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Valuing Genetically Modified Traits in Canola Using Real Options

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This study specifies a framework to evaluate an investment strategy combining a market assessment with a valuation method using a stochastic binomial real option model. The market assessment uses multi-criteria analysis to determine which markets should be targeted for commercialization of a genetically modified trait in a target crop. The stochastic binomial real option model is developed to determine whether commercialization is financially viable. The framework was applied to canola being developed using gene technology to increase its drought tolerance. Our results showed that drought-tolerant canola would be more profitable than conventional varieties, but it would only be sufficiently profitable to pursue commercialization in targeted regions or countries.

Key words: canola, commercialization, drought tolerance, investment valuation, real options analysis

Introduction

Developing new genetically modified (GM) crops and traits involves long timelines, multiple project phases, numerous risks, and high investment costs. Firms developing new traits face a complex development and commercialization process that requires strategic investment decisions. Phillips McDougall (2011) estimated that, on average, the discovery, development, and regulatory approval of a new GM crop trait requires approximately US$136 million and 11.7 years. A case study on Monsanto reported that a new GM crop has a 5% probability of success in the discovery stage, which then increases to 90% by the regulatory stage (Bell and Shelman, 2006).

This paper develops a framework to evaluate an investment strategy that could guide the firm's decision at the outset of developing a new trait; given a trait already partially developed, the framework could also guide decisions at successive stages whether to continue, postpone, or abandon trait development. The framework is applied to a genetically modified trait for drought tolerance in canola.

The investment strategy under evaluation answers two distinct but sequential questions. First, for crops that are traded globally, it is necessary to target multiple markets when commercializing a new GM trait. But which multinational markets should be targeted? To answer this question, we develop a market assessment using a multi-criteria analysis of various countries that accounts for agronomic characteristics, regulatory regimes, and market environments. Although firms traditionally seek global approvals for frequently traded crops and traits, it is more strategic and economical to pursue

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targeted strategies for specialized traits such as drought tolerance. This is particularly the case when a trait's value and profitability differ across markets. It is also important to identify target countries while a new GM trait is still being developed because this process defines the market size, investment, regulatory environment, and entry strategies required. Given the many factors considered by a firm when determining which markets to target, a multi-criteria analysis consolidates information from various sources and expressed in different measurements. This information can then be assessed and, in this case, target countries can be ranked based on a set of *a priori* criteria.

Second, is commercialization of a new GM trait worth pursuing in the target markets identified? To answer this question, we develop a valuation method based on a stochastic binomial real option model to value traits at each stage of the development process. The model analyzes historical data of critical exogenous variables (such as weather, conventional yields, and farm budgets) to generate distributions and estimates endogenous trait and investment values across the initial and subsequent development stages. Sensitivity analyses are used to measure how sensitive investment metrics are to the model's key assumptions and identify several assumptions that have the largest impact on investment values. The study also includes scenario analyses to compare the profitability of various market entry strategies.

Real Options and Related Literature

Compared to other valuation methods such as the discounted cash flow method, real options provides a more appropriate valuation of high-risk investments (Amram and Kulatilaka, 1999; Guthrie, 2009; Trigeorgis, 1996) and supports firms targeting opportunities to redeploy, delay, modify, or even abandon capital-intensive investments (Amram and Kulatilaka, 1999). Use of real options to value investment in research and development (R&D) is well documented in the literature (Jensen and Warren, 2001; Meng, 2008; Morris, Teisberg, and Kolbe, 1991; Seppä and Laamanen, 2001; Turvey, 2001; Whalley, 2011), including in agriculture (Ehmke et al., 2004; Feil, Mußhoff, and Balmann, 2013; Hertzler et al., 2013; Nadolnyak, Miranda, and Sheldon, 2011; Odening, Mußhoff, and Balmann, 2005; Tozer, 2009; Tozer and Stokes, 2009).

Two earlier studies applying real options to value GM wheat (Carter, Berwald, and Loyns, 2005; Furtan, Gray, and Holzman, 2003) analyzed government decisions about commercialization rather than investment during trait development. They used continuous real options analysis, ignoring the underlying risks. In contrast, this study analyzes private investment decisions during the trait development process and captures impacts of risky variables using a stochastic binomial real option model to account for the randomness of many of the variables and the discrete nature of the successive development stages. More recent studies of real options to value GM drought-tolerant wheat (Wilson, Shakya, and Dahl, 2015) and corn (Shakya, Wilson, and Dahl, 2013) provide a basis to estimate the ex ante value of a new trait.

This study makes several contributions to the evolving literature on valuing new crop technologies. Our study is novel in using real options to value the global commercialization of a GM trait, using multi-criteria analysis to identify target markets, using multi-peril crop insurance to estimate the value of a new GM trait, and scenario testing to evaluate various market entry strategies. Rainfall and yield data (instead of drought indices) are used specifically to analyze probability of drought for the Australian modeling. It also documents a market assessment for the global commercialization of a GM trait and considers issues related to heterogeneous characteristics of individual markets and the process of deregulation. Finally, it provides quantitative evidence, at least for canola, of why it is not sufficiently economically attractive for biotechnology companies to pursue commercialization in all regions, as has been traditional.

Investment Strategy Design

The framework developed in this paper is applied to a GM canola trait for drought tolerance being developed by Agriculture Victoria, a government-funded organization in Australia. This trait is particularly relevant for major canola-producing countries—such as the United States and Canada—as they seek to "sustainably and profitably increase canola production…to meet global demand" while "outsmarting uncommon weather" (Canola Council of Canada, 2014). A private biotechnology company has partnered with Agriculture Victoria and provided investment to continue trait development for potential global commercialization. The two groups jointly decide when and how to continue their investment; in this study we refer to them collectively as the "firm."

Market Assessment and Multi-Criteria Analysis

The market assessment determines which multinational markets should be targeted for commercialization using multi-criteria analysis of various countries, their regulatory regimes, and market environments. Multi-criteria analysis can assess large amounts of complex information using a single methodology and helps decision-makers choose from among alternative options. An explicit set of three performance criteria is developed using input from discussions with industry experts. Each option is scored against these criteria, with scores aggregated to establish overall performance of each option.

The first criterion requires each target country to be a good agronomic fit for the trait and considers which countries produce canola, whether the canola is produced for domestic use or export, and whether the canola-producing countries suffer from droughts that affect canola production. The second criterion evaluates the complexity of navigating the regulatory process for obtaining approval to cultivate or import GM crops. The third criterion focuses on the market environment for trait commercialization and considers how each target country ranks in intellectual property (IP) protection, quality of overall infrastructure, goods market efficiency, technological readiness, business sophistication, and innovation. These criteria are discussed in greater detail below.

Production data were used to identify the largest canola-producing countries (those countries producing approximately 1 million metric tons or more per annum) (FAOSTAT, 2014b). Trade data were used to determine the value of production and whether the canola produced was used domestically or for export (FAOSTAT, 2014a). If a country exports more than 50% of the canola it produces, their largest export markets were also identified (FAOSTAT, 2014a) and their regulatory systems and market environments assessed.

A global map of potential drought risk across land cultivated for agriculture was used to identify countries with high, medium, and low risk of drought (Pardey, Beintema, and Dehmer, 2006). The impact of drought on canola production was assessed using a number of sources (Abraham, 2009; Agrimoney.com, 2011; Burka and Ivanitskaya, 2012; Crop Science Society of America, 2009; Hlavinka et al., 2009; Hogan, 2011; U.S. Department of Agriculture, Joint Agricultural Weather Facility, 2012; Pennington, 2012; Ruitenberg, 2011; U.S. Department of Agriculture, 2012; U.S. Deparment of Agriculture, Foreign Agricultural Service, 2013), and a shortlist of canola-producing countries affected by drought was developed.

Information on the regulatory systems in each shortlisted country was collected and used to assess the process for seeking authorization for cultivating (or importing in the case of an importing country) a GM product.[1] This paper does not judge the appropriateness of regulating GM crops.,

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[1] The U.S. Department of Agriculture's country-specific Agricultural Biotechnology Annual reports were used as primary information sources for this assessment process. Vigani and Olper (2012) also provide a useful index of GM regulatory "restrictiveness" for sixty countries. An extensive review of additional literature on the regulatory systems in each shortlisted country was undertaken; however, due to their volume, these details are not included here. These references are available from the author on request.

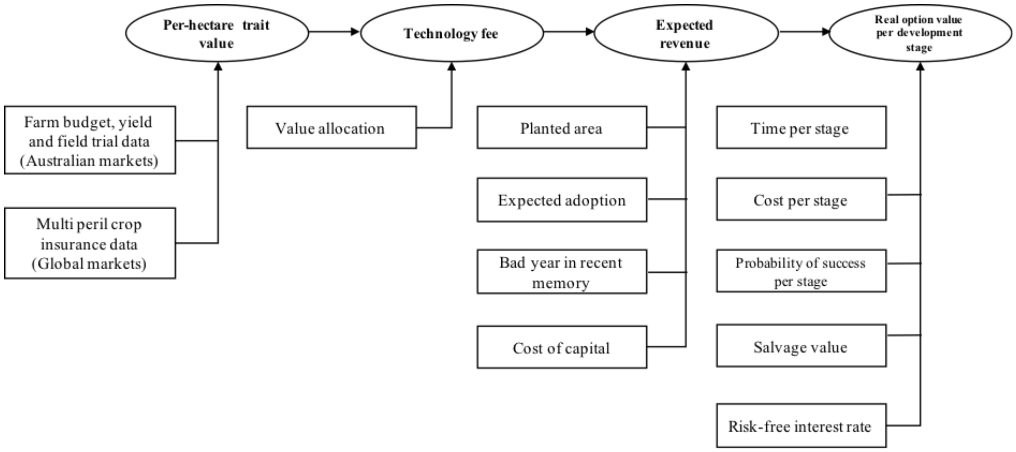

Figure 1. Calculation Process for Valuing a New GM Trait

but it does recognize that regulation adds financial cost to businesses on the basis that businesses change behavior to comply with regulation. Accordingly, countries were assessed on the complexity of navigating the regulatory process for obtaining approval for cultivating or importing GM crops. For each country, this assessment considered the legislative and regulatory frameworks for GM crop cultivation/importation; whether there was a legislative ban on cultivation/importation; whether the government had publicly announced support for or opposition to GM cultivation/importation; the extent of GM research undertaken in the country (indicated by the number of organizations or programs, or number of crops and traits); the number of field trials in recent years; the number of commercial releases in recent years; and requirements and timing of regulatory approval process for GM cultivation/importation

Indicators of the market environment developed for use in the World Economic Forum's Global Competitiveness Report (Schwab, 2013) were used to assess whether the commercialization of a new GM trait would be welcomed and supported by the market.[2] A selection of indicators was chosen as being particularly applicable to the market entry of GM products, including IP protection, quality of infrastructure, goods market efficiency, technological readiness, business sophistication, and innovation.

A multi-criteria analysis of the agronomic fit, regulatory system, and market environment data was used to rank each country in terms of suggested timing for market entry. Countries with poor results in the multi-criteria analysis were excluded for commercialization and from the remaining analysis and modeling. Six countries with promising results were selected for potential commercialization.

Valuation Method and Stochastic Binomial Real Option Model

The valuation method is based on a stochastic binomial real option model and determines whether commercialization of a new GM trait is worth pursuing. The model analyzes historical data, forecasts potential future scenarios, and estimates investment values across development stages.

Figure 1 illustrates the four-step calculation process for valuing a new GM trait, including how much farmers would pay for the new GM trait (value); how much the firm can charge for the new GM trait (technology fee); how much revenue the firm could earn from the new GM trait (expected revenue); and what the firm's option to invest in each stage is worth (real option value per

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[2] The Global Competitiveness Report ranks countries' competitiveness based on statistical data from the International Monetary Fund; the United Nations Educational, Scientific, and Cultural Organization; and the World Health Organization as well as a survey of 14,000 business leaders in 140 economies.

development stage). The figure also demonstrates how earlier components were used as inputs into the calculation of later components.

Per Hectare Trait Value in Australia

The value of the new GM trait is the amount a farmer would pay for it. We calculate this value using certainty equivalents and risk premiums. Here, the certainty equivalent is the amount required for a farmer to be indifferent between the returns for cropping with the new GM trait and a riskless alternative and depends on the decision-maker's attitude toward risk. The risk premium is the additional certainty equivalent required for the farmer to be indifferent between cropping with the new GM trait and a base strategy (here a conventional variety without the GM trait). The risk premium is then used to calculate the technology fee and the firm's potential revenue from the new trait.

For Australia, certainty equivalents and risk premiums were calculated using historical farm budget data, yield for conventional canola, rainfall, and field trial data. As farmers' attitudes toward risk are uncertain, stochastic efficiency with respect to a function (SERF) was used to estimate the certainty equivalents by analyzing the expected returns and ranking each across a range of attitudes toward risk (Hardaker et al., 2004; Hardaker and Lien, 2010).

Expected returns were calculated as the income less variable costs incurred and, as future expected returns are uncertain, the model uses @Risk (Palisade Corporation, 2013) to fit distributions to historical farm budget data (Australian Bureau of Agricultural and Resource Economics and Sciences, 2013). It was assumed that productivity gains would match any increases in inflation and that returns per hectare would not change significantly over the lifecycle of the trait. Future yields for conventional canola are also uncertain; the model uses a triangular distribution based on historical data (Australian Bureau of Agricultural and Resource Economics and Sciences, 2013) and assumes a 0.5% per annum yield gain.

Results from Australian field trials conducted in the winter of 2011 (Kant et al., 2015) were used to define the yield advantage achieved by the GM drought-tolerant canola relative to non-GM canola. The drought-tolerant GM canola uses delayed leaf senescence technology called "LXR®," which modifies levels of plant hormones (cytokinin) that influence growth and development and inhibit leaf aging (senescence) and stress responses in plants.

The canola field trials occurred in Horsham, Victoria (rainfed and irrigated), and in Hamilton, Victoria (rainfed). These sites represent different soil and climatic conditions. The yields achieved were analyzed across GM and non-GM canola, across trial sites, and against the yield of other canola grown locally in that season. The rainfall (or irrigation) received during the season was also analyzed against rainfall averages for each region. Results of the field trials indicated that GM canola had a 25% yield advantage over conventional canola when rainfall is more than 30% below average; a 20% yield advantage when rainfall is 0–30% below average; and a 15% yield advantage when rainfall is above average.

Rainfall data from the Bureau of Meteorology Climate Data online database (Australian Bureau of Meteorology, 2013) were used to analyze the occurrence and timing of rainfall and its impact on canola yield. Seasonal rainfall data were analyzed against canola yield data spatially (using weather stations representative of each Natural Resource Management region in each relevant Australian state) and temporally (annually and monthly across a growing season). Statistically significant correlations between rainfall and canola yield were included in the model.

Correlations between historical costs of crop and pasture chemicals; fertilizer; fuel, oil and grease; repairs and maintenance; and seed as well as yield and the price received by farmers were analyzed and statistically significant correlations (at a 95% confidence level) were included in the model. It was also conservatively assumed that the GM canola would be sold at a 5% discount compared to conventional canola based on current discounting practices in Australia (Australian Wheat Board, 2014).

Expected returns were derived and simulated 10,000 times for each relevant Australian state and for canola with and without the GM trait (where the presence of the trait increases canola yield and thus income and expected returns). For each region, the simulated returns were evaluated using Simetar (Richardson, Schumann, and Feldman, 2005) and the second method outlined in McCarl and Bessler (1989) across a scale of absolute risk aversion coefficients (ARACs) ranging from risk neutral to extremely risk averse. We used ARACs because the modeling focuses on ranking risky alternatives for annual returns (which can be positive or negative) and the ARAC is the only measure able to accommodate these positive and negative scenarios. We took a triangular distribution of the slightly, moderately, and very risk averse levels as the base case for trait value in each Australian region and then averaged these regional risk values to estimate an Australia-wide risk value for the new GM trait.

Per Hectare Trait Value in Target Countries

In absence of equivalent data for the other target countries, we developed an alternative method to determine the trait value in each country. Multi-peril crop insurance was identified as a substitute product to drought-tolerant crops as it similarly protects farmers from yield and profit loss caused by drought. Although only recently available in Australia, multi-peril crop insurance has been available in other target countries for years and provides a reasonable proxy of the value a farmer may pay for a drought-tolerant crop. This alternative method is the only way to calculate the value of the new GM trait across countries.

Data on conventional canola yields were collected in each country (FAOSTAT, 2014c). Data on premium rates (as a percentage of insured value) or average premiums (in US$ per hectare) paid by farmers for multi-peril insurance (covering canola where possible, otherwise crops) against yield loss caused by drought were also collected for each country (see table 1). In addition, data on the amounts paid by governments to subsidize multi-peril crop insurance were collected for each country (see table 1) in order to ensure that the estimate accurately represented the amount paid by farmers rather than the higher amount required for the insurance companies to commercially provide the insurance. Finally, a flat rate of US$500 per metric ton was assumed as the global market price (or insured value) for canola.

We assumed that 75% of historical yield would be covered by the multi-peril crop insurance in all countries and that this roughly represents the yield advantage provided by the drought-tolerant canola trialed in Australia. This assumption is based on analysis of the field trial results and the last twenty years of rainfall and conventional yield data in the region in which the field trials were conducted (Australian Bureau of Agricultural and Resource Economics and Sciences, 2013; Australian Bureau of Meteorology, 2013).

As future insurance premiums are uncertain, the model uses a triangular distribution, including the estimated insurance premiums as the most likely future premium and 20% above and below as the minimum and maximum future premium. The insurance premiums were estimated on a per hectare basis to compare with the Australian value of the new GM trait. Both estimates were then used as inputs into the calculation of the technology fee, which, like seeds, is priced per unit (hectare or kilogram).

Technology Fee

The technology fee, which reflects the amount that the firm charges farmers for the new GM trait, is calculated by allocating the trait value between the farmer and firm. Farmers receive a share of the benefit through a lower-than-otherwise seed price to incentivize them to adopt the technology over existing technologies (as established by Grilliches, 1957). Firms use their share to recover R&D costs while competing with other varieties. Public information suggests that biotechnology companies price their GM seeds to share the benefit of increased yields with farmers on a 30/70 basis (Bunge, 2016; Demont et al., 2007; Kukutai, 2016; Price et al., 2003); this allocation is used in the model.

Expected Revenue

The firm's expected revenue is the potential return that it would earn if the trait is successfully commercialized. It is calculated by multiplying the technology fee by the number of hectares expected to be planted in each target country with the new trait and also involves analyzing adoption patterns for the new trait and the applying a weighted average cost of capital (WACC) adjusted for risk.

As future plantings are uncertain, the model uses a triangular distribution for planted hectares in each of the target countries, the values of which were subjectively determined using historical data on planted hectares (FAOSTAT, 2014b). This is a conservative estimate of hectares to be planted over the trait's lifetime; the model does not account for potential expansion into marginal cropping areas. Canola hectares are currently limited, particularly in North America, where it is impossible to grow in marginal cropping areas prone to drought. However, there is likely considerable scope for a drought-tolerant canola, such as the new GM trait examined in this study, to expand into marginal growing areas as has been predicted for *Brassica juncea* that tolerates drier and hotter conditions (McCaffery, Banbach, and Haskins, 2009). Future adoption rates are uncertain and were determined subjectively using data on adoption rates for GM varieties (James, 2008; Shakya, Wilson, and Dahl, 2013; Wilson, Shakya, and Dahl, 2015) as well as industry trends and modeled using a triangular distribution.

The model assumes a WACC of 10% to reflect the risk profile of a trait that has been successfully commercialized. Public and private firms may use different WACCs because their opportunity costs of capital may differ, a public firm tending to apply a lower WACC than a private firm. As the project in this study is being undertaken by a publicly funded organization using private investment, the WACC applied seeks to balance both public and private interests. Alternative WACC rates were also tested in the sensitivity analysis.

Real Option Value per Stage of Development

Expected revenue is the firm's potential reward if the investment continues successfully to commercialization. Prior to regulatory submission, a binomial option tree (shown in figure 2) represents the investment choices available to the firm at each development stage. Investing in the project buys the option to continue to the next stage of development, wait, or abandon the project.

This binomial model uses discrete event simulation, in which variables change at discrete points in time, to derive real option values at each stage of the trait development process. This model is appropriate for complex investments with multiple sources of risk and uncertainty, and many of our distributions were non-normal.

The real option value indicates the financial merit of each of the choices available to the firm at each development stage. The option's value is estimated for each stage; if expected cash flows at an early development stage are positive, the option is worth pursuing. The firm may wait or abandon the project if expected cash flows are negative.

Summation of the expected revenue over fifteen years of commercialization (the actual fifteen-year period varies across countries) was used to calculate values at each development phase in the binomial option tree using backward induction. The model uses estimates of investment time, costs, and salvage values along the development and investment process, including estimates for the "LXR®" technology currently being developed well as other studies (Bell and Shelman, 2006; Phillips McDougall, 2011; Shakya, Wilson, and Dahl, 2013; Wilson, Shakya, and Dahl, 2015). The investment time and cost variables are treated as random, with probability distributions, while the salvage value is treated as nonrandom; this treatment is detailed in tables 1 and 2. The cost estimates

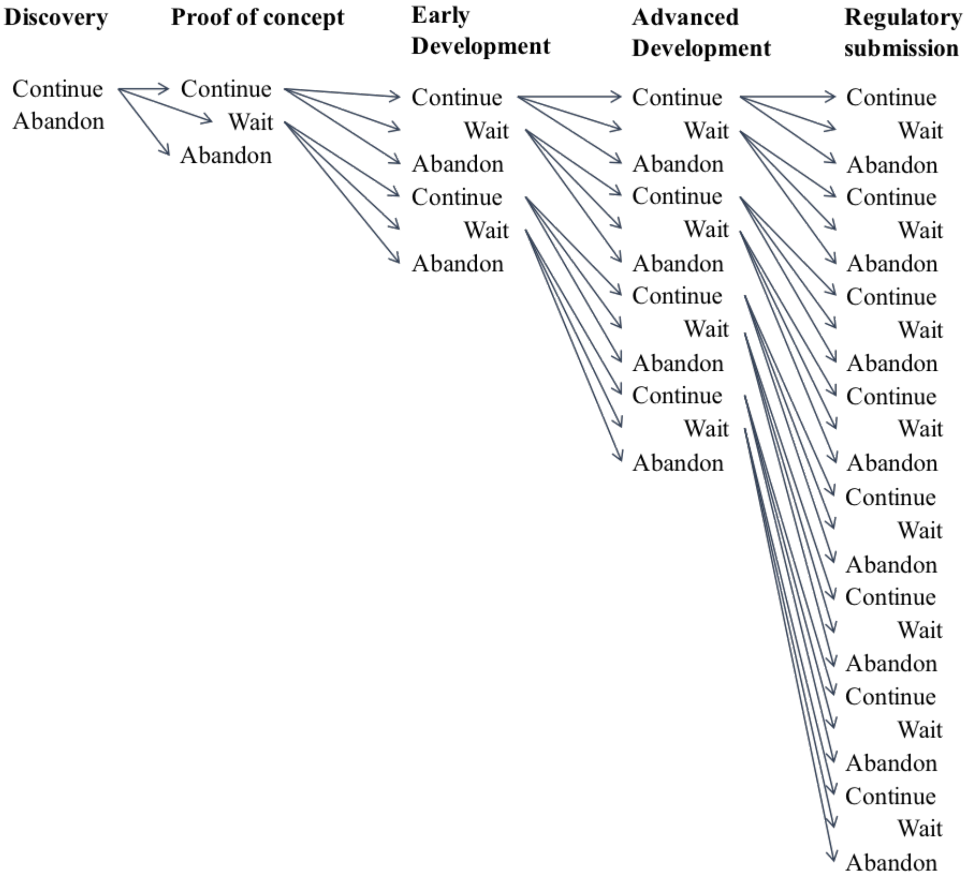

Figure 2. Option Tree for R&D Process

are likely to be low at the regulatory stage as they assume cultivation approval for only 1–2 countries and import approval for 5–7 countries. Higher cost estimates are tested in the sensitivity analysis. Each phase has a probability that the technology will successfully proceed to the next phase; these nonrandom probabilities have been estimated based on previous research (Bell and Shelman, 2006; Phillips McDougall, 2011; Shakya, Wilson, and Dahl, 2013; Wilson, Shakya, and Dahl, 2015) and converted into risk-neutral probabilities by setting the risk-free rate of interest as equal to the rate of the United States generic government ten-year yield (Bloomberg, 2014).

At each stage, the value of the firm's option to continue the investment is calculated as

$$(1) \qquad [Prob(V_{cn}) + (1 - Prob)V_{sn}](1/1 + r^{c}) - V_{ic},$$

where r is the risk-free interest rate, c refers to the number of years at the current stage, $Prob$ is the risk-neutral probability at the current stage, V_{cn} is the value to continue at the next stage, V_{sn} is the salvage value at the next stage, and V_{ic} is the cost of investment at the current stage.

The value of the firm's option to wait is calculated as

$$(2) \qquad [Prob(V_{cnw}) + (1 - Prob)V_{snw}](1/1 + r^{w+c}) - V_{icw},$$

where w refers to the number of years already waited, V_{cnw} is the value to continue at the stage following the period of waiting, V_{snw} is the salvage value at the stage following the period of waiting, and V_{icw} is the cost of investment at the stage following the period of waiting.

Table 1. Data Sources and Distributions for Nonrandom Variables

Variables Used in the Model (Units)	Source	Distribution Parameters or Assumption
Yield (metric tons per hectare, 2004–13)	FAOSTAT (2014c)	CAN 1.8, USA 1.6, CHN 1.9, IND 1.1, UKR 1.8, CZE 3.1, RUS 1.2, AUS 1.1, FRA 3.3, GER 3.8, POL 2.7
Yield coverage provided by insurance and/or yield advantage provided by GM drought tolerant canola (percentage of historical yield)	Assumption	75%
Insured value (US$ per metric ton)	Assumption	500
Premium rate (percentage of insured value)	Various[a]	CAN 9.5%, USA 9.1%, CHN 5.1%, IND 3.5%, UKR 6%, CZE 1.8%, RUS 6.6%, FRA 1.7%, GER 1.2%, POL 6%
Government subsidy (percentage of premium)	Various[b]	CAN 60%, USA 61%, CHN 60%, IND 6%, UKR 50%, CZE 30%, RUS 50%, FRA 35%, GER 0%, POL 50%.
Farmers' share of value (percentage of trait value retained by farmers)	Bunge (2016); Demont et al. (2007); Kukutai (2016); Price et al. (2003)	70%
Weighted Average Cost of Capital (WACC) discount rate	Assumption	10%
Scheduled year of market entry	Assumption	CAN 2023, USA 2023, CHN 2025, IND 2025, CZE 2025, AUS 2021
Probability of success at each development stage (single period probability)	Bell and Shelman (2006); Phillips McDougall (2011); Shakya, Wilson, and Dahl (2013); Wilson, Shakya, and Dahl (2015)	Discovery stage: 20%, Proof of concept stage: 50%, Early development stage: 67%, Advanced development stage: 83%, Regulatory submission stage: 90%
Salvage value (percentage of investment value)	Assumption	40% of the cumulative value of the investment at each stage
Risk free government bond rate	Bloomberg (2014)	2.5%

Notes: [a] Agricorp (2014); Bielza Diaz-Caneja et al. (2008); IFC Agri-Insurance Development Project (2011); Kaczała and Łyskawa (2013); Mahul and Stutley (2010); Mahul and Verma (2011); World Bank (2007).

[b] Bielza Diaz-Caneja et al. (2008); Klak and Jacobson (2013); Mahul and Stutley (2010); Mahul and Verma (2011); Rain and Hail Insurance Society (2013); World Bank (2007).

Table 2. Data Sources and Distributions for Random Variables

Variables Used in the Model (Units)	Source	Distribution Parameters or Assumption
Trait value for Australia (US$ per hectare)	Australian Bureau of Agricultural and Resource Economics and Sciences (2013), Australian Bureau of Meteorology (2013), Kant et al. (2015), and assumptions	See discussion in section entitled "Valuation method and stochastic binomial real option model."
Trait value for other countries (US$ per hectare)	See table 1, notes a and b, for sources of individual components	Triangular distribution used. The most likely value is the product of yield, yield coverage, insured value, premium rate and (1-government subsidy). The minimum value is 80% and the maximum value is 120% of the most likely value.
Hectares planted to canola (hectares in 2013)	FAOSTAT (2014b)	Triangular distribution used. The most likely value is CAN 8,007,000, USA 685,000, CHN 7,500,000, IND 6,340,000, UKR 996,090, CZE 418,800, RUS 1,119,737, AUS 3,271,649, FRA 1,437,736, GER 1,465,600, POL 920,705. The minimum value is 80% and the maximum value is 120% of the most likely value.
Adoption (percentage of planted hectares)	James (2008); Shakya, Wilson, and Dahl (2013); Wilson, Shakya, and Dahl (2015); Kuehne et al. (2011)	Triangular distribution used. The most likely value changes each year over the 15-year lifecycle of the technology from 10% in 2021, up to 70% in 2027 and back to 37% in 2035. The minimum value is 80% and the maximum value is 120% of the most likely value.
Investment duration (time in years)	Bell and Shelman (2006), Phillips McDougall (2011)	Uniform distribution used. Discovery stage: 3-4.5 years, Proof of concept stage: 2-2.3 years, Early development stage: 2-2.5 years, Advanced development stage: 2-3.1 years, Regulatory submission stage: 2-7.17 years.
Investment cost (US$)	G. Spangenberg, (personal communication, 2013), Bell and Shelman (2006), Phillips McDougall (2011), assumptions	Triangular distribution used. Discovery stage: 150,000, 3,500,000, 31,000,000; Proof of concept stage: 250,000, 7,500,000, 28,300,000. Uniform distribution used. Early development stage: 12,500,000, 13,600,000; Advanced development stage: 22,500,000, 28,000,000; Regulatory submission stage: 30,000,000, 35,100,000.

Table 3. Results from Market Assessment and Multi-Criteria Analysis

	Criterion 1: Agronomic Fit				Criterion 2: Regulatory Systems	Criterion 3: Market Environment	Overall Result
Country	**Production Size (million metric tons)**	**Percentage of Production Exported**	**Drought Risk (low, medium, high)**	**Evidence that Drought Impacts Canola Production**	**Ease of Navigating Regulatory System (very low, low, medium, high)**	**Market Support for GM Trait Commercialization (score out of 7)**	**Include or Exclude from List of Target Markets**
Canada	18	56	High	Yes	High	5.2	Include
China	14	0	Low	Yes	Medium	4.1	Include
India	8	0	Medium	Yes	Low	3.8	Include
Germany	6	6	Low	Yes	Very low	5.6	Exclude
France	4	31	Medium	Yes	Very low	5.3	Exclude
Australia	4	66	High	Yes	High	5.0	Include
Poland	3	7	Medium	Yes	Very low	4.0	Exclude
Ukraine	2	70	High	Yes	Very low	3.4	Exclude
United Kingdom	2	24	Low	No	Very low	5.6	Exclude
Czech Republic	1	16	Low	Yes	Low	4.1	Include
Russia	1	4	High	Yes	Very low	3.7	Exclude
United States	1	27	High	Yes	High	5.4	Include

Table 4. Trait Values and Technology Fees (US$ per Hectare)

Country	Trait Value (per hectare)	Technology Fee (per hectare)
Canada	$26.20	$7.86
United States	$21.83	$6.55
China	$14.15	$4.25
India	$13.94	$4.18
Czech Republic	$14.41	$4.32
Australia[a]	$32.17	$9.65

Notes: [a] Australia's trait value was converted to US$ using an exchange rate of US$1 = AU$0.70.

The option to abandon the investment is also available to the firm at each stage, and the value of abandoning is the salvage value for that stage. Tables 1 and 2 provide summaries of data sources and assumptions used in the model, including nonrandom and random variables.

Results

Market Assessment and Multi-Criteria Analysis

As shown in table 3, there are multinational expansion opportunities for canola that has been genetically modified to increase its tolerance to drought. Most of these countries produce canola for domestic use. Three countries— Canada, Australia, and Ukraine—produce canola for export. The regulatory systems and market environment for the import markets in these three countries were also analyzed. Countries with a high risk of drought include Canada, Australia, Ukraine, Russia, and the United States. Drought was found to impact canola production in all countries except the United Kingdom.

The regulatory systems and market environments for trait commercialization differ considerably among canola-producing countries. The regulatory systems in Canada, Australia, and the United States are considered to be relatively easy to navigate. Countries with the most supportive market environments for trait commercialization include Canada, Germany, France, Australia, the United Kingdom, and United States.

Based on the multi-criteria analysis, six large canola-producing countries were identified as having an appropriate combination of agronomic fit, ease of navigation in the regulatory system, and market environment for trait commercialization and were scheduled for potential commercialization. Ranked by their score in the multi-criteria analysis and order of proposed market entry, these countries are Australia, Canada, the United States, China, Czech Republic and India. The technology is tentatively planned for Australian commercialization in 2021 (G. Spangenberg, personal communication, 2015). This study assumes the technology is commercialized in Canada and the United States in 2023 and in other countries in 2025. Six large canola-producing countries (France, Germany, the United Kingdom, Poland, Ukraine, and Russia) were excluded for commercialization because of lack of agronomic fit and/or lack of regulatory ease for trait commercialization.

Valuation Method and Stochastic Binomial Real Option Model

As shown in table 4, the average premium charged for multi-peril crop insurance covering yield loss caused by drought (and thus the expected value of the new GM trait) ranges from US$13.94 per hectare in India to US$26.20 per hectare in Canada. The value of the new trait for Australia, estimated using farm budget and field trial data, was US$32.17 per hectare. The Australian value is relatively close to the value estimated for the other countries, particular Canada, even though these

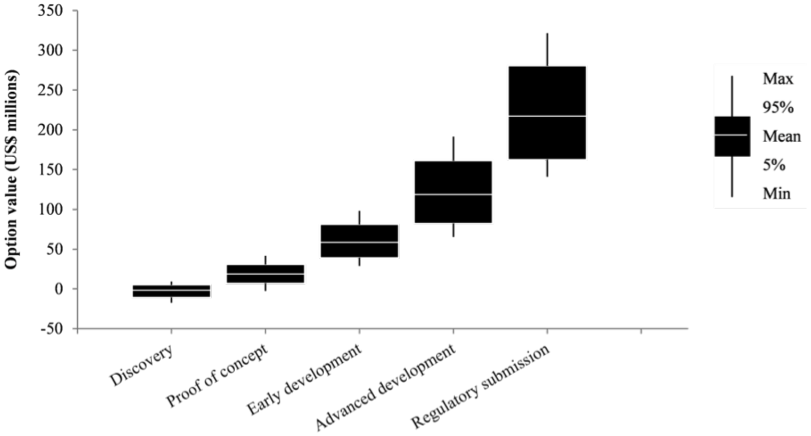

Figure 3. Real Option Values for Drought-Tolerant Canola across Development Stages

estimates were derived using different methodologies. The technology fee varies from US$4.18 per hectare in India to US$9.65 per hectare in Australia.

The premiums estimated for multi-peril crop insurance do not account for excess amounts or the effect of competition. Excess amounts are typically calculated as a proportion of a claim, and it would be difficult to make assumptions about the frequency and size of claims to then estimate the excess amounts for each country. If excess were included in the model, the insurance premiums and thus trait value would be slightly higher. Furthermore, as discussed earlier, a new drought-tolerant GM crop can be seen as a substitute or competitor product to multi-peril crop insurance. To compete with multi-peril crop insurance, the firm commercializing the drought-tolerant canola may want to price its canola competitively. If we included competition in the model, the trait value would be slightly lower. Thus, for the purpose of this model, the excess amount and competition effects are assumed to balance each other.

Figure 3 illustrates the real option values if the firm continues its investment in drought-tolerant canola across the development stages. The whisker plot in figure 3 shows that the mean option value is positive for all stages of development except discovery and that the range of option values widens in the later stages as uncertainty increases. At the discovery stage, there is a 58% probability that the option value will be negative and the mean option value is –US$2 million. By the regulatory stage, the mean option value is US$217 million.

As anticipated, the option value is increasingly positive at successive development stages. The mean option values are positive after the initial discovery stage. These results have strategic implications for the firm. Based on these results, if the firm had not yet started the project, the negative option value in the discovery stage may discourage the firm from investing, particularly if the firm is a for-profit private company. In this study, the development of the new GM trait was started by a government-funded organization that may view the discovery stage as providing important preliminary research with public good elements before commercial-quality events are identified. Such a public organization may consider the project worth investing in despite the small initial negative option value. If the firm was part-way through the project, as is the case in this study, results indicate that the optimal decision for the firm (regardless of whether it is public or private) is to continue the investment and not wait or abandon it.

Scenario Testing and Sensitivity Analysis

Scenario testing was conducted on the countries included for commercialization, which are inputs into the expected revenue calculation; a change to these would increase or decrease the expected

Table 5. Countries Included for Commercialization under Scenario Testing

Scenario	Countries Included
Base case	CAN, USA, CHN, IND, CZE, AUS
Scenario 1 – excluding China and India	CAN, USA, CZE, AUS
Scenario 2 –Canada and United States only	CAN, USA
Scenario 3 – including Ukraine and Russia	CAN, USA, CHN, IND, UKR, CZE, RUS, AUS
Scenario 4 – including France, Germany and Poland	CAN, USA, CHN, IND, CZE, AUS, FRA, GER, POL

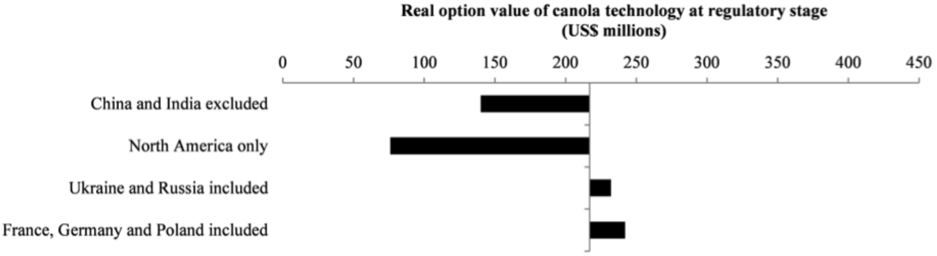

Figure 4. Results of Scenario Testing on Countries Included for Commercialization

revenue to be earned from the technology and the real option value for the firm at the regulatory stage. Sensitivity analysis was also conducted on other assumptions used in the model.

Scenario Testing on Countries Included for Commercialization

Table 5 outlines the scenarios considered and figure 4 shows how the base case real option value would change under each scenario. If China and India were excluded for commercialization, the real option value at the regulatory stage would decrease from US$217 million to US$140 million. If only Canada and the United States (North America) were included for commercialization, the real option value at the regulatory stage would decrease from US$217 million to US$76 million, suggesting that the technology could still be profitable even if it were only commercialized in North America.

If the currently excluded countries of Ukraine and Russia were included for commercialization, the real option at the regulatory stage would increase from US$217 million to US$232 million. If France, Germany, and Poland were included, the real option value at the regulatory stage would increase from US$217 million to US$242 million, suggesting that including these markets would not have a big impact on the overall option value, even if the regulatory regimes in these countries become less restrictive for GM food over the next 15–20 years. This also provides quantitative evidence, at least for canola, for why it is not sufficiently economically attractive for biotechnology companies to pursue commercialization, particularly to warrant navigating the difficult regulatory process, in Europe. Canada, China, and India are the largest markets for the commercialization of drought-tolerant canola, and so their inclusion in the modeling drives the real option values.

Sensitivity Analysis on Other Assumptions Used in Model

Table 6 outlines the assumptions for the sensitivity analysis. As shown in figure 5, the model is particularly sensitive to the proportion of the trait value retained by farmers. Lowering the proportion by 20% increases the real option value at the regulatory stage from US$217 million to US$334 million. When the proportion is increased by 20%, the real option value at the regulatory stage decreases to US$101 million. The model is also sensitive to the WACC discount rate and equally sensitive to the value of the new GM trait, planted hectares (and adoption) and probability of success.

Table 6. Assumptions under Sensitivity Analysis

Variable	Base Case (assumption used)	Sensitivity Test 1 (assumption used)	Sensitivity Test 2 (assumption used)
Insurance coverage level (GM yield advantage)	75%	Increase by 20%	Decrease by 20%
Risk premium	(See table 2)	Increase by 20%	Decrease by 20%
Proportion of trait value retained by farmers	70%	Increase by 20%	Decrease by 20%
Planted hectares (adoption is as equally sensitive as planted hectares)	(See table 1)	Increase by 20%	Decrease by 20%
WACC discount rate	10%	Increase by 20%	Decrease by 20%
Investment duration	(See table 1)	Increase by 20%	Decrease by 20%
Investment cost	(See table 1)	Increase by 20%	Decrease by 20%
Probability of success	(See table 1)	Increase by 20%	Decrease by 20%

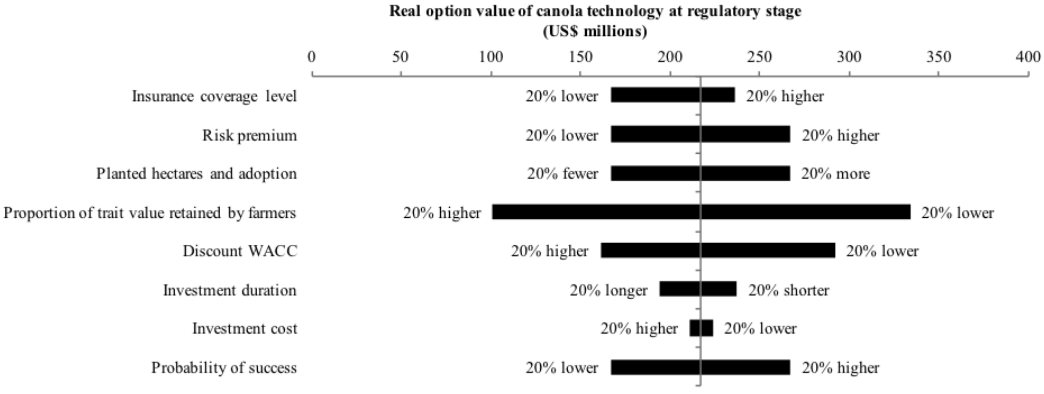

Figure 5. Results of Sensitivity Analysis

The sensitivity test of 20% more planted hectares may indeed be realistic if drought-tolerant canola expands into marginal grain-growing regions. The model is somewhat sensitive to the assumption that the yield advantage provided by the drought-tolerant canola trialed in Australia is equivalent to an insurance coverage level of 75% of historical yield in other countries. The model is not particularly sensitive to the assumptions on investment duration and cost. Overall, the sensitivity analysis indicates the importance of several assumptions, particularly the proportion of the trait value retained by farmers.

Conclusion

Developing new GM traits is risky, complex, and costly, and firms developing the traits must make strategic investment decisions. This paper developed a framework to evaluate an investment strategy that could guide the firm's decisions.

The evaluation framework combined a market assessment with a valuation method based on a stochastic binomial real option model. The framework was applied to a canola trait genetically modified to be drought tolerant. The market assessment determined which multinational markets should be targeted for commercialization and used multi-criteria analysis of various countries, their regulatory regimes, and their market environments. The valuation method was based on a stochastic binomial real option model and determined whether commercialization of a new GM trait was worth pursuing. The model analyzed historical data, forecasted potential future scenarios, and estimated investment values across development stages.

The market assessment showed that most countries produce canola for domestic use, while Canada, Australia, and Ukraine produce canola for export. Countries with a high risk of drought include Canada, Australia, Ukraine, Russia, and the United States. Drought was found to impact canola production in all countries except the United Kingdom. The regulatory systems in Canada, Australia, and the United States are considered relatively easy to navigate. Countries with the most supportive market environments for trait commercialization include Canada, Germany, France, Australia, the United Kingdom, and United States. Based on the multi-criteria analysis, Australia, Canada, the United States, China, Czech Republic, and India (in this order of proposed market entry) were identified as having an appropriate combination of agronomic fit, ease of navigation in the regulatory system, and market environments for trait commercialization and were scheduled for potential commercialization.

Introducing a drought tolerant GM trait to canola was found to be more profitable for farmers than cropping with conventional varieties, with an expected value of between US$13.94 and US$26.20 per hectare depending on the target country. This finding is supported by previous research undertaken in the United States (Shakya, Wilson, and Dahl, 2013; Wilson, Shakya, and Dahl, 2015). The results also suggested that after the initial stage, the optimal decision for the firm is to continue the investment. Canada, China, and India are the largest markets for the commercialization of drought-tolerant GM canola; their inclusion in the modeling drives the real option values.

Using scenario testing to evaluate various market entry strategies, our model also presented quantitative evidence, at least for canola, for why it is not sufficiently economically attractive for biotechnology companies to pursue commercialization in certain countries or regions, such as Europe. This has important implications for future growth and technology adoption in the canola industry. The sensitivity analysis indicated the importance of several assumptions, particularly the proportion of the trait value retained by farmers.

While interpreting these results, it is important to remember that they represent a single point in time and are based on the most current information. Some large canola-producing countries were excluded for commercialization primarily because of their current restrictive regulatory regimes for GM crops. By the time the technology begins to be commercialized, countries' regulatory regimes may have changed. Also, as market entry is staggered and values in the distant future are more heavily discounted than values in the near future, the expected revenue from the trait in today's dollars is lower than if the trait were simultaneously commercialized across the target countries. The model is also conservative in that it does not consider potential expansion to marginal cropping areas (under the base case) or the impacts of climate change. Future climate change may increase the frequency and severity of droughts and increase the value of a GM trait that improves drought tolerance in crops. The model is able to be regularly revised as new information becomes available.

Our study offers the scientific community a means to evaluate the commercial viability of their efforts at the early stages of development. The framework could also contribute to the discourse between the public and private sectors through an improved understanding of the risks and uncertainty associated with R&D research. Future economic research could apply and validate our framework for other technologies in agriculture and other industries. In particular, it would be beneficial if future research examined and validate this study's novel use of multi-peril crop insurance to estimate the value of a new GM trait. This research should also guide future research into the use of real options analysis and investment and commercialization strategy. In particular, possible future research directions include valuing options in commercial negotiations and identifying and analyzing strategies for value allocation and capture.

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