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Quantifying the external cost of oil consumption within the context of sustainable development

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Abstract

The concept of sustainability implies that the flow of services derived from the use of natural capital must be constant over time and should be obtained at a constant price. For a depletable resource such as oil, the future generations are highly impacted due to the consumption behavior of the current generation. Since the ultimate oil stock within the Earth declines with cumulative consumption, excessive consumption of oil now reduces the availability of oil for future needs. Moreover, since oil reserves are normally extracted in the order of ascending cost and descending quality, excessive consumption of relatively high-quality, cheap oil reserves by the current generation raises the cost at which future generations can meet their needs of oil and hence imposes an external cost on the future generations. This study aims to quantify the external cost of consuming a barrel of oil within the context of sustainable development. An option-pricing model is developed to quantify this external cost assuming that the external cost of consuming a barrel of oil now equals the value of the option to get a barrel of oil in the future at the same current cost. Then, the total cost of consuming a barrel of oil now, that should be used in lifecycle costing to design more sustainable products, is the summation of the oil price and the external cost.

Keywords: Sustainable development; The external cost; Oil consumption; Lifecycle costing

1. Introduction

There is an increasing demand for integrating the concepts of sustainability into the earliest stages of production planning to design more economically sustainable products or product systems. In this respect, lifecycle costing is widely adapted as a means for connecting the environmental and social requirements with business strategies. According to the US Office of Management and Budget, lifecycle cost is the sum total of the direct, indirect, recurring, nonrecurring, and other related cost, incurred in the design, development, production, operation, maintenance, and support of a major system over its anticipated useful life span. The lifecycle cost assessment can be used to evaluate options for reducing total lifecycle costs and optimizing the use of resources (US EPA, 1995).

The cost of oil consumption in lifecycle cost assessment is usually accounted as the product of the amount of oil consumed and the market price of oil. Since oil is an exhaustible, nonrenewable, resource, excessive consumption by current generation reduces the resource available for future needs. Clearly, the new oil discoveries and the advances in technologies that make known resource stocks economically viable to extraction can increase the oil inventory available for consumption (Blignaut et al., 2000), but this does not alter the fact that the ultimate oil stock in the Earth declines with extraction. As illustrated by Adelman (1990), 'what actually exist are flows from unknown resources into a reserve inventory'. Although the ultimate resource is unknown, it is clearly nonrenewable. Since the sustainable economic development of societies relies on the sustainable supply of energy resources, the consumption behavior of the current generation affects the economic development and welfare of future generations.

With the increasing demand for oil and the declining resource base, the excessive consumption imposes a burden on the future generations and raises the cost at which they can meet their needs of oil. As explained by Vincent et al. (1997), oil extraction has an upward-sloping marginal cost curve (i.e., the marginal cost of extracting oil increases with the amount extracted).

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Also, Watkins and Streifel (1997) argue that the use of relatively cheap oil reserves now hastens the day when reliance must be placed on more costly oil reserves. As explained by Adelman (1990), at a given point of time, the market scans all known deposits to take the cheapest into production. Accordingly, the better quality, lower cost deposit will be exploited first until it is exhausted, and the lower quality, higher cost deposit will be exploited subsequently. Therefore, in addition to the private cost of consuming a barrel of oil now, whish is the current market price of the barrel, there is an external cost. This external cost is not a real cost incurred by consumers and accordingly they do not take it into account when making their consumption decisions. This type of cost is referred to as the external cost or externality because although the consumers are not financially responsible for it, it represents a real cost for other society members. Since oil is an exhaustible resource, the excessive consumption by current generation imposes a high external cost on the future generation. Therefore, this external cost should be quantified and taken into account when comparing two products or operations and in the earliest stages of planning to design more economically sustainable product or product system.

Sustainable development is a process of change in an economy, in which the word "sustainable" implies that certain indicators of welfare or development are nondeclining over the very long term (Stern, 1997). The main goal of development in general is to satisfy human needs and wishes (Tengbe, 2001). The most widely accepted definition of sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition implies that there are both basic needs and limits or constraints on economic activity that stem from both the human and physical dimension of the economy-environment system (Stern, 1997). De Janvry et al. (1995) argue that the concept of sustainability implies that the flow of services derived from the use of natural capital must be constant year after year over an infinite time horizon and this flow of services is obtained at a constant price.

For a nonrenewable resource such as oil, the sustainable development challenge is to provide sustainable supply of oil required for economic development and social welfare of generations. To meet the goals of sustainable development, the cost of obtaining oil should be constant over time. Since the oil reserves are normally exploited in the order of ascending cost and descending quality, and the ultimate stock of oil within the Earth decreases with cumulative consumption, which leads to increasing the long-term cost of obtaining oil, then current consumers should be charged for the externality they impose on the future generations. Therefore, within the context of sustainability, the total cost of oil consumed in producing a product or service should be the summation of the oil price and the external cost. This external cost can be regarded as an energy price tax that aims to reduce the oil consumption. As explained by Mulder et al. (2003), an energy price tax reduces energy consumption because it speeds up the diffusion of new energy-saving technologies. In this case, the reduction in energy inputs does not affect the economic growth since with induced technical change, the reduction in energy inputs is offset by faster improvement in energy-related technology (Smulders and De Nooij, 2003).

This study aims to develop a model for estimating the externality of oil consumption. The model is developed using option-pricing technique based on the concepts of sustainable development. The main idea is to find the value of the option to get a barrel of oil in the future at the same current cost, taking into account the time value of money. The value of this option represents the external cost, or externality, of consuming a barrel of oil now. Then the full cost of consuming a barrel of oil now is the summation of the barrel price (the private cost) and the value of the option to get a barrel of oil in the future at the same current cost (the external cost). This full cost is the appropriate one that should be used in the lifecycle cost analysis of a product or system.

2. Modeling the external cost

The concept of sustainable development implies that the future generations should obtain their needs of oil at the price whose present value equals the current market price of oil. This implies that the cost of consuming oil should be constant over time in real terms, taking into account the time value of money. In this context, the value of the external cost per barrel of oil consumed now can be regarded as the amount a consumer is willing to pay now in order to hold the option to get a barrel of oil in the future at the same present cost. This option is similar to the options traded on the financial exchanges. As explained by Amram and Kulatilaka (1999), one option contract traded on the financial exchanges gives the buyer the opportunity to buy a stock at a specified price on a specified date. Since the future stock price is uncertain, these options are valuable. Similarly, since the future oil price is uncertain, the option to buy oil in the future at a specified price is valuable. Within the context of sustainable development, this specified oil price should be the current market price of oil adjusted for the time value of money, and the value of the option to buy oil in the future at this specified price represents the external cost of consuming oil now. Therefore, the amount of the external cost per barrel of oil consumed now can be estimated using option-pricing technique.

To ensure a constant cost, it is assumed that every time a consumer buys a barrel of oil, he also buys an option to get another barrel in the future at the same cost, adjusted for the time value of money. Since oil is a nonrenewable resource, its price is expected to increase with cumulative consumption. When the current consumers buy the option to hedge future oil prices they ensure that they will meet their future needs of oil at the same present cost. If they did not buy this option, they will have to obtain their future needs of oil at costs that may be higher than the present cost. To generalize, when the current generation consumes oil, they reduce the amount available to future generations. With the decreasing amount of oil stock and the increasing population, which leads to increasing the demand for oil, the price of oil is expected to increase. In this case, future generations will have to get their needs of oil at higher costs as a result of the consumption behavior of the current generation. Then the consumption of the current generation imposes a cost on the future generations. To internalize this externality, the current generation should be charged for the full cost of oil consumption. Therefore, the total cost of consuming a barrel of oil now should be the summation of the market price of oil and the value of the option to get another barrel in the future at the same present cost. Here, the current market price of oil represents the private cost and the value of the option represents the external cost per barrel of oil consumed now.

The value of the option to get a barrel of oil in the future at the same current cost can be approximated using a modified form of Black–Scholes valuation model. The original Black–Scholes valuation model is expressed such as (Amram and Kulatilaka, 1999; Lumby and Jones, 1999)

$$C = SN(d_1) - Xe^{-r_f T} N(d_2), \tag{1}$$

where C is the value of the call option, S is the current market price of the related share, X is the future exercise price, r_f is the annual risk-free interest rate, T is the time (in years) to expiry, and σ is the standard deviation of the share price.

The terms $N(d_1)$ and $N(d_2)$ represent the cumulative areas under the normal distribution curve for Z values of d_1 and d_2, respectively, where,

$$d_1 = \frac{\ln(S/X) + r_f T}{\sigma\sqrt{T}} + \frac{1}{2}\sigma\sqrt{T} \tag{2}$$

and

$$d_2 = d_1 - \sigma\sqrt{T}, \tag{3}$$

where Z is normally distributed with mean zero and variance one.

The Black–Scholes valuation model represented by Eq. (1) is usually used to estimate the value of the option to buy a share of stock whose current price is S at an exercise price of X. The model can be modified to estimate the value of the option to get a barrel of oil in the future at the price whose present value equals the current market price of oil. Here, the terms of the model are modified such as:

C is the value of the option,
S is the current market price of oil, \$/bbl,
X is the future price of oil, \$/bbl,
r_f is the annual risk-free interest rate,
T is the time horizon of the planning policy, and
σ is the standard deviation of oil prices.

The term $Xe^{-r_f T}$ represents the present value of the future price of a barrel of oil bought after T years. Since the concepts of sustainable development imply that the cost of obtaining oil must be constant over time, this term should equal to the current market price of oil S. Substituting for $S = Xe^{-r_f T}$, then Eq. (1) can be rewritten as follows:

$$C = S[N(d_1) - N(d_2)]. \tag{4}$$

Since $S = Xe^{-r_f T}$, $S/X = e^{-r_f T}$, then substituting in Eqs. (2) and (3)

$$d_1 = \frac{-r_f T + r_f T}{\sigma\sqrt{T}} + \frac{1}{2}\sigma\sqrt{T} \tag{5}$$

then

$$d_1 = \frac{1}{2}\sigma\sqrt{T} \tag{6}$$

and

$$d_2 = d_1 - \sigma\sqrt{T} = -\frac{1}{2}\sigma\sqrt{T}. \tag{7}$$

Since $d_2 = -d_1$, then using the symmetry of the normal distribution curve, as illustrated in Fig. 1, the cumulative probabilities at $Z = d_1$ and d_2 are:

$$N(d_1) = 0.5 + a \tag{8}$$

and

$$N(d_2) = 0.5 - a \tag{9}$$

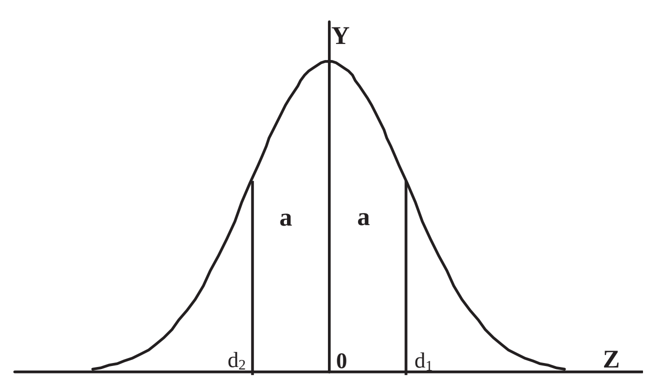

Fig. 1. Normal distribution curve.

then

$$N(d_1) - N(d_2) = 2a, \tag{10}$$

where Z is normally distributed with mean zero and variance one, and a is the area under the normal distribution curve between the two ordinates $Z = 0$ and d_1. Since the standard form of normal distribution is

$$Y(z) = \frac{1}{\sqrt{2\pi}} e^{-0.5Z^2}. \tag{11}$$

Then the area a can be estimated as the area of the trapezoidal whose lower base is $Y(0)$, upper base is $Y(d_1)$ and height is d_1, then

$$N(d_1) - N(d_2) = 2\frac{d_1}{2}[Y(d_1) + Y(0)]. \tag{12}$$

Since

$$Y(d_1) = \frac{1}{\sqrt{2\pi}} e^{-0.5(d_1)^2}. \tag{13}$$

Substituting for d_1 from Eq. (6),

$$Y(d_1) = \frac{1}{\sqrt{2\pi}} e^{-0.125\sigma^2 T} \tag{14}$$

and

$$Y(0) = \frac{1}{\sqrt{2\pi}} \tag{15}$$

then

$$N(d_1) - N(d_2) = d_1\left[\frac{1}{\sqrt{2\pi}} e^{-0.125\sigma^2 T} + \frac{1}{\sqrt{2\pi}}\right]. \tag{16}$$

Rearranging Eq. (16) and substituting for d_1 from Eq. (6):

$$N(d_1) - N(d_2) = 0.2\sigma\sqrt{T}[e^{-0.125\sigma^2 T} + 1]. \tag{17}$$

Substituting for $N(d_1) - N(d_2)$ in Eq. (4), then the value of the option to get a barrel of oil after T years at the same present cost is

$$C = 0.2\sigma S\sqrt{T}[e^{-0.125\sigma^2 T} + 1]. \tag{18}$$

Within the context of sustainable development, Eq. (18) gives the external cost of consuming a barrel of oil. The external cost as a percentage of the oil price, Ec, can be expressed such as:

$$Ec, \quad \% = 20\sigma\sqrt{T}[e^{-0.125\sigma^2 T} + 1]. \tag{19}$$

When conducting a lifecycle cost analysis, the total cost of consuming a barrel of oil, should be accounted for as the summation of the barrel price, S, which represents the private cost, and the external cost estimated by Eq. (18). Then, within the context of sustainable development, the total cost of consuming a barrel of oil now, Tc, can be formulated such as:

$$Tc = S\left[1 + 0.2\sigma\sqrt{T}[e^{-0.125\sigma^2 T} + 1]\right]. \tag{20}$$

As estimated by Pindyck (1999), the annual standard deviation of oil prices (σ) ranges between 15% and –20%. Then, substituting for $\sigma = 0.15$ in Eq. (20), the total cost of consuming a barrel of oil now becomes:

$$Tc = S\left\{1 + 0.03\sqrt{T}(e^{-0.0028T} + 1)\right\}. \tag{21}$$

Also, substituting for $\sigma = 0.15$ in Eq. (19), the external cost of consuming a barrel of oil as a percentage of the ongoing oil price becomes:

$$Ec, \ \% = 3\sqrt{T}(e^{-0.0028T} + 1). \tag{22}$$

3. Discussion

As indicated from Eq. (22), the external cost of consuming a barrel of oil, as a percentage of the ongoing oil price, depends on the time horizon of the planning policy, T. This time horizon reflects the extent to which the decision-makers evaluate sustainability when making their planning decisions. Fig. 2 elucidates the dependence of the external cost per barrel of oil consumed now, as a percentage of the ongoing market price of oil, on the time horizon of sustainability. It is obvious from the figure that the external cost of consuming a barrel of oil now increases as the time horizon of sustainability increases. In other words, consuming a barrel of oil now imposes an external cost of 18.71% of the current market price of oil if the time horizon of sustainability is 10 years. Accordingly, if the current market price of oil is \$25/bbl, the external cost of consuming a barrel of oil now is \$4.7. Then, the full cost of consuming a barrel of oil now is \$29.7. This full cost is the summation of the private cost (the current market price of oil) and the external cost per barrel of oil consumed now. If the time horizon of sustainability is chosen to be 50 years, the external cost becomes 39.66% of the ongoing market price of oil. In this case, consuming a barrel of oil now imposes an external cost

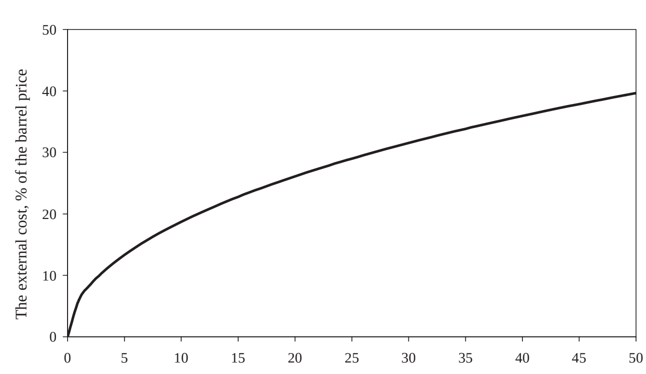

Fig. 2. Relationship between the external cost and the time horizon of sustainability.

of \$9.92. Then, the full cost of consuming a barrel of oil now is \$34.92.

The increase of the externality with the time horizon of sustainability reflects the fact that the degree by which future generations are affected due to the cumulative consumption increases with the time lag. As shown in Fig. 2, the external cost equals 0 when the time horizon is 0. This is because at time 0 the oil is available to all consumers at the same price, then the consumption behavior of a consumer does not affect significantly other consumers and consequently imposes no external cost on the other consumers. Since the ultimate oil stock within the Earth decreases with cumulative consumption, the cost at which future generations can obtain their needs of oil is expected to increase with time. Therefore, the more distant future generations are highly affected by the consumption decisions of the current generation and hence the external cost increases as the time horizon of sustainability increases. As the time horizon goes to infinity, the resource base will be completely depleted as a result of the cumulative consumption of generations. In this case, the cost of obtaining oil reaches infinity and consumers cannot get their needs of oil at all. Substituting for $T = \infty$ in Eq. (22), the resultant external cost equals infinity. Then, if the time horizon of sustainability is chosen to be infinity, the external cost of consuming a barrel of oil now becomes infinity.

4. Conclusion

In this study, a model is developed on the basis of option-pricing technique to quantify the external cost of consuming a barrel of oil within the context of sustainable development. This external cost is assumed to be equal to the value of the option to get a barrel of oil in the future at the price whose present value equals the current market price of oil. It has been found that the estimated external cost is very sensitive to the time horizon of sustainability. As the time horizon increases, the external cost increases. This finding coincides with the fact that the more distant future generations are highly impacted by the consumption behavior of previous generations, due to the declining oil stock within the Earth as a result of cumulative consumption. As the time horizon of sustainability goes to infinity, the oil stock of the Earth will be completely depleted and consequently the consumers at that time are impacted by an external cost equals infinity since they cannot get their needs of oil at all.

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