Food Policy 44 (2014) 218–226

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

The case for a real options approach to ex-ante cost-benefit analyses of agricultural research projects

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ARTICLE INFO

Keywords:
Expected net present value
Decision tree analysis
Contingent claims analysis
Agricultural research
Real options
Cost-benefit analysis

ABSTRACT

The United States Agency for International Development (USAID), like many other development agencies and donors, increasingly emphasizes evidence-based programming. This requires assessments of project performance at all stages of implementation, comprising ex-ante impact assessment, monitoring and evaluation, and ex-post attribution of outcomes. Ex-ante impact assessment, in particular, involves performing Cost-Benefit Analysis (CBA) to determine the Expected Net Present Value (ENPV) of the project in question. Unfortunately, the traditional ENPV approach has proven inadequate for dealing with uncertainty in the timing of investments and flexibility in future decision making. This is especially relevant for Research and Development (R&D) projects which require several stages of product development and multiple rounds of testing prior to releasing final products. As a consequence, the *real-options approach* to CBA has increasingly been used to evaluate private sector R&D projects. This paper advocates for the adoption of the real options approach in the evaluation of public investments in agricultural research, and illustrates its practical utility with an assessment conducted by USAID to determine the economic viability of a proposed project to develop improved varieties of critical food security crops in Uganda.

Introduction

Development agencies and donors increasingly emphasize evidence-based programming. This renewed focus relies on assessments of project performance at all stages of implementation, comprising ex-ante impact assessment, monitoring and evaluation, and ex-post attribution of outcomes. USAID is specifically applying Cost-Benefit Analysis (CBA) for ex-ante impact assessment within its billion-dollar investment in agriculture and nutrition under the *Feed the Future* initiative. By applying CBA, USAID is able to determine which investments offer the best prospects of generating the highest possible return in terms of higher incomes or reductions in negative health outcomes. Moreover, USAID is able to more clearly demonstrate to host countries and the U.S. public alike what it is achieving with scarce development funds.

Investments in agricultural Research and Development (R&D) are critical elements of the *Feed the Future* initiative, and as such must be subjected to CBA. Unfortunately, traditional CBA models have proven inadequate for analyzing research projects. Agricultural research, like most research, requires several stages of product development and multiple rounds of testing prior to releasing final products (new or improved seeds, for example). The high degree of uncertainty and the options built into research projects require a more flexible and robust analytical model than the traditional Expected Net Present Value (ENPV) model. To address this shortcoming, we advocate adoption of a *real-options approach* to CBA.

Although it is widely used in private sector research evaluation, the real options approach remains largely at the fringes of impact assessments of public sector projects. While we know of no study specifically dedicated to agricultural research, some path-breaking studies have demonstrated the effectiveness of the real options approach in evaluating the adoption of new technologies in agriculture and other applications. Purvis et al. (1995) use the concept of real options to model technology adoption decisions under uncertainty. Taur (2006) and Hyde et al. (2003) apply the approach to the analysis of dairy farming technologies, and Mushoff and Odening (2008) evaluate organic farming decisions as real options.

The paper proceeds as follows: Section A presents a discussion of cost-benefit analysis within the precepts of decision theory. We demonstrate the limitations of traditional ENPV under conditions of uncertainty. Section B lays forth the necessary variation in the form of the real-options approach, demonstrating the flexibility of this CBA methodology to address challenges associated with research and development investments. In Section C, the application

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0306-9192/$ - see front matter Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.foodpol.2013.09.016

of the methodology to R&D investments in Uganda is used as a case study to illustrate the process and results of using the real-options approach. Section D draws from the Uganda case to illuminate necessary information that researchers can provide to inform the methodology. Section E concludes.

Cost-benefit analysis decisions under uncertainty

The decision to invest under conditions of uncertainty involves an objective assessment of the possible streams of future value, and a subjective evaluation of the probabilities of realizing each relevant stream. A third element, the investor's attitude to risk, is rarely considered explicitly (except in portfolio selection contexts), but is nevertheless implied in the choice of models. This is certainly the case with the expected net present value model.

With ENPV the investment decision is based on a single parameter, namely, the probability-weighted average of net benefits (i.e., expected net benefits). Mathematically:

$$\mathrm{ENPV} = \sum_{t=0}^{N} \frac{p_t(v_t - c_t)}{(1+k)^t} \qquad (1)$$

where N is the duration of the project (including beyond the investment period); v_t the monetary benefit in period t; c_t the monetary cost in period t; p_t the probability of realizing the net benefit in period t; and k is the discount rate.

With ENPV the decision maker is presumed to be indifferent between a small payoff with a high probability of occurrence, and a large payoff with a low probability of occurrence, so long as they both have the same expected value. Hence the decision maker would be indifferent between a \$100 payoff with a 10% probability, and a \$25 payoff with a 40% probability. Such an investor exhibits risk-neutral behavior. The risk-neutral investor has a weak incentive to manage risks as it is the expected payoff (and not its volatility, for instance) that concerns him. This is problematic because, except for a few special cases, investors are risk averse rather than risk neutral. For the risk-averse investor, the ENPV model is clearly inadequate because the investor is concerned with risk minimization in addition to return maximization.

It might appear that the ENPV captures risk-aversion to the extent that the discount rate (k) reflects a positive risk premium. In fact, the discount rate represents the opportunity cost of capital to the investor while the risk premium captures the market price of risk (in the case of private investments) or the aggregate sensitivity of savers and investors to the shadow price of capital (in the case of public investments). Consequently, the risk premium in the discount rate does not in general reflect the investor's risk preferences.

One way for the risk-averse investor to manage risks is to attempt to gain as much information as possible before deciding in which project(s) to invest. By waiting for more information the decision maker essentially exercises the option to defer the project. Such an option has value to the extent that more usable information can be obtained about the project. It also has a cost in instances where delay may lead to the loss of an opportune time or resources to initiate the investment. This implies that for the risk-averse investor, selecting the optimal occasion to invest is an endogenous component of the investment decision. In more concrete terms, the probability of realizing a given payoff is in fact a function of the level of information available to the decision maker.

We can compute an upper bound for the value of information by calculating the project payoff conditional on the availability of perfect information about all possible future outcomes of the project. The project-specific value of perfect information is then determined as the difference between the conditional NPV given perfect information, and the ENPV. It constitutes the maximum that the investor should be willing to pay to obtain additional information.

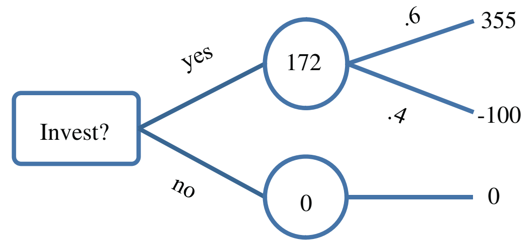

Fig. 1. Decision tree representation of ENPV decision rule.

For convenience, we illustrate with the following simple example. Let's assume a one stage investment opportunity to develop a disease resistant variety of a key food staple. The project will depend on an impending test of improved planting materials. Based on current knowledge, the probability of a successful test is 60%. If the test is successful the improved variety will be multiplied and disseminated at a cost of \$100 (thousand). The anticipated end of period benefit is estimated at \$500 (thousand), and the discount rate is 10%.[1] The ENPV of this project turns out to be \$172 (thousand), calculated as follows:

$$ENPV = \frac{0.6(500)}{1.10} - 100 \approx 172$$

It is instructive to examine a decision tree representation of the ENPV decision rule. This is depicted in Fig. 1 below:

The rectangle depicts a decision point (in this case, the decision whether or not to invest), and the circles depict events. The pay-off for each event is shown in the circle. The decision tree shows that the ENPV rule pre-supposes that the decision to invest has been made, or put another way, that the option to wait has been taken off the table. In the present example, a successful test would generate a terminal pay-off of \$500, which, discounted at 10% yields about \$455. Subtracting the project cost of \$100 gives us the net discounted pay-off of \$355. There is a 60% chance of realizing \$355 and a 40% chance of losing the project cost of \$100. The expected net present value of the decision to invest is thus $.6(355) + .4(-100) = 172$.

Suppose we have the benefit of perfect information about the outcome of the test. We would then base our decision to invest on what the test outcome happens to be. In terms of a decision tree, we start by depicting the outcomes, followed by the decision choices. This is the opposite of the ENPV rule, as we can see from Fig. 2 below:

Given perfect information, we would choose the option that yields the best outcome. Hence given knowledge that the test would be successful, if we choose to invest we would get a payoff of \$355. If we know that the test would be successful and choose not to invest, the benefit is \$0. Obviously, if we know that the test would be successful we would choose to invest and therefore the pay-off of \$355 in the decision box. By analogous reasoning, the best option given knowledge that the test would fail is to not invest. We see that the expected value given perfect information (ENPV|PI) is .6(355) + .4(0) = \$213. The expected net present value of perfect information (ENPVPI) is the difference that is attributed to perfect information. That is:

$$\mathrm{ENPVPI} = \mathrm{ENPV|PI} - \mathrm{ENPV} \qquad (2)$$

In the above example ENPVPI is \$41 (*i.e.*, \$213 − \$172). This value represents the maximum that one would be willing to pay to obtain additional information *prior* to investing in the project.

Perfect information is an unrealistic expectation in any practical

[1] The net benefits of all discounted cash flow models are highly sensitive to the choice of discount rates. We discuss some theoretical and practical considerations that should inform this choice below.