linear formula for the risk premium and the asymmetrical distribution assumptions. The highly asymmetric outcome shown in figure 2 means that very high changes in the risk premium are possible, but with a fairly low probability.

Figure 2 Monte Carlo simulation results



Conclusions

In this study we use a relatively narrow definition of changes in security of supply since it is simply regarded as a matter of a change in the volatility of consumption as a consequence of changes in the society's sensitivity to fuel price changes. Real physical shortness is assumed to be limited to either very short periods or states of war and can hardly be handled in economic analysis. The security policy question stemming from OPEC's ability to paralyze the western world through oil embargoes is also hard to quantify and include in cost benefit analysis.

If the uncertainty concerning the assumptions on risk averseness and correlations coefficients is diminished, the value of changes in security of supply could quite easily be calculated and included in standard cost benefit analysis. However even with high estimates of future price volatility the additional information from including changes in the security of supply seems to be small and may not be worth the effort, especially considering that the calculations of the value of the security changes themselves suffers from a high degree of uncertainty.

There are projects though where including the value of changes in the security of supply in the calculations can alter the net present value more than insignificantly. These are projects with a little investment and a significant fuel switch, and where the annual operation costs are heavily dependent on the fuel.

The Danish Ministry of Transport has generously granted the financial support for the work presented here.

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