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SECURE
Security of Energy Considering its Uncertainty, Risk and Economic implications

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Linkages between the ad hoc and risk-based measures of Energy Security

- Linking of Analytical measures of Risk Aversion to Traditional Measures of Energy Security -

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SECURE

Security of Energy Considering its Uncertainty, Risk and Economic implications

Deliverable 3.1

Linking of Analytical measures of Risk Aversion to Traditional Measures of Energy Security

FEEM

Authors: Anil Markandya, Malcolm Pemberton

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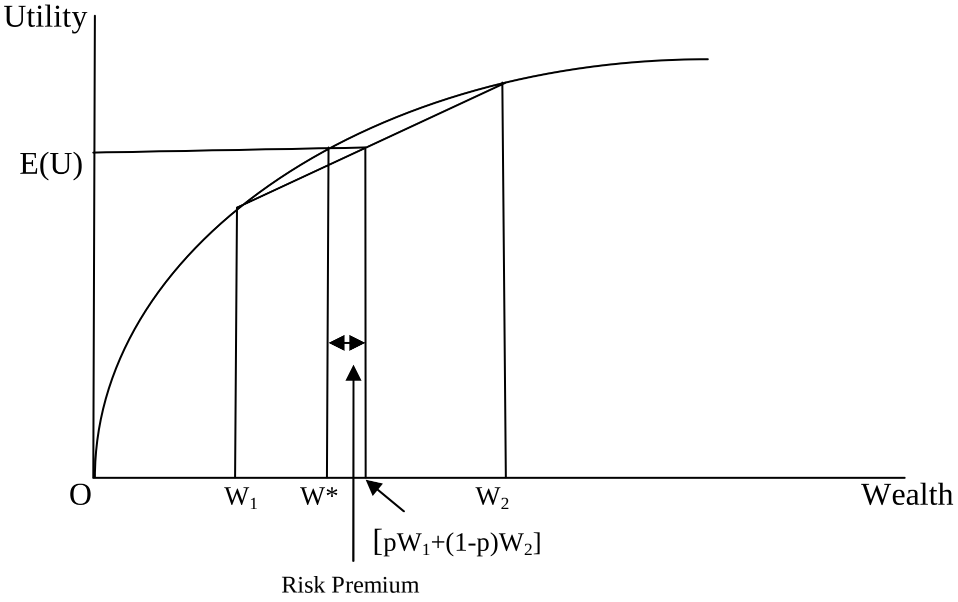
According to the DoW, Task 1.3 should investigate the following issue:

"The aim of this task is to link the analytical measures of risk aversion to the more common measures of energy security. The former are based on a full (or at least substantial) characterization of the probabilities of different events while the latter are sensible *ad hoc* measures that practitioners use. This task will provide links between the two for plausible scenarios of energy supply and demand. Naturally the *ad hoc* will not be perfect representations of risk premiums as calculated in Task 2, but it should be possible to carry out Monte Carlo experiments and see when and under what conditions the two sets of indicators are correlated; and what is the degree of correlation"

1. Introduction

The literature on risk aversion defines a risk premium associated with different risk-related choices. This premium can be calculated based on the maximization of an expected utility function, which defines the expected utility a decision-maker would obtain from a choice in which the outcomes are probabilistic. Given any given expected utility, the risk premium is the amount by which the decision maker would accept a lower expected return that is certain. The premium is illustrated in Figure 1. The expected utility with wealth W_1 obtained with probability p and wealth W_2 obtained with probability $(1-p)$ is given by $pW_1+(1-p)W_2=E(U)$. The same utility can be obtained, however, with a certain wealth of W* and the difference in wealth between $pW_1+(1-p)W_2$ and $W*$ is the risk premium.

Figure 1: Measuring the Risk Premium In an Expected Utility Framework



In the case of energy, the use of this framework would require:

a. Defining the 'units' in which the energy variability is to be measured. In some cases it is referred to in quantity terms and sometimes in price terms.

Ideally both should be taken into account but that raises issues of how to define utility with respect to two closely linked variables.

b. Defining the utility function. The main issue is the degree of risk aversion. The more 'concave' is the function shown in Figure 1, the higher will be the risk premium and the more risk averse will be the decision-maker. Fortunately, based on extensive work in this area, we have a range of functions that can represent risk aversion typically found in financial markets. See the annex for details. At least as a point of departure, one can take these functions.

c. Defining the probabilities of different events. This is problematic, but in the case of energy markets we do have some long run frequencies of failures of supply or sharp price increases, which can be used to obtain the relevant probabilities.

In the remaining sections we present two approaches we can use to define risk aversion estimates and discuss the extent to which we can identify *ad hoc* measures related to them.

2. A Risk Aversion Approach Based on Expected Utility

The following is a recent attempt to define energy security in terms of expected utility (Markandya and Pemberton, 2009). It defines a simple model with the following characteristics:

A. The cheapest source of energy is imported energy, when it is supplied under 'normal' conditions. However, if the imported energy supply fails, for one reason or another, the result is a shortage in the domestic markets and prices are substantially higher.

B. Domestic production can and does meet a part of the national energy demand. The higher the supply price of energy, the more will be met from domestic sources[1].

C. The risks of energy supply disruptions or failures are well understood and can be characterized in probability terms, based on the historic experience.

Society's wellbeing is a function of the utility it derives from the consumption of energy, and that utility function is a well-behaved von Neumann-Morgenstern utility function that exhibits risk aversion. The main argument of the utility function is the consumer and domestic producer surplus that a given level of energy provides. Recall that consumer surplus is the difference between the total willingness of consumers to pay for a given amount of a commodity and the amount that they actually pay. Producer surplus is the difference between the revenues received by the suppliers and their full costs of supply.

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[1] This is a medium to long term perspective, as potential for switching to domestic sources in the short term is limited.

Society's choice can be described in terms of setting the total consumption of energy to maximize the expected utility of consumer plus producer surplus[2]. Of course, in a market economy the government does not directly determine levels of imports and domestic output. But, by setting the domestic price of energy, it can influence both these variables. This price will typically be higher than the 'normal' international price of imported energy, the 'premium' being added to encourage domestic production and reduce dependence on imports.

The problem is shown in Figure 2. At the normal international price of energy, domestic production would be OA. This price does not, however, maximize the expected consumer surplus because there are times when the price is much higher for external reasons. In order to maximize consumer surplus, a tax has to be placed on imported energy. This tax increases the returns to domestic production, raising it to OB, representing an increase in domestic production of AB. At the same time it reduces the returns to the importing party, and imports fall from AD to BC, a reduction of AB + CD.

There are many aspects of energy security that this analysis captures but not all. A recent UNECE publication (UNECE, 2007) identifies the following sources of energy insecurity:

a. The narrowing margin between oil supply and demand, which has driven up prices.
b. The volatility of oil prices arising from international tensions, terrorism and potential for supply disruptions.
c. The concentration of known reserves and resources in a limited number of the world's sub-regions.
d. The restricted access to oil and gas companies for developing hydrocarbon reserves in some countries.
e. The rising cost of developing incremental sources of energy supplies.
f. The lengthening supply routes.
g. The lack of adequate investment along the energy supply chain.

We do not agree with (a) above – energy security is not really an issue of high prices but of volatile prices. The model focuses therefore on (b). It should be possible to look at the impacts of (e) and (f) using this model – i.e. the increase in costs of energy supply over time but this has not been done in the present paper.

In terms of policies, the same publication identifies the following measures as addressing the problem of energy security:

i. Promoting investment in the energy sector though the provision of legal frameworks, regulatory environments, tax incentives together with fair and transparent processes to foster the public-private partnerships needed to promote and protect investments in existing and new oil and gas supplies.

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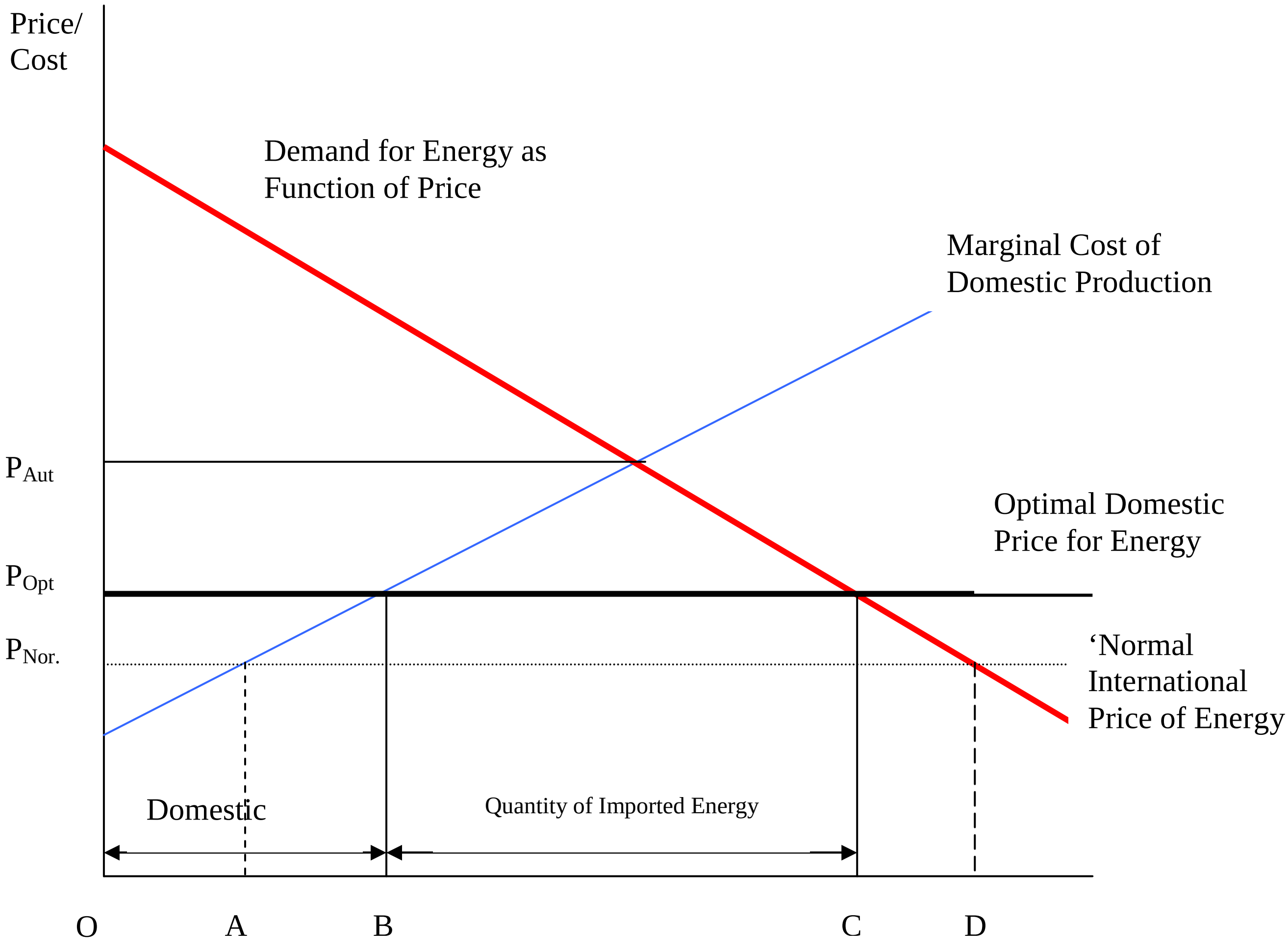
[2] Of course by taking a consumer and producer surplus approach in one market we are ignoring effects across markets. This limitation should be recognized. We would argue that, in the context of understanding the energy market better, much can be gained from such an approach, although work in a general equilibrium context should also be pursued.

ii. Removing barriers to promote and protect investment in existing and new oil and gas supplies.
iii. Removing barriers to trade and investment for both private and public energy companies.
iv. Encouraging both energy producers and consumers to secure long term contracts that reflect a committed demand for hydrocarbons.
v. Seeking convergence of norms, standards and practices as well as new forms of cooperation to facilitate the financing of resource developments.

The application of the model has been made to look specifically at tax policies and how they can increase energy security. Policies under (ii) to (v) can be seen as reducing the risks of disruptions and could therefore also be modelled in this framework.

Figure 2: Optimal Response to Insecure Imported Energy



Notes: P_{Aut} = Price with no imports (i.e. under autarky).
P_{Opt} = Price that maximizes expected consumer surplus.
P_{Nor} = Price that would prevail in the absence of any disruptions to supply

The key findings from the paper, which takes typical utility functions as specificed in the Annex are:

(a) It is never optimal to tax or subsidize only the domestic production of energy. All taxes should be applied to all energy sources. In this context the WTO rules in terms of forbidding public support to specific domestic industries and altering market competition make sense. Nevertheless, there are a number of instances where subsidies are effectively provided to domestic energy producers. Cases in point include, for example biofuel programs in the EU and US.

(b) The optimal tax rate is:
  a. Very sensitive to the costs arising from a disruption of supply and to the elasticity of demand for energy.
  b. Somewhat less sensitive to the probability of disruption and the degree of risk aversion.

The model is, of course, only a partial representation of reality. But it is an important one and captures the significant role that internal energy pricing can play in reducing the impacts of uncertainty of foreign supply. To make the model more 'realistic' one would need to:

- Model risk and costs more realistically as a joint probability distribution for the two.
- Take account of measures that reduce costs of disruption but have a cost themselves (e.g. holding of stocks). Stock levels are not calculated in this way at present.
- Develop links between measures of dependence and vulnerability and parameters such as risk of disruption.
- Assess more carefully exactly how much ES is an externality – how much of the risk has been internalized.

The approach indicates that one can obtain insights into the setting of energy taxes as a means of reducing energy insecurity. It is of less use in developing measures of the degree of energy insecurity that a country faces. Loosely speaking the percentage of energy imported is a measure of the exposure to risk as well as the volatility of supply of that energy. Furthermore the more risk averse are the policy-makers, the more these two factors matter. In general, the amount of risk is a function of:

- The percentage of energy that is imported from each source.
- The volatility of the supply of each energy source
- The degree of risk aversion

This suggests we should work on an ad hoc measure that incorporates all three factors. We are working on this and will report the results in the next progress report.

3. A Portfolio Approach

An approach that is also based on risk aversion, and that can be tied to the expected utility method described above, is the portfolio approach.

Portfolio theory was originally developed in the context of financial assets. An asset's return is modelled as a random variable and a portfolio is a weighted combination of assets so that the return of a portfolio is the weighted sum of the assets' returns. Thus, a portfolio's return is a random variable and so has an expected value and a variance. Risk is measured by the standard deviation of the return.

For a two-stock portfolio, the expected return $E(r_P)$ is the weighted average of the individual returns $E(r_i)$ of the two securities:

$$E(r_P) = w_1 E(r_1) + w_2 E(r_2)$$

where w_1 and w_2 are the proportions of assets 1 and 2 in the portfolio.

The portfolio risk σ_P is given by

$$\sigma_P = \sqrt{w_1^2\sigma_1^2 + w_2^2\sigma_2^2 + 2w_1w_2\rho_{12}\sigma_1\sigma_2}$$

where σ_1 and σ_2 are the standard deviations of the returns of assets 1 and 2, and ρ_{12} is the correlation coefficient between the two returns.

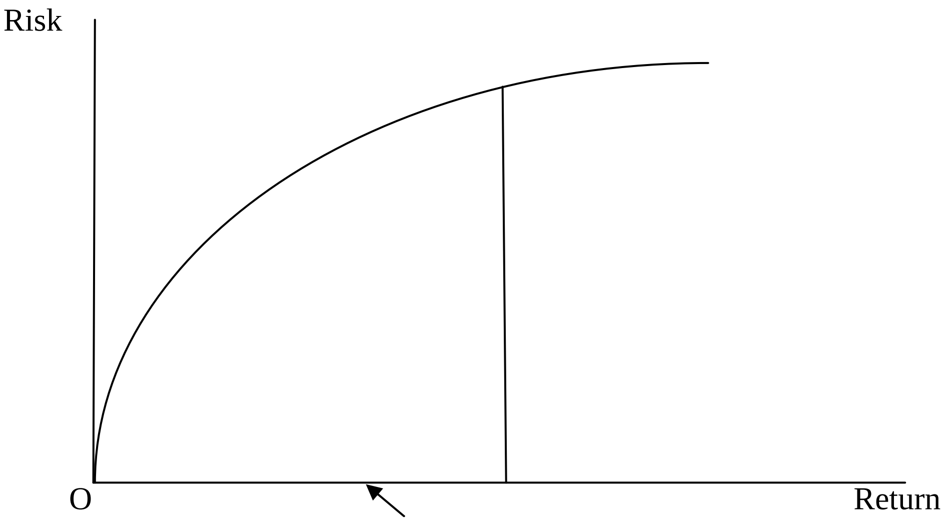
In a prudently designed portfolio, there will be a risk reduction achieved through diversification. This is called the **portfolio effect**. It is present whenever the returns of the two assets are not perfectly correlated (ie $\rho_{12} < 1$) but is significant only when the correlation coefficient is less than about 0.7.

Without further information, it is not possible to prescribe a single optimal portfolio, only a range of efficient portfolios. An efficient portfolio is one which achieves maximum expected return at a given value of risk. An investor will then choose a particular efficient portfolio based on his own preferences and degree of risk aversion. This idea can be made more precise as follows.

It is assumed that the risk/reward preferences can be described by a quadratic utility function.

Every possible asset combination can be represented by a point in risk-return space. The **efficient frontier** is the set of all optimal portfolios. Along the efficient frontier, return cannot be increased without accepting more risk, as shown in Figure 3.

Figure 3: The Efficient Frontier



More explicitly, for a given "risk tolerance" parameter $q \in [0,\infty)$, the efficient frontier is found by minimizing

$$\tfrac{1}{2} w^T \Sigma w - q(R^T w)$$

where

w is a vector of portfolio weights so that each $w_i \geq 0$ and $\sum_i w_i = 1$

Σ is the covariance matrix for the assets in the portfolio
q is the "risk tolerance" parameter, where 0 gives the portfolio with minimal risk and ∞ gives the portfolio with maximal return
R is the vector of expected returns

The efficient frontier is found by repeating the optimization for various $q \in [0,\infty)$.

Following Awerbuch (2004), this framework can be adapted to the analysis of energy security. For the power sector, the portfolio return is the inverse of generating costs and is measured in kWh/€Cent and portfolio risk is the standard deviation of historic annual expenditure on fuel, operation and maintenance and construction. The efficient frontier can be formulated analytically but it is often more practical to use a numerical optimisation procedure. Such procedures are available in Microsoft Excel and Matlab[3].

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[3] Stirling (1994) argued against the use of portfolio theory in electricity planning on the grounds that fuel price movements exhibit no pattern and that electricity investment decisions were made in the presence of ignorance rather than risk. He put forward the concept of diversification as a way of responding to this ignorance. See also Stirling (1996). We would argue, however, that, notwithstanding the presence of ignorance it is useful for policy makers to know the implications of their decisions and to make future decisions on a more rational basis.

For the energy sector the efficiency frontier can be obtained by defining the portfolio return can be defined as cost per unit of delivered energy (e.g. €/toe), and the risk is the standard deviation of the annual expenditure on each energy source. We will pursue this with actual historic data for a given country.

4. Future Plans

As noted above we plan to carry out the following:

- Develop an *ad hoc* measure that includes the percent of energy that is imported from each source, the volatility of the supply of that energy source and the degree of risk aversion. Decompose the measures into the sources of risk (amount of imports, volatility of imports);
- Use the portfolio approach to estimate the portfolio risk for a given country using historic data and decompose that risk into its sources (quantity and cost);
- Estimate the efficiency frontier for energy for a single country based on the method outlined above.
- Explore an entirely new approach, recently adopted from the finance literature. This is based on the real options concept. See Kumbaroglu et al (2008).

Annex: Choice of Utility Functions for Risk Aversion

As noted in the note the degree of risk aversion depends on the concavity of the utility function. There are two main measures of this concavity: the coefficient of absolute risk aversion and the coefficient of relative risk aversion. Given a utility function of the form

$$U = U(W)$$

where W is the wealth of the individual and U is utility, absolute risk aversion is given be A_r and relative risk aversion is given by R_r where

$$A_r = -U''(W)/U'(W)$$
$$R_r = -WU''(W)/U'(W)$$

U' is the first derivative of U with respect to W and U'' is the second derivative of U with respect to W.

The terms 'absolute risk aversion' and 'relative risk aversion' are tied to the nature of the lottery. Absolute risk aversion applies to additive lotteries that are expressed in monetary units while relative risk aversion applies to multiplicative lotteries in rates or fraction. In our case, the monetary consequences of accidents will be expressed in terms of percentage of loss wealth. We will thus use the relative risk aversion coefficient (R_r).

From the theoretical point of view, various functional forms of utility functions have been studied which reflect different attitudes towards risk. Many experimental studies have also been developed to estimate the risk aversion coefficient of individual decision-makers by presenting them lotteries (i.e. a set of probabilities associated with different loss of wealth) and by letting them rank these lotteries. See, ExternE 1995, Friend and Blume, 1975, Hanson and Singleton, 1982, Szpiro, 1986, Mehra and Prescott, 1985. These studies usually show that the absolute risk aversion decreases with wealth. As far as relative risk aversion is concerned, they seem to support the idea of a rather constant coefficient of relative risk aversion. As a consequence, two potential functional forms of the utility function emerge:

- Either the utility function is logarithmic: $U(W) = \ln W$; implying that the coefficient of relative risk aversion is equal to unity
- Or the utility function is a power function defined by: $U(W) = \frac{W^b - 1}{b}$ with $b < 1$. This function exhibits positive and decreasing absolute risk aversion while the coefficient of relative risk aversion (R_r) amounts to $1 - b$.

Notice that the logarithmic utility function is a limiting case of the power function which is obtained by letting $b \to 0$. Our calculation will thus be made using the second utility function, except in the case of a relative risk aversion factor equal to 1, where the first one will be used.

If the individual is risk neutral, the relative risk aversion coefficient is zero, and the corresponding utility function is: $U(W) = W - 1$.

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