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The Impact of Uncertainty and Irreversibility on Investments in Online Learning

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Uncertainty and irreversibility (i.e., most costs are sunk costs) are central to online learning projects, but have been neglected in the existing educational cost–benefit analysis literature. This paper builds some simple illustrative models of the impact of irreversibility and uncertainty, and shows how different types of cost and demand uncertainty can have substantial impacts on investment decisions. The techniques used are drawn from the financial option pricing literature. In some situations uncertainty should lead decision makers to delay projects which would be accepted under the usual rule "invest if the net present value (NPV) is positive," and in other situations it suggests that projects with negative NPVs should be undertaken. The application of one of these models will then be illustrated in relation to a new online course: the Master of Educational Technology offered by the University of British Columbia. Q1

Introduction

Considerable progress in analysing the costs and benefits of information and communications technology and online teaching has been made in recent years (Bartolic-Zlomislic & Bates, 1999; Bates, 1999; Cukier, 1997; Massy, 2003; Rumble, 1997). However, one question that has received little attention is how uncertainty about costs and benefits affects decisions.

Uncertainty is a central issue both for policy makers and university managers concerned with information and communications technology and online teaching. Rapid change in the available technology, and the costs of this technology, combined with the volatility of the market for online courses all contribute to uncertainty for decision makers. This uncertainty is compounded by the irreversibility of investment in online teaching. Irreversibility comes from the fact that most of the costs of online teaching projects are sunk costs. For instance, computer hardware has a very low resale value while software has none. Building renovations to

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accommodate teaching with technology also tend to lead to the creation of teaching spaces that have few alternative uses. Expenditures on setting up systems for delivering online courses and expenditures on marketing courses are specific to the institution and hence have no outside market value if a project is abandoned. Indeed, is it difficult to think of other areas of investment where such a high proportion of costs are sunk costs as is the case with online teaching.

The cost–benefit and investment analysis literature within economics (e.g., Layard & Glaister, 1994) has so far been of little help to decision makers trying to deal with uncertainty, as indicated by the silence of the educational cost–benefit analysis survey of Hough (1994) on the topic. Where uncertainty is considered in cost–benefit analysis, the economist's usual method is to adjust the discount rate used to convert future costs and benefits to current dollars. A higher discount rate is used where future cash flows are uncertain, reducing the present value of these cash flows, and hence their impact on the decision. The amount by which the discount rate should be adjusted should depend on the estimated variability of the cash flows, expressed as an estimated standard deviation. The interest rate premium necessary to compensate investors for cash flow streams with different standard deviations can be obtained from financial markets. When cash flows are discounted in this way at an appropriate rate for the level of risk, the economics literature suggests that projects should go ahead if, and only if, the net present value (NPV) is positive. Unfortunately this procedure is not terribly helpful in the context of the use of information and communications technology in teaching and learning as the uncertainty in such investments is not of the type that can easily be expressed as a standard deviation of returns around some expected value. This unhelpfulness of the existing cost–benefit techniques may explain why uncertainty has so far been neglected in the educational technology literature.

However, some new investment analysis techniques have recently emerged which are more helpful in the context of information and communications technology. These techniques were first used by economists in the early 1990s (accessible discussions include Pindyck, 1991, and Dixit, 1992—a more technical treatment is Dixit & Pindyck, 1994). The techniques are sometimes referred to as the "real options approach to investment" because the analytical tools are similar to those used to value financial options.

This paper outlines these techniques and builds a number of simple models for use by information and communications technology decision makers. The use of the techniques will then be illustrated for a new online course—the Master of Educational Technology offered by the University of British Columbia.

Some Simple Models

Models in this section are developments of the simple two-period models (Dixit & Pindyck, 1994, pp. 26–55; Pindyck, 1991). They convey the basic points about the value of waiting, without the need for stochastic calculus. More complex models using stochastic calculus (Dixit & Pindyck, 1994, pp. 135–246) are more general and yield further insights. In these more complex models demand and/or costs evolve over time following geometric Brownian motion (the continuous time equivalent of a random walk, with a variance increasing over time), and can be solved for the optimal time to invest. However, few university managers are familiar with stochastic calculus, and the main idea of balancing costs of delay against option values of waiting can be expressed through simple two-period models.

Consider an investment by a university of $900,000 in an online teaching project. For simplicity, assume that all costs are sunk costs and none of this investment is recoverable should the project be abandoned. The university Vice-President responsible estimates that the project will yield revenues from student fees (net of operating costs) of either $120,000 or $80,000 per year, commencing a year after the initial investment. Each of these revenue streams is equally likely, and which occurs will depend on developments over the next year of marketing for these types of courses. The rate used by the university to discount future costs and benefits is 10% per year.

Should the Vice-President go ahead with the online course? The traditional cost–benefit rule suggests that projects should go ahead if the NPV is positive. Let the initial investment be denoted as C, the annual net revenue in the bad outcome as B_G, the annual net revenue in the good outcome as B_B, the probability of the good outcome as p_G, and the discount rate as r. (Note that the present value of an infinite stream of $1 payments with the discount rate r approaches $1/r$. This is a perpetuity, and details may be found in introductory mathematics or finance texts; e.g., Oslington, 1998, pp. 61–80.) The NPV is:

$$\begin{aligned} NPV_0 &= -C + [(p_G B_G + (1 - p_G) B_B)/r] \\ &= -900{,}000 + [100{,}000/0.1] \\ &= 100{,}000. \end{aligned}$$

This is positive, so going ahead would be following the procedure recommended by most finance and cost–benefit analysis texts (e.g., Layard & Glaister, 1994).

Going ahead with the investment, though, destroys the option to wait for more information before investing. What is the value of this option to wait for more information? We must first calculate the present value of the project if we wait a year and see whether demand is good or bad. At the end of the year, the NPV of the project would be the sum of the initial investment and the discounted expected annual revenue under the good outcome, multiplied by the probability of the good outcome. (The revenue in the bad outcome is not relevant, as the project would not go ahead under these circumstances.) This sum must then be discounted back 1 year to reflect the year delay. Thus:

$$\begin{aligned} NPV_1 &= [-C + B_G/r]\ [1/1(1+r)]\ [p_G] \\ &= [-900{,}000 + [120{,}000/0.1]\ [1/1.1]\ [0.5] \\ &= 136{,}363. \end{aligned}$$

The value of the option to wait is the difference between the present value of the investment if we wait for more information and the present value if we invest now:

$$V = NPV_1 - NPV_0$$
$$= 36{,}363.$$

As the NPV if the university waits is greater than the NPV for investing immediately, the value of the option to wait is positive, and the value-maximizing decision for the university should have been for the Vice-President to wait and proceed only if the market for courses strengthened.

In general, the value-maximizing procedure in situations where uncertainty and irreversibility are important is to calculate the NPV of investing immediately, of waiting, and of not investing, ensuring that the value of any options created or destroyed is included. The alternative with the highest NPV, including the value of any options created or destroyed, should be chosen. This and other formulae for calculating option values can be easily implemented in MS Excel™ and similar spreadsheet programs commonly used for investment analysis.

Varying the Level of Uncertainty

It is interesting to see the effect of greater uncertainty on the option value. This can be assessed by considering good and bad outcomes with the same mean as the previous example but greater spread. For $B_G = 200{,}000$ and $B_B = 0$ NPV_0 is unchanged, but NPV_1 using the above formula is \$500,000, and the option value is \$400,000. This means that the option value is increasing in uncertainty, which makes sense. It is uncertainty combined with irreversibility that creates option values in the first place.

Impact of Technical Progress

Technical progress at a known rate can easily be incorporated into the model. For example, let there be technical progress that reduces costs by $t = 5\%$ per year.

The NPV of investing now is unchanged, but the NPV if we wait a year increases to:

$$NPV_1 = [-C(1-t) + B_G/r]\ [1/1(1+r)]\ [p_G]$$
$$= [-900{,}000\ (0.95) + [120{,}000/0.1]\ [1/1.1]\ [0.5]$$
$$= 156{,}818.$$

increasing the option value to $V = 56{,}818$.

Thus technical progress reinforces the incentive to wait created by uncertainty and irreversibility.

Cost Uncertainty Rather Than Demand Uncertainty

Waiting can give a decision maker more information about costs as well as about student demand. Costs can change through the introduction of new technologies, changes in the regulatory environment, new partnership possibilities, or the availability of grants to offset some of the development costs.

To keep the example simple, abstract from demand uncertainty and assume, say, that annual cash flows will be $B = 100{,}000$ with certainty, and costs could be either $C_G = 500{,}000$ or $C_B = 1{,}300{,}000$ with equal probability. As before, the discount rate is $r = 10\%$. The formulae for dealing with this type of cost uncertainty are similar to those for dealing with demand uncertainty.

$$\begin{aligned} NPV_0 &= -[p_G C_G + (1 - p_G) C_B] + B/r \\ &= -900{,}000 + 100{,}000/0.1 \\ &= 100{,}000. \end{aligned}$$

$$\begin{aligned} NPV_1 &= [-C_G + B/r]\ [1/(1+r)]\ [p_G] \\ &= [-500{,}000 + [100{,}000/0.1]\ [1/1.1]\ [0.5] \\ &= 227{,}273 \\ V &= 127{,}273 \end{aligned}$$

Again, there is a value to waiting in that investing now destroys the option to wait for more information about costs. The correct decision with these illustrative numbers is to delay the investment.

Cost Uncertainty Resolved by Investing Rather Than Waiting

What makes these demand and cost uncertainty problems similar is the assumption that the additional information was gained by waiting, and independent of the decision to invest straightaway or wait. Sometimes, though, it is not waiting but investing that reveals information about costs. Consider an example where the university needs to spend $C = \$700{,}000$ to begin a project, and there is a 25% probability that an additional $A = \$2{,}000{,}000$ will be required. The institution can only discover whether or not the additional expenditure is required by investing, and can choose, after this is revealed, whether or not to proceed with the project. Net cash flows are \$100,000 per year and the discount rate is 10%, as in the previous examples.

The NPV of the project is:

$$\begin{aligned} NPV_0 &= -C - Ap_A + B/r \\ &= -700{,}000 - (2{,}000{,}000)\ (0.25) + 100{,}000/0.1 \\ &= -200{,}000. \end{aligned}$$

The NPV, taking into account the option not to proceed if the additional expenditure is required, is:

$$\begin{aligned} NPV_1 &= -C + (1 - p_A) B/r \\ &= -700{,}000 + (0.75)\ (100{,}000/0.1) \\ &= 50{,}000. \\ V &= 250{,}000. \end{aligned}$$

Here, the option not to proceed created by the decision to invest makes the decision not to invest the correct one, even though the NPV calculated in the traditional way is negative. In contrast to the earlier examples where considering irreversibility and uncertainty leads the decision maker to delay projects with positive NPVs, here, uncertainty pushes forward investments. This is because in the earlier examples investing destroyed a valuable option to wait; here, investing creates a valuable option to proceed.

Summary

The main point from these illustrative real option models is that the traditional rule—invest if NPV is positive—needs modification for information and communications technology investments that are irreversible (in the sense that most costs are sunk) and made in a highly uncertain environment. In many cases this will mean that delay is optimal, but not always, as was illustrated by the case where investing was the only way of resolving cost uncertainty.

Illustration

Having outlined the real options approach to investment under uncertainty, this approach will now be illustrated through an analysis of a particular online learning investment: the University of British Columbia's (UBC) Master of Educational Technology program. The program—which was developed and offered online jointly by the UBC and the Mexican Institution Tec de Monterrey (ITESM)—comprises four core courses and eight options chosen from a list of approximately 20. The decisions to go ahead with the program were made in 2001 on the basis of a business plan prepared by the UBC that ignored option values. This decision and the business plan that supported it are described in Bates (2000, pp. 59–75, 122–152). I will reanalyse the decisions using the techniques outlined earlier in the paper, not so much to confirm or criticize the decision made by the UBC but to illustrate how the techniques can be used by a manager. The analysis will be undertaken from the point of view of the UBC, ignoring the impact on the ITESM.

Before considering the UBC program, the model will be adapted as explained below to suit this particular context where the crucial issue is demand uncertainty that can be resolved only by investing.

The adapted model will be illustrated using some hypothetical numbers. Consider investing $C = \$900{,}000$ now which gives the UBC the option of proceeding if student demand (indicated by inquiries and enrolments) is sufficient. In other words, if net cash flows are $B_G = \$500{,}000$ per year, but not if they are $B_B = -\$100{,}000$ per year. Before considering the investment which reveals student demand, the UBC's assessment of the probability that student demand is good is $p_G = 0.5$ and the discount rate is 10%.

The NPV of the project is:

$$\begin{aligned} NPV_0 &= -C + [(p_G B_G + (1 - p_G)B_B)/r] \\ &= -900{,}000 + [200{,}000/0.1] \\ &= 1{,}000{,}000. \end{aligned}$$

The NPV considering the option not to proceed is:

$$\begin{aligned} NPV_1 &= -C + p_G B_G/r \\ &= -900{,}000 + [0.5]\ [500{,}000]/[0.1] \\ &= 1{,}600{,}000. \end{aligned}$$

The value of the option not to proceed is thus:

$$\begin{aligned} V &= NPV_1 - NPV_0 \\ &= -(1 - p_G)B_B/r \\ &= 5{,}00{,}000. \end{aligned}$$

Note from the expression for V that the sign of V is opposite to B_B, i.e., V is positive if, and only if, B_B is negative. This makes sense as it is the avoidance of losses that makes the option to abandon the project valuable. Another way of putting this is that if there were no losses in the bad state then the additional information gained by investing has no value, as it would not change the decision. This is another example of the "bad new principle" discussed by Dixit and Pindyck (1994, p. 40).

The value of the option will be higher the lower (i.e., more negative) B_B is, and the lower p_G is, as these reflect more downside risk in the project. The option value will also be higher the lower r is, as a lower r increases the present value of a given amount of future downside risk.

We turn now to the details of the UBC program, drawing on unpublished data in Bates (2001). Some information about the Diploma program which preceded the Master's program was published previously in Bartolic-Zlomislic and Bates (1999), and Bates (2000, pp. 134–146). The sort of analysis in these papers and the present paper is only possible because of the detailed activity-based accounting methods used for these courses by Distance Education and Technology which runs these types of courses at the UBC.

The focus will be on additional (i.e., marginal) costs and benefits of the program for the UBC as a whole. Internal charges between units within the UBC are ignored, as the focus of the paper is the whole institution rather than the within-institution distribution of funds. Additional, indirect costs of running the program are estimated at 25% of identifiable costs based loosely on some calculations done within Distance Education and Technology. This figure, though, is the most rubbery in the analysis. It is extremely difficult to assess the impact of a new program on the general university computer network costs, student support, parking, etc.

The UBC business plan considered a high-demand scenario with 60 students per year, and a low-demand scenario with 40 students per year. It is difficult to assign probabilities to these scenarios, and for the purposes of analysis it will be assumed that each was equally likely.

The UBC treasury rate charged for funds borrowed by units of 6% has been used

Table 1. Analysis of the UBC's Master of Educational Technology program

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	Year 1 ($)	Years 2–7 under high demand (per year)	Years 2–7 under low demand (per year)
Revenue			
Enrolments		60	40
Fees (per student)		1,250	1,250
Total		75,000	50,000
Fixed costs			
Program coordinator	15,000	5,000	5,000
Subject expert	9,000	4,000	4,000
Web/graphic design	4,000	1,000	1,000
Library	1,000	300	300
Copyright	800	800	800
Marketing	5,000	3,500	3,500
Total	34,800	14,600	14,600
Variable costs (per student)			
Admissions and advising		180	180
Tutors		220	220
Course package		60	60
Technical support		150	150
Stationery, postage, etc.		70	70
Total		680	680
Indirect costs (25% of other costs)	8,700	13,850	10,450
Net cash flow per year	–43,500	19,600	–2,250
NPV		–819	
NPV if wait and proceed if demand is high		4,716	
Value of option to proceed		5,535	

as a proxy for the rate of return on other projects that the funds tied up in the Master of Educational Technology project. Following the UBC business plan, the horizon of analysis is 7 years (cash flows are not infinite as in the models used to outline the real options techniques).

Costs and revenues for a representative course (taken from the business plan) are shown in Table 1, together with calculated NPVs and option values.

In Table 1 the NPV of the online Master's program is negative, but with the option not to proceed with the project, the analysis suggests that the project was viable. The calculated option value of $5,535 is not particularly high, reflecting the small amount of downside risk for the UBC—losses in the low-demand scenario are small. For other institutions beginning to teach online and lacking the systems that the UBC has built up over a number of years, the downside risk would be larger and the option value more significant in relation to the other costs and revenues.

The UBC illustration shows how important option values can be—here they change the decision. If the decision was made strictly on a traditional NPV basis using the above numbers, but ignoring option values, then the Master of Educational Technology program should not have gone ahead. With the option to proceed properly valued, the project could have been shown to be viable. Of course, the project did go ahead even though the original business plan prepared in 2001 neglected option values. The right decision was made, perhaps because the decision makers were prepared to trust their instincts rather than a traditional NPV analysis.

Subsequent history has worked out well for the UBC. The first students enrolled in the program in September 2002, enrolments have been stronger than the projections in the business plan, and the program is currently running successfully. However, when we are dealing with uncertainty then hindsight is not necessarily the best test of a decision. A good decision (in other words one that maximizes expected NPV taking into account option values) can be made and yet the outcome can be bad. Alternatively, a bad decision can be made and turn out well. The future is unknowable but the point is to develop techniques that improve decision making and increase the probability of good outcomes.

Complications and Caveats

Educational institutions operate in widely different contexts: in other contexts, cost uncertainty will be more important than it has been for the UBC; in these contexts the cost uncertainty variants of the model outlined earlier in the paper will be more appropriate. In other contexts, other variants developed earlier in the paper will be appropriate. Unfortunately there is no single model applicable to all situations.

In many contexts, option values may work in the opposite direction to the UBC example. Including option values in some cases should push decision makers to delay or abandon investment plans that the traditional NPV rule indicates should be undertaken. For instance, some recent high-profile investment failures (e.g., Cardean University, Harcourt) may have been due to rushing to invest based on a positive NPV and ignoring costs of destroying the option to wait.

One consideration (prominent in accounts of recent information and communications technology investments such as in Wilson, 2002) that has not been included in the models in this paper is the strategic motive for investment. An example of the strategic motive is investing to be the first in a new market with only enough room for one provider. It is debatable whether markets for online courses are like this, because barriers to entry are not excessive, but to the extent that they are, strategic considerations have to be weighed alongside costs of waiting. It is very difficult, however, to include strategic motives in a useful model because of their variety and complexity.

It is important to emphasize that these techniques for dealing with uncertainty rely on the decision maker having sufficient knowledge to be able to formulate good and bad scenarios and attach probabilities to them. The techniques do not have magical power to do away with uncertainty; rather, their purpose is to help us to organize and use the limited knowledge we have.

Conclusion

The real options approach outlined in this paper is a powerful tool for improving information and communications technology decision making where uncertainty and irreversibility are important. A number of variations of the model have been outlined, along with discussion of the contexts where they apply. For one particular context, the application of the techniques was illustrated in detail and this can guide the application of the techniques in other contexts.

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