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Examining the Prospects for Commercialization of Soybean Peroxidase

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The purpose of the article is to examine the prospects for the commercialization of soybeans peroxidase (SBP) from soybean hulls and to model uncertainty and strategic flexibility in biotechnology management and investment. The article provides an empirical application of the discounted cash flow and contingent claim approaches to a biotechnology investment. The present value of net benefits from an investment outlay of CAD$8.6 million[1] in SBP extraction is approximately $1.4 million. While the extraction plant is financially feasible, the results are sensitive to the cost of the spray dryer to extract the SBP, which represents more than 90% of the investment cost and the price of SBP. The value of the project is also very sensitive to genetic improvement of peroxidase content; a 5% genetic improvement in peroxidase content leads to an approximately 100% increase in the value of the project (*other things being constant*). Given the uncertainty associated with bio-products such as SBP, the analysis is extended to incorporate uncertainty and managerial flexibility through a contingent claim analysis of the option to expand the scale of operation and option to delay production. The option values of waiting and expansion strategies are $3.56 and $34.1 million, respectively.

Key words: soybean peroxidase, soybean hulls, genetic improvement, capital budgeting, real options.

Introduction

The movement toward a green economy hinges on the use of biosciences to develop new products and services. These bioproducts range from energy goods (McLaren, 2008) to therapeutic proteins (Einsiedel & Medlock, 2005) and functional foods (Muth, Mancini, & Viator, 2002), and soybeans form the base commodity behind many of the developments. For example, soybean oil can be used to make biodiesel, while genetic modification can result in high olelic oil soybeans that are healthier (Giannakas & Yiannaka, 2004) and can enhance the antimicrobial properties of soybean meal in animal feed (Kerley & Allee, 2003). Biotechnological developments have also resulted in the introduction of a new use from the hulls of soybeans. The seed coats removed from soybeans in the joint-crush production of meal and oil are currently either put back into the meal or sold for direct use as animal feed. While hulls have traditionally been viewed as a waste by-product, there is potentially high commercial value associated with the enzymes contained within the seed coats; one of these enzymes is soybean peroxidase. Soybean peroxidase represents 3% of the total protein content of soybean seedhulls, which have a protein content of 0.5% (SOY 20/20, 2003). It has been known since the 1960s that soybeans contain various peroxidase isoenzymes, but only recent technological developments have allowed peroxidase to be measured and extracted from soybean hulls (Vierling & Wilcox, 1996).

The use of peroxidase enzymes (Enzyme Commission 1.11.1.7) spans the bioscience and biotechnology spectra, ranging from bioremediation and biocatalysis through to diagnostics and biosensors to recombinant protein expression, transgenics, bioinformatics, protein engineering and even to therapeutics (Ryan, Carolan, & O'Fagain, 2006). The peroxidase from soybean hulls belongs to class III of plant peroxidase that includes horseradish, barley, and peanuts peroxidase (Kamal & Behere, 2002). However, horseradish is the most widely studied of the peroxidases, which has found many diagnostic, biosensing, and bio-technological applications because of its high stability in aqueous solution (Alpeeva & Sakharvo, 2005).

Production of peroxidase from soybean hulls is of interest in Canada, the United States, and other countries because it is renewable, can reduce environmental damage, and generally does not compete with animal feed or for land or other agricultural resources. The environmental, economical, and chemical strengths of soybean peroxidase (SBP) make it potentially a unique, value-added product for what has been viewed largely as a residual from the crushing of soybeans. From an envi-

1. *All figures in this article are in Canadian dollars.*

ronmental standpoint, the use of plant peroxidase may replace harsh chemicals that might otherwise be used in bioscience and biotechnology spectra, and it represents a transition from a petroleum-based economy to a bio-economy. SBP can be a cheaper substitute for many industrial chemicals because it is more stable, it can act on a broad range of compounds, and has higher oxidating power than other enzymes (Wright & Nicell, 1999). Manufacturers are interested in SBP because the supply of the horseradish is limited and horseradish peroxidases are very unstable under high temperature (Kamal & Behere, 2002). Furthermore, SBP has been reported to be less susceptible to both heme loss and permanent inactivation by hydrogen peroxide than horseradish peroxidase. SBP stabilizes reactive compounds by providing a binding site for oxygen, resulting in a less reactive form. SBP is an enzyme that provides a functional improvement over other enzymes for many commercial applications because it has greater heat stability, shelf life, and oxidative properties than other chemical-oxidizing compounds.

Isolation of crude SBP from waste soybean hulls may offer a cheap bulk peroxidase catalyst for applications such as wastewater treatment and organic synthesis, whereas the more costly peroxidase alternatives (plant horseradish peroxidase and recombinant horseradish peroxidase and SBP) will prove themselves in higher-value niches such as diagnostics and therapeutics (Ryan et al., 2006). Unlike horseradish peroxidase, SBP is active in the pH range 2-6, offering a greater variety of potential biosensing applications. *ScienceDaily* press, for example, indicated that

> "… soybeans [peroxidase] replaces horseradish peroxidase, which is an integral part of kits designed to help diagnose a myriad of viral, bacterial, and parasitic diseases, including AIDS and malaria. Standard kits lose effectiveness in about four months without refrigeration…. Vierling's preliminary research suggests that kits made with soybean peroxidase should last unrefrigerated for at least a year. Such kits will be very useful in places such as China, Africa, and Central America…" (Purdue University, 1997).

Further, SBP could be used instead of hydrogen peroxide as a bleaching agent in the pulp and paper industry to decrease the color of the pulp and make the resulting paper whiter. Additional uses for SBP include wastewater treatment, soil remediation, on-site waste destruction, formaldehyde replacement, bread dough conditioning, and as a substitute for horseradish peroxidase in medical diagnostics.

Continued research into the 'traditional' horseradish peroxidase has been accompanied by the slow, but steady, progression of research into SBP. Despite its unusually high catalytic activity and stability—as well as higher potential supply compared to other plant peroxidase—SBP has met limited success to date in commercialization, and this success has been mostly in medical diagnostic applications as a less expensive substitute for horseradish peroxidase. With a better understanding of the catalytic and stability traits, the increasing use of implantable devices in the medical field and the investigation of its commercial feasibility, SBP may rapidly develop its own high-value market niche. Currently, the information on technological and commercial feasibility of SBP is limited to private companies such as Mead Paper, Inc., and Enzymol International, Inc. (Wick, 1996). Keith E. Taylor, professor of chemistry and biochemistry at the University of Windsor, indicates that research has shown that the extraction of soybean peroxidase is feasible, but we have yet to see any large-scale production of soybean peroxidase facilities because its commercial viability at realistic prices has not been examined (personal communication, 2008). Initial research on these cultivars indicates that the level of peroxidase has no association with other soybean varietal characteristics such as yield, protein, or oil content. However, the quantity of peroxidase available in soybean hulls is affected by grain storage and handling procedures. Research has shown that the loss of peroxidase in stored soybeans is a function of time, temperature, and mechanical damage of the soybeans (Lentz & Akridge, 1997). Lentz and Akridge (1997) evaluated four supply-chain arrangements for SBP from the farmer to the processor. One used the existing commodity supply chain while the other three involved segregating soybean cultivars with higher yielding peroxidase in the hulls. The budgets for each hinged on the premium added, the segregation costs, and the quantity of peroxidase extracted. The actual feasibility of the extraction plant under current conditions was not evaluated.

The purpose of this article is to assess the financial feasibility of soybean peroxidase production. While it is technically feasible to produce SBP from soybean hulls, the commercial feasibility for this natural enzyme is unknown. The article evaluates the net present value of investing in a processing facility in Ontario, Canada to extract SBP. It also examines the effect of uncertainty and managerial flexibility on the investment into SBP using a real options approach. Real options has been used to explain the US comparative advantage in biotechnology by Lavoie and Sheldon (2000), but few studies have used real options to assess strategic investment options in bioproducts despite the inherent randomness underlying these markets. The next section of the article describes the SBP extraction process and the associated cost assumptions. The following section outlines the methods for the financial analysis followed by the results.

Soybean Peroxidase Extraction Process

The technology associated with the extraction and processing of peroxidase has primarily been developed by private corporations including Mead Paper, Inc., and Enzymol International, Inc. (Vierling & Wilcox, 1996). The water solvent extraction process for SBP begins with the transport and storage of soybean hulls from the nearby soybean crushing plant. The hulls are transported from the storage silos by conveyor belts into a reservoir where they are stirred with water. The result of this process is a mash that needs to be dewatered. By pressing the mash, the water that contains the enzyme is removed and captured in a tank. The pressed mash that remains after the removal of the water is dried and then stored in another silo for processed hulls or shipped to a buyer, such as an animal feed company. The enzyme extract is separated from the water by spray drying and then stabilized and stored for shipping. The size and purchase price for the equipment required in each step are discussed below and summarized in Table 1.

Capital Equipment and Costs

Soybean hulls are a by-product of soybean crushing, so it is assumed that the extraction of SBP will occur close to a crushing facility in order to minimize transportation costs. The size of the land required for building and operating a soybean peroxidase extraction plant next to an existing crusher is 0.5 ha (K. Taylor, personal communication, 2008). There are two major soybean crushers in Ontario that process approximately the same amount of soybeans. For the purpose of this analysis, the Bunge plant in Hamilton has been chosen since it is more centrally located. The price of the 0.5 ha site close to Bunge is $166,000 for commercial-zoned land available in the Hamilton real estate market (M. Ludica, personal communication, June 24, 2008).

Around 1.55 million tonnes of soybeans are crushed annually in Ontario and about half of this amount is crushed in Hamilton. Since soybean hulls comprise approximately 8% of the bean, then 62,000 tonnes of soybean hulls are assumed to be available for SBP use in Hamilton. It is assumed that 10% of the available soybean hulls from all the beans crushed at Bunge is used to make SBP. The SBP yield of those hulls is assumed to be 90,000 units of catalytic activity per kg of hulls. Thus, 6.2 metric tons (MT) of hulls generate 0.56 billion units of crude SBP.

The required weekly storage capacity for the raw soybean hulls is 123 tonnes. A vertical silo is chosen as the storage option rather than a warehouse building because it has smaller land and labor requirements, as well as reduced storage losses. A 1,000-tonne silo was estimated to cost $82,000 and includes a blower to put the hulls into the silo and an unloader (International Silo Association, 2008).

Three conveyor belts are required for transporting—one for moving soybean hulls from the storage silo to stirring reservoir, one for moving hulls from the dewatering device to dryer for pressed mash, and one for moving the dried hulls to a storage silo. The three conveyor belts employed in the production process are each 10 meters long and cost $4,626 per conveyor, for a total of $13,878 (Gilmore-Kramer Company, 2008).

The soybean hulls are mixed with water at a ratio of 1 kg of hulls to 20 liters of water, so the daily requirements are 493,834 liters of water with 24,692 kg of soybean hulls. Assuming that the mixing takes 40 minutes and the facility operates 8 hours a day, the stirring reservoir tank capacity must be approximately 40,000 liters. Given that one liter of capacity costs $0.53 to custom-make, the capital outlay for a stirring device with a 40,000 liter capacity is $21,108 (CST Industries, personal communication, May 23, 2008). Besides the tank, an agitator or propeller mixer is required to mix the soybean mash within the reservoir. The agitator is $40,000 resulting in total initial costs for the stirring reservoirs of $61,108 (CST Industries, personal communication, May 23, 2008).

The soybean mash is separated into pressed mash and a liquid enzyme extract (water and soybean peroxidase) by filter press. There are a variety of dewatering technologies available for industrial and municipal applications and most of them can be customized to specific plant requirements to provide a dewatering solution to most all process flows—from as little as 100 liters to more than 4.5 million liters per day (D. Beaudrey, personal communication, May 23, 2008). In this process, the dewatering device is a water screen attached to the edge of the stirring tank and it costs

Table 1. Base case model parameters.

Parameter	Units	Value
Capital investment		
Land	0.5 ha	$166,734
Silos for storing soybean hulls & mash	Two 1,000-tonne silos	$114,800
Conveyor belts	Three 10-meter belts	$13,878
Reservoir for stirring hulls with water	400,000 liters	$21,108
Agitator to stir hulls in water		$40,000
De-watering device (screen on stirring tank)		$100,000
Tank to capture the water after stirring	400,000 liters	$21,108
Belt dryer to dry pressed mash	209,800 kg/day	$30,000
Spray dryer to extract enzyme from water		$8,000,000
Storage building for SBP		$84,000
Total investment cost		**$8,591,628**
Annual operating expenses		
Water	0.49 million liters/day × 251 days × $0.00094/liter + $1040 × 12	258,897
Labor	12 employees	571,797
Maintenance and administration	$15,000 × # of employees	1,756,745
Patent fees	2% of revenues	
Revenue		
Soybean seed (SB)	10% of 0.77 million MT crushed at Bunge	77,426.5
Percentage of hulls from soybeans (q)		0.08
Soybean hulls (SH)		
Soybean hull price	$/MT	$169
SBP yield per kg of hulls	Unit of catalytic activity	90,000
SBP production	Million units of catalytic activity	557,786
SBP price	$/million units of catalytic activity	7.5
Used soybean hulls	MT	6,197
Total annual revenue		**$5,126,051**
Other parameters		
Risk-free rate	%	3.2
Discount rate	%	12
Corporate income tax rate	%	36

$100,000 (D. Beaudrey, personal communication, May 23, 2008).

A belt dryer is chosen to dry the pressed mash that continuously flows from the dewatering device to a storage silo. Hot air from a generator is passed through the moving porous bed of the wet material. The moisture is transferred from the wet particles to the hot air. The material becomes progressively drier as it traverses along the length of the belt dryer and the air is exhausted via an induced draft fan. The dryer processes 24,692 kg of soybean hulls and the investment costs associated with the belt dryer are $30,000 (R.E. Morrison Equipment, Inc., personal communication, May 25, 2008).

The liquid enzyme extract resulting after the mash is pressed must be stored. For that purpose, another tank is installed, but without the stirring technology. Assuming that no water is lost in the process up to this point, the required capacity of this tank is the same as the stirring reservoir tanks. Thus, the investment is $21,108.

The last step is to remove water from the enzyme extract and purify the soybean peroxidase. This is done by a spray-drying technique that atomizes the feed liquid (solution or slurry) into fine droplets using high-speed rotary discs or standard spray nozzles. The droplet size, along with drying speed, has a lasting impact on the final particle size and shape of the dried product. The liquid components of the feed evaporate and leave the product behind as a spherical powder that is sprayed into a cylindrical chamber. This powder is subsequently separated and collected from the gas flow directly at the base point of the spray dryer or by means of an aerocyclone and a bag filter (Ohkawara Kakohki Co. Ltd., 2008). After spray drying, the captured water is disposed and the soybean peroxidase enzyme is placed into storage. Given that the volume of water containing the enzyme extract is approximately 0.5 million liters per day, the price of the spray dryer is estimated to be $8 million. Spray driers are used for sensitive materials in pharmaceutical, chemical, food, and dairy industries (Marriott Walker Corporation, 2008). The cost of a storage building is $84,000.

Annual depreciation for the above capital expedentidures is simply the investment cost divided by the number of years the equipment is in service. Storage equipment, the spray dryer, and buildings belong to the 20-year property class; the stirring reservoir and the enzyme tank are in the 15-year property class; and conveyor belts, the dewatering device, and dryer are in the 7-year property class according to the Modified Accelerated Cost Recovery System.

Operating Expenses

Soybean hulls are purchased from the nearby Bunge soybean processing plant located in Hamilton. The opportunity cost of the hulls was based on the average price paid by local animal feed companies over the last 2 years. The price has fluctuated from a low of $140/tonne in February 2007 to a high of $210/tonne in the spring of 2008. The average over the period ($169/tonne) is assumed for the hulls, and no transportation costs are included since the crushing plant is adjacent to the extraction facility.

Water is a major input in the extraction process for SBP. The water price of $0.994 per cubic meter is the actual market price that industrial firms pay for water in Hamilton (Horizon Utilities Corporation, 2008). The charge consists of a monthly fixed fee and per-cubic-meter charge. Total annual water costs are $258,897; this is calculated by 0.5 million liters per day multiplied by 251 days and $0.000994/liter plus a fixed charge of $1,040 per month.

It is assumed that 12 workers are required with the estimates based on similar facilities for bioethanol production (Tetarenko, 2001). Using annual average salaries for the required professions, the total labor costs are $0.57 million. Anticipated administrative costs associated with items such as insurance, taxes, electricity, phone bills, office equipment, and security are calculated by multiplying number of workers by the respective per worker cost. The average amount per worker in Canada is within a range of $15.00-20.00/year (E. Currie, personal communication, 2008).

The average tax that corporations operating in Ontario pay is 36.12%. This rate consists of both provincial and federal taxes and is an average for manufacturing and resource industries, according to the Canada Revenue Agency.

Another cost facing a processor of SBP is the royalty required by the developer of the technology. Patents associated with soybean peroxidase production are owned by the Mead Corporation, now called Mead-Westvaco. One approach for estimating the royalties on a patent is to let it be determined by a market negotiation (Porter, 2008). A second method is a cost approach, which involves estimating the expense associated with designing around the patent-in-suit. Once the full cost of working around the patented technology is determined, an effective royalty rate can be calculated through division of that cost by revenue achieved (and expected to be achieved) by the product-in-suit over the duration of the life of the patent (Porter, 2008). In this study, the rate of 2% of revenue from SBP sales is estimated as the cost associated with patent fees.

Revenue Streams

The major revenue comes from extraction and sale of SBP. The revenue from the SBP business is defined as $P_{SBP} \bullet Q_{SBP}$, where P_{SBP} is the price of SBP and Q_{SBP} is the production of SBP. The amount of soybean hulls (SH) from soybeans (SB) is given by $SH = \theta \bullet SB$, where θ is a technological parameter indicating the percentage of hulls in the soybean seed. The amount of SBP coming from the hulls is defined as $Q_{SBP} = \lambda \bullet SH = \lambda \bullet \theta \bullet SB$, where λ indicates the amount of SBP that can be extracted from soybean hulls.

In this example, it is assumed that 10% of the total soybeans crushed at Bunge are available, so SB = 77,470 MT. Given θ is equal to 0.08 • SB, 6.2 MT of hulls are used in the extraction process. The SBP yield is assumed to be 90,000 units of catalytic activity per kg of hulls (λ=90), resulting in the extraction of 557,786 million units of SBP. The selling price for soybean peroxidase (P_{SBP}) is assumed to be $7.50 per million units, which is the market price for Novozymes' crude microbial peroxidase. Novozymes has a stabilized, concentrated liquid preparation that is a comparable substitute for SBP (K. Taylor, personal communication, 2008). Thus, annual sales of SBP are $4,183,393.

The feed value of the dried hulls is unchanged and therefore can be sold as a food/feed additive (K. Taylor, personal communication, 2008). In this project, the assumption is made that all hulls after SBP extraction are sold to feed companies at a 10% discount of the market price of $169/tonne (which is the purchase price of the hulls).

Investment Model

While the extraction of soybean peroxidase is technically feasible using the process described in the previous section, its commercial feasibility is unknown. A new biotechnology may increase benefits, but its cost may outweigh its returns, thereby making it unattractive to commercial investors. A new biotechnology must not only be economically feasible, but it must also be shown to be at least as feasible as the existing technologies or products on the market. In this study, we use both discounted cash flow and real options approaches to value investment in SBP extraction and commercialization.

Discounted Cash Flow Model

The basic approach to evaluate the financial feasibility of any investment is to determine the net present value (NPV) of future cash flows that the investment will generate. The NPV of an investment is defined as the sum of the increase in current wealth:

$$NPV = -I + \sum_{t=1}^{n} \frac{E(CF_t)}{(1+r)^t}, \qquad (1)$$

where I is the capital outlay at the beginning of the investment time, n is the total time of the project-planning horizon, r is the discount rate, and $E(CF_t)$ is the expected net cash flow (CF) at time t. If the NPV is greater than zero, the project should be accepted. In the case where there are several mutually exclusive investments competing for funds, then the project with the greatest NPV should be adopted.

The risk-adjusted discount rate is a key parameter in the NPV analysis, as it converts future returns into present-day dollars that are compared to the initial investment cost. Per dollar of prospective net cash flow, any corporate investment opportunity will be worth more the lower is its systematic risk, since the yield demanded of it by investors will decline commensurately (Lewellen, 1977). This is especially true when evaluating biotechnologies because there is a high level of uncertainty.

Traditional methods used to determine a risk-adjusted discount rate are the capital asset pricing model (CAPM) and the capital market line (CML), but neither is appropriate for this situation. The CAPM is appropriate to calculate the risk-adjusted discount rate for projects undertaken by publicly traded companies (Ross, Westerfield, & Jaffe, 2005). According to Brigham and Gapenski (1997), the CML provides a linear relationship between the risk and return for efficient portfolios of assets but it cannot be calculated without the market risk and the risk associated with the asset, both of which are unknown for this particular project. As a result, a real risk-adjusted discount rate of 12% is used, which is in the range of other studies using capital budgeting techniques for a bioproduct investment analysis (Degiorgis, Santarelli, & Cali, 2007; Turvey, 2001).

Real Options Model

Even if the present value exceeds the investment cost and its opportunity cost, additional strategic decisions face the biotech investor. These decisions include proceeding with the project immediately or waiting until more information is available, and if the decision is to invest today rather than defer, whether the investor should include the possibility of permitting a future, larger investment in the project.

The value of the expansion option given an initial investment of K can be decomposed in terms of both assets in place and the embedded options (Pindyck, 1988).

$$V_i = N_i(K,\varepsilon) + O_i(K,\varepsilon), \qquad (2)$$

where V_i is the value (or the expanded NPV) of the investment as estimated by the i^{th} firm; $N_i(K,\varepsilon)$ is the value of the assets in their current use, equivalent to the DCFs of expected earnings; $O_i(K,\varepsilon)$ is the valuation of flexibilities embedded in the project; and ε is the current value of an uncertain state variable. The expansion is justified when the perceived value to the investor is greater than the expansion cost (exercise price), so the timing of the expansion is critical.

For a financial option, the terminal value is given by the stock price and exercise price as set by the initial contract.

$$f = \text{Max}[V_t - X, 0], \quad (3)$$

where f is the value of the option; V_t is the price of the underlying asset at time t, or the present value of cash flows as given by $V_t = \sum_{t=1}^{T} \frac{E(CF_t)}{(1+r)^t}$; and X is the exercise price.

The empirical analysis of this study adopts the standard discrete time option pricing, using a multiplicative binomial approach (Cox, Ross, & Rubinstein, 1979). The binomial approach is the simplest of the option pricing models (Elton & Gruber, 1995). It does not depend on the probability of certain outcomes, and it requires less mathematical background compared to the Black-Scholes model (Black & Scholes, 1973). In the binomial tree model, the value of the underlying asset evolves in different states, and the value of the underlying asset is given by an up state and a down state for future period. The payoff is calculated in the final period. The algorithm of backward induction is used to price the option at time zero. The parameters required in option valuation are the present value of the underlying asset (V), the present value of implementation cost of the option (X), volatility of the natural logarithm of the underlying free cash flow returns in percent (σ), time to expiration in year (T), risk-free interest rate (r), and continuous dividend outflows (or cost of waiting) in percent (q). In addition, the binomial lattice model requires two additional sets of computations a measure of risk neutral probability (p), given by

$$p = \frac{e^{(r-q)\Delta t} - d}{u - d}, \quad (4)$$

and a measure of the up (u) and down (d) factors given by $u = e^{\sigma\sqrt{\Delta t}}$ and $d = \frac{1}{u}$, where Δt is the time interval or step size. Note that the cost of waiting[2] implies the opportunity cost of waiting for valuable information on executing the option. Note that as $\Delta t \rightarrow 0$, the parameters of the multiplicative binomial process converge to the geometric Brownian motion (GBM).

$$dV = \mu V dt + \sigma V d\varepsilon, \quad (5)$$

where μ is the deterministic drift, $d\varepsilon$ is the increment of a standard Wiener process, and σ is the volatility of V.

2. Option to wait assumes that competitive or market effects (market share erosion, first to market, strategic positioning, etc.) have negligible effect on the value of the project.

Option to Wait by Five Years. The option to wait provides management with the flexibility to postpone the project implementation to time T_1. The project is expected to generate future cash flows, and the resulting gross project value V_t at time t acts as the underlying asset value for the project's real options and is assumed to follow a geometric Brownian motion. The payoff option to wait at the final node is

$$f_n^{\,w} = \max\,[V_t - C_5, 0], \quad (6)$$

where V_t is the present value of cash flows or option value at different points in time (different steps of the binomial tree), $f_n^{\,w}$ is the final single value of the options, and CF_5 is the required outlay in Year 5. Working from the payoff at the final node of the tree, the value of the option at each node is given by

$$v_n = \max\left(f_n^{w}, \frac{\left(p \times f_{u(n+1)}^{w} + (1-p) f_{d\,(n+1)}^{w}\right)}{1+r} \right). \quad (7)$$

Option to Expand Processing Plant. Once a project is undertaken, the expansion option allows management to expand the scale of the project by ϕ at time T_1 by making an investment outlay C_E if it turns out that SBP is well received in the market.

$$f_E = \max\,[V_t, \phi V_t - C_E, 0], \quad (8)$$

where ϕ is scale of expansion and C_E is the present value of the additional cost of expansion.

Working from the payoff at the final node of the tree, the value of the option at each node is given by

$$v_n = \max\left(\phi V_n - C_E, \frac{\left(p \times f_{un+1}^{E} + (1-p) f_{dn+1}^{E}\right)}{1+r} \right). \quad (9)$$

Results and Discussion

Net Present Value

The net present value of investing in a SBP extraction facility is \$1.38 million (see Table 2). The annual discounted net cash flow for each year is approximately \$1 million for 20 years, and this is sufficient to cover the \$8.6 million investment. The payback period is 8.8 years and the profitability index is 1.14.

The results of the sensitivity analysis identify the critical factors underlying the uncertainty of net benefits. The sensitivity of the results to changes in key

Table 2. NPV (% change) to changes in key parameter values.

Parameters		SBP price (% change)		
		$6.00 (-20%)	**$7.50 (Base)**	**$9.00 (+20%)**
Discount	5% (-58%)	-1,315,922 (-201%)	6,255,153 (380%)	13,826,229 (961%)
	8% (-33%)	-2,591,005 (-299%)	3,779,237 (190%)	10,149,481 (679%)
	12% (Base)	-3,862,421 (-396%)	1,302,954 (0%)	6,468,329 (396%)
	16% (33%)	-4,792,397 (-468%)	-514,024 (-139%)	3,764,349 (189%)
	20% (67%)	-5,488,294 (-521%)	-1,877,379 (-244%)	1,733,534 (33%)
	25% (108%)	-6,133,621 (-571%)	-3,144,907 (-341%)	-156,194 (-112%)
Hulls price	$135 (-20%)	-3,702,608 (-384%)	1,462,767 (12%)	6,628,142 (409%)
	$169 (Base)	-3,862,421 (-396%)	1,302,954 (Base)	6,468,329 (396%)
	$203 (20%)	-4,022,233 (-409%)	1,143,141 (-12%)	6,308,516 (384%)
Investment cost	$6,873,302 (-21%)	481,440 (269%)	3,106,480 (138%)	8,271,855 (535%)
	$8,676,828 (Base)	-3,862,421 (-396%	1,302,954 (Base)	6,468,329 (396%)
	$10,309,953 (19%)	-5,495,545 (-522%	-330,170 (-125%)	4,835,204 (271%)
SPB content	90,000 (0%)	-3,862,421 (-396%)	1,302,954 (0%)	6,468,330 (396%)
	94,500 (5%)	-2,829,346 (-317%)	2,594,298 (99%)	8,017,942 (515%)
	99,000 (10%)	-1,796,271 (-238%)	3,885,642 (198%)	9,567,555 (634%)
	103,500 (15%)	424,840 (-67%)	5,176,986 (297%)	12,899,222 (890%)

model parameters is summarized in Table 2. The break-even discount rate (or internal rate of return) is 14.74%, which is a 25% increase from the base assumption of 12%. As illustrated in Table 2, the NPV of the project is quite sensitive to changes in the discount rate. For example, at a SBP price of $7.50, a 33% increase in the discount rate may result in an approximately 139% decrease in the NPV of the project.

In addition to the discount rate, SBP price is another parameter that has a significant influence on the feasibility of the project. The price for SBP only has to drop by 5% to $7.10 before the NPV becomes negative. In contrast, the break-even price of hulls is $447/tonne, or a 164% increase from the current level. The financial feasibility of the extraction plant is not sensitive to the price of soybean hulls since this input represents only 12% of total expenditures. However, the NPV drops quickly with relatively small decreases in SBP price, and the break-even point is reached with only a 5.3% decline in output price, suggesting that SBP price is one of the sources of uncertainty. Consequently, although the plant appears to be very profitable, the feasibility could be threatened by changes in the marketplace stemming from changes in the price of competing products, such as hydrogen peroxide or horseradish peroxidase.

We have also examined the impact of changes in genetic improvement of the peroxidase content of the soybean hull. For example, a 5% increase in the SBP content of soybean hulls results in an approximately 100% increase in the NPV of the project.

Table 3. Values of parameters of real options analysis.

Variable	Notation	Value
Present value of subsequent expected cash flows from the project	V	$10,751,276
Required investment expenditure	X_d	$8,676,828
Additional investment expenditure for expansion	X_e	$66,066,772
Volatility	s	15%
Risk-free interest rate	r	3.2%
Scale of expansion	f	4
Decay rate (cost of waiting)	d	5%

Real Options

The values of the option to defer and the option to expand are calculated using a binomial tree model (see the section "Real Options Model"). The movements of the underlying asset values along the lattice are determined by parameters listed in Table 3. The binomial tree is constructed using Microsoft Excel. The maturity is estimated to be five years for the option to delay, with four time steps within each year totaling 20 time steps for the binomial tree.

The option to defer gives the investor a choice between investing in a project today with uncertain future cash flows and deferring the decision until later, by which time the uncertainty is expected to clear. The option to defer is an American call option and gives the investor the right to invest in a SBP extraction facility

Table 4. Real option value of SBP project in million $ CAD.

	Without cost of waiting			With cost of waiting		
	Static NPV	eNPV	Option value	Static NPV	eNPV	Option value
DCF	2.07	–	–	–	–	–
Option to expand	-23.1	11	34.1	-23.1	8.41	31.5
Option to defer	2.07	5.63	3.56	2.07	4.19	2.12

Note: eNPV=expanded net present value

anytime within the next five years. The expanded NPV for the option to defer is approximately $5.63 million (see Table 4). This suggests that the strategic value of being able to defer investment to wait until information becomes available and uncertainties become resolved is worth $3.63 million. This is the expected value of perfect information. Thus, assuming market research can be used to obtain credible information to decide if the project is a viable one, the maximum the firm should be willing to spend for this information is $3.63 million. If the cost to obtain credible information exceeds $3.63 million, then it is optimal to take the risk and execute the project immediately for $8.67 million.

In addition, the cost related to waiting is reflected in the option value analysis. When the cost of waiting (perhaps due to loss in market share) increases, it is better not to defer; the higher the cost of waiting or the cost of obtaining valuable information, the lower the strategic value of option to defer. For example, at a 5% annual cost of waiting, the expanded NPV declines from $5.63 million to $4.19 million. This result suggests that the optimal timing under uncertainty and competition involves a trade-off between flexibility value and strategic value of early commitment. Flexibility value reflects the ability to wait to invest under uncertain condition until valuable information is obtained, whereas the strategic value signals a credible commitment that can influence competitors' investment decisions (Smit & Trigeorgis, 2004).

Once the project is undertaken, management may have the option to expand the scale of production by incurring a follow-up investment outlay, provided SBP prices and general market conditions turn out better than initially expected. Growth options are particularly valuable in an emerging industry—such as biotechnology—where there may be a very significant upside in the future demand, but at the same time there is a considerable technological risk and uncertainty. The market for SBP seems attractive, but is as yet untested.

In the SBP case, in the first year, management can choose either to maintain the initial scale of production at no additional cost or expand by fourfold the scale of production by incurring the extra cost of expansion. From the binomial option pricing model, the option to expand is calculated to be $34.1 million and the expanded NPV with this option is $11million (see Table 4). This is intuitive because if the underlying asset value of pursuing the existing business operation is high based on the current market situation (demand and supply), then it is wise to expand the project's current level of operation.

The cost of expansion, the expansion factor, volatility, underlying asset value and other parameters can change over time as business conditions change. Figures 1 and 2 illustrate the sensitivity of option values to changes in the gross project value and volatility. With other factors held constant, the expanded NPV increases with: (a) increases in the gross value of the underlying project, (b) increases in the volatility of the project, and (c) decreases in the investment (expansion) cost.

Concluding Remarks

Developments in bioscience and biotechnology have resulted in the introduction of a new and environmentally friendly use for soybean costs in areas such as bioremediation, bioinformatics, diagnostics, therapeutics, water waste management, coal tar processing, metal casting, and many others. The literature on peroxidase extraction from soybean is quite extensive, but few studies offer estimates of a large-scale commercial feasibility of soybean peroxidase. The purpose of the study was to examine the prospects for the commercialization of soybeans peroxidase from soybean hulls and to model uncertainty and strategic flexibility in biotechnology management and investment. Investment in biotechnology carries a certain degree of technological and market risks. Real-options pricing techniques can help assess the value investors place on agricultural biotechnology firms. The valuation of the firm is derived from the expected profits of the firm's products and the potential for growth of the firm. In order to incorporate uncertainty surrounding the valuation of biotechnology commercialization, real-option analysis was conducted. Given the assumptions on the parameters of the dis-

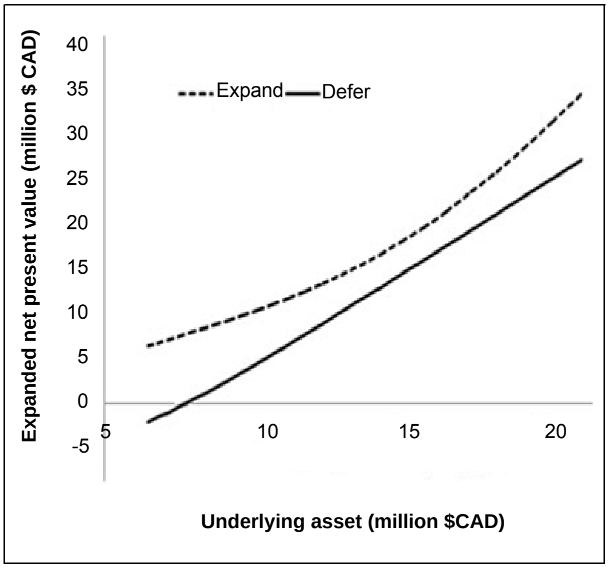

Figure 1. Sensitivity analysis of the effect of changes in value of the underlying on the expanded NPV for option to delay and to expand.

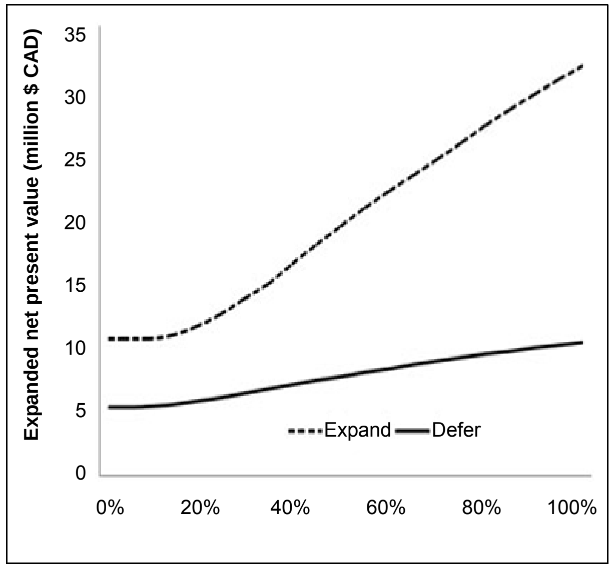

Figure 2. Effects of changes in volatility on expanded NPV for option to delay and expand.

counted cash flow technique and real option model, both the DCF and real option analysis suggest that investment in an SBP extraction facility is profitable. If market conditions change in an unfavorable way, the investor can use the option to wait and invest later. Under a highly uncertain business environment, having an option and sometimes keeping this option open are valuable. Note, however, that the optimal investment timing under uncertainty and competition often involves a trade-off between the wait-and-see flexibility value and the strategic value of early commitment.

The real-option approach and results are of interest to agribusiness investors because they provide a means to value agricultural biotechnology companies that have no current revenue. Agricultural product producer groups or associations can use the real-options approach to value value-added projects and compare their relative worth for capital budgeting purposes. For academics, this is an interesting case study that provides empirical evidence of the usefulness of real options valuation methodologies. Finally, this study has an academic contribution by proving that the major element having impact on feasibility and commercialization of biotechnology is still associated with capital investment costs, as other studies have suggested (Degiorgis et al., 2007).

In addition to the elements of the capital budgeting analysis, other factors that may influence the value of investment in agricultural biotechnology processing are potential market size and competitors' reactions and genetic improvements. A closer examination of the capital budgeting model indicates that a firm's expected value is dependent upon the degree of competition in the peroxidase market. One important question to ask is: for a given peroxidase industry market size, what is the rate at which soybean peroxidase sales would grow given the competitors' actions? The actual success investment in soybean peroxidase is dependent upon the growth in the size of the market in which it operates and the actions and reactions of processors of substitute products (e.g., horseradish peroxidase). Thus, it may not always be advisable to follow a flexible wait-and-see strategy from a competitive perspective (Smit & Trigeorgis, 2004). When soybean peroxidase investment is contingent on competitors' moves, a more rigorous game-theoretic treatment of capital budgeting may be necessary.

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