

# VALUING AGRICULTURAL RESOURCE ASSETS - A REAL OPTIONS VALUATION

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## Abstract

Real options are well known for their usefulness in evaluating non-renewable resources. This study derives an asset valuation model using real options methodology to evaluate renewable agriculture investments. The model calculates the value of an investment project as well as computing the critical strike prices at which it becomes optimal to exercise various options over the asset, including when to invest (commence or recommission operations), disinvest (temporarily decommission or delay operations) or divest (abandon the asset altogether). A case study application of the model is presented, which evaluates investments in corn cropping across various US Corn Belt states.

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# **A REAL OPTIONS APPROACH TO VALUING AGRICULTURAL RESOURCE ASSETS**

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## **1. Introduction**

This study investigates the evaluation of agricultural resource assets using a real options approach. Whilst initial real options literature focussed on natural resource assets with finite reserves, there is a growing research interest in applications involving renewable resource assets. This is unsurprising given that renewable resources such as water, food and renewable energy, are of vital importance to the world's population. Our research has implications for financial practitioners and policy makers concerned with obtaining accurate and reliable valuations for agricultural investments.

Real options approaches to evaluating investment opportunities are heralded as significant theoretical developments in financial economics (Schwartz & Trigeorgis, 2004). Within these approaches, the managerial flexibility to react to new information and the management of uncertainty in future conditions confer significant value to an investment (Trigeorgis & Mason, 1987; Kelly, 2015). Over recent decades these approaches have been applied to evaluate investment decisions across a wide range of assets albeit mainly theoretically-based. While much of the early literature has focussed on natural resource assets which have finite reserves there has been a growing research interest in applications involving renewable resource assets. This study

derives an innovative working asset valuation model within the real options methodology to evaluate renewable agricultural resource assets. The model calculates the value of an investment project as well as computing the critical strike prices at which it becomes optimal to exercise various options over the asset, including when to invest (commence or recommission operations), disinvest (temporarily decommission or delay operations) or abandon the asset altogether. An implementation of the renewable resource model including a user-friendly interface is presented. The case of U.S. Corn crops is evaluated to demonstrate the applicability of the model to a real world setting.

The remainder of this paper is as follows. Section 2 provides a theoretical basis for the valuation of agricultural inventory by adapting the theory of real options approaches to evaluate investments in natural resources, while Section 3 presents the renewable resource model. Section 4 presents the results of an application to evaluate agricultural investments in U.S corn crops while Section 5 provides a discussion of the findings. Section 6 concludes the paper.

## **2. Theoretical Model**

Evaluating investment under uncertainty is a well-known problem of central importance in financial economics (Cortazar & Schwartz, 1993). Specific issues arise when the valuation of such investments is contingent on the realisation of one or more stochastic variables (Cortazar & Schwartz, 1993; Colwell et al., 2002). While these issues are not unique to any particular industry, they are especially relevant to renewable resource investments. This is due to the value of renewable-resource assets being dependent on the volatile nature of market prices for their underlying commodities.

The traditional DCF method is widely criticised for neglecting the stochastic nature of output prices and its inability to capture value created by the strategic capacity of management to respond operationally to output price volatility over the life of an investment (Brennan and Schwartz, 1985). The shortcomings of the traditional methods, which essentially ignore these strategic concerns, led to the development of alternative methods to value real investments. The best-known of these approaches is the real options pricing approach by arbitrage methods.

Real options are, in a practical sense, analogous to financial options but include various strategic and operational flexibilities that impact on the market value of the asset. A real option exists where a firm or investor reserves various strategic and operational alternatives pertaining to a particular asset which can be activated (or deactivated) under different sets of business conditions. For example, McDonald and Siegel (1986) describe how the investment opportunity is similar to a perpetual call option whereby it gives the investor the right to invest (the exercise price of the option) and receive an asset (the share of a stock). Similarly, Kester (1984) views “growth options’ as the discretionary opportunity to invest in productive assets like plant, equipment and brand names with the cost outlay equivalent to the exercise price of a call option. In a broader sense real options may be categorised as being either strategic flexibilities or operating flexibilities (Kelly, 2015).

Real options theory posits that the markets value the rights of firms (or investors) to exercise specific strategic and/or operational options during the course of the business cycle. Furthermore, the more volatile the business conditions, the more valuable are the options that enable the owners of assets to react under uncertainty in order to maximise gains and limit potential losses. This is consistent with a number of empirical studies which have found that options inherent to investment opportunities tend to be valued positively (as measured by a premium) in markets involving real, physical assets (see, for example, Quigg, 1993; Berger, Ofek & Swary, 1996; Kelly, 2015). Accordingly, the real options approach has important practical implications for investment decisions in the sense that it is useful to augment the traditional NPV measure to effectively enhance the decision-making capabilities of firms (Kelly, 1998).

Whilst the Black and Scholes (1973) model is considered the seminal paper for pricing financial options, the first, and generally also considered seminal, paper that significantly defined the area for evaluating real options using continuous-time modelling is Brennan and Schwartz (1985). In this paper they derived a real options pricing model and further illustrated its use via a manufactured copper mine example and a contrived infinite resource mine. In the spirit of the work of Black and Scholes, Brennan and Schwartz (1985) develop a system of partial differential equations whereby the value of the mine’s cash flows is dependent on the volatility of output prices, the respective operational policy and the output production rate.

During the same period, other theoretical developments in real options valuation models include the work of McDonald and Siegel (1985) which developed a similar methodology for valuing risky investment projects which reserve the option to shut down production temporarily and without cost whenever variable costs exceed operating revenues. McDonald and Siegel (1986) and Madj and Pindyck (1989) consider the use of the investment rate as the control variable instead of the production rate, the former investigating the value of the option to wait to invest, while the latter applies option pricing methods to derive optimal decision rules for investment outlays over the entire construction program.

It is well-known that empirical research has indeed lagged the development of conceptual frameworks of real options theory (Colwell et al., 2003; Kelly, 2015). That is, although a good deal of work has been developed with respect to conceptual models that treat various aspects of real options from a theoretical perspective, attempts to empirically test the validity of the value of optionality in a real-world setting remain sparse. In the attempts that have been made, a significant portion of this research has been applied to specific cases involving natural resource assets. Commodity markets, in particular, are suitable case studies due to the fact that they are typically highly irreversible investments which exhibit significant underlying spot price volatility (thus the problem is especially acute for valuing these particular assets) and have well developed futures markets (Cortazar, Gravel & Urzua, 2005). However, the typical private and confidential nature of a firm's financial and operational records does indeed make it difficult to compile a relevant and complete set of data to conduct this type of analysis (Colwell et al., 2003).

In a classic empirical study by Quigg (1993) focussed on option-based land valuations. The study searched for empirical evidence for the value of the option to wait to develop land parcels by examining market prices of 2700 land transactions in Seattle during the period 1976-1979. In particular, the study found that market prices reflect a premium for the option to wait to be on average 6% of the land value. This work suggests that investors appear either to directly apply a real option valuation framework, or otherwise, they behave in a manner consistent with predictions of real options theory. Berger et al. (1996) researched how firms value the option to abandon an asset. Their approach was to investigate whether investors use balance sheet information to value their option to abandon the continuing business at the exit value of the asset. They treated the

option to abandon as analogous to owning an insurance policy that pays off if the firm performs below expectations. Their method was to analyse the relationship between book value and exit value for major asset classes by examining the discontinued operations footnotes of 157 firms. They found a positive, highly significant relationship between market and exit values and that, if all other factors are equal, investors prefer firms with greater exit values over those with lower values.

Renewable resources are those natural resources useful to human economies that exhibit growth, maintenance, and recovery from exploitation over an economic horizon (Erickson, 2002). While some renewable resources involve a rotational period subject to growth and maintenance (such as forestry resources, seasonal orchards and live fish stocks harvesting) others (for example, energy derived from solar and wind farms as well as water catchments and desalination utilities) are subject to regular, ongoing recovery to inventories. Literature involving applications of real options approaches to evaluate renewable resource investments tends to be growing, particularly with respect to such areas as agriculture, forestry and renewable energy.

Examples of real options applications to agricultural investments includes soybean processing (Plato, 2001), tart cherry production (Nyambane & Black, 2004), dairy operations (Engel & Hyde, 2003; Tauer, 2006), citrus operations (Iwai, Emerson and Roka, 2009) and livestock farms (Bartolini, Gallerani & Viaggi, 2010). In particular, Tauer (2006) uses the analytic approach of Dixit (1989), which is close in spirit to the Brennan and Schwartz (1985) model, to calculate the entry and exit prices for New York dairy farming. The study found there was a wide range between exit and entry prices for individual farmers which was affected by the relative size of the farm and that smaller farms required higher prices to induce entry and would exit at higher prices also.

Real options applications to forestry investment, which spans several decades, has predominantly examined the investment timing options involving the underlying timber resource. These include early works by Clarke and Reed (1987) who derive an analytical model which determines economically optimal harvesting policies under both single and rotational conditions, and Morck, Schwartz and Strangeland (1989) who develop a model to evaluate a white pine forestry asset in

Canada which holds a ten-year logging lease. Morck et al. (1989) use the cutting rate as the optimal control whereby both the timber price and level of inventories are governed by stochastic processes that follow geometric Brownian motion. The authors acknowledge that their model is equally applicable to fisheries resources and any other similar renewable resource management problem.

Investment in forestry assets is also examined by Duku-Kaakyire and Nanang (2002) who evaluate a set of managerial options using the binomial option pricing method. These options include the timing option to delay reforestation, the option to expand the size of the wood processing plant, the option to abandon the processing plant if timber prices fall below a certain threshold or due to corporate takeover, and multiple options in which all three options are evaluated together. While others such as Kerr, Martin, Kimura, Perera and Lima (2009) analyse the optimal timing decision of when to harvest a stand of eucalyptus trees in Brazil.

Recent studies involving renewable energy investments include Schmit, Luo and Tauer (2008) who evaluate the optimal trigger prices for exercising the options of entering, suspending, reactivating and exiting a corn-based, dry-grind ethanol facility. They note that while research into ethanol firm operations have been analysed from the perspective of NPV, return on investment and break-even analysis, however, little attention has been paid to evaluating these optimal investment decisions from a real options perspective. By analysing the gross margin of ethanol price over corn price they find that, compared to a standard NPV analysis, option values increase entry prices and lower exit prices.

The option to switch between alternative sources of production using renewable energy is analysed by Kjærland and Larsen (2009). They apply the switching model developed by Kulatilaka (1988) to evaluate the operational flexibility relating to a hydro-based operator who holds the option to add thermal power to augment production. This switching option creates value for a hydro operator as it allows the operator to reschedule more production during peak price periods. The study finds that significant option values arise when thermal power plants are controlled by a hydro operator.

The most well-known of the options pricing approaches is the binomial lattice method. A significant operational advantage of using this approach, and the real options approach more generally, is that it does not require an estimated value of the expected cash flows based on forecasted output price movements in the underlying asset. In applying the binomial method, the expected future price movements are calculated using the current output price and the volatility of output prices which is inferred from an historical distribution.

Other option pricing techniques, such as the continuous-time models, are the most operationally complex of the real options models. The complexity in using these techniques is due to the need to implement various numerical methods to solve the resultant set of differential equations that these models are cast as (see, for example, Brennan & Schwartz, 1985). The method generally arrives at these differential equations after careful consideration and application of the mathematics of a standard Gauss-Wiener process in conjunction with Ito's Lemma to derive the total differential of a function of stochastic variables. The resulting set of differential equations establish a continuous-time arbitrage condition which describes the value of an investment based upon the current spot price, the resource inventory and a number of other model parameters. However these equations are rarely amenable to analytic, or closed-form, solution and hence they require unique implementations of numerical methods tuned specifically to cover the applications in real options cases.

A continuous-time model to evaluate real options involving natural resource assets was published by Brennan and Schwartz (1985). This model calculates the present value of the cash flows of an asset based on a no arbitrage argument between the investment opportunity itself and a self-financing portfolio of risk-free bonds and future contracts over the underlying commodity (Kelly, 2015). This seminal paper demonstrated a stylised application of this approach to a copper mine example where the only source of uncertainty is the output price of the underlying commodity. The Brennan and Schwartz (1985) model assumes that the value of the asset is a function of the commodity price and the quantity of reserves. The spot price of an underlying commodity is modelled as a continuous stochastic process in which the logarithm of the randomly changing quantity is assumed to follow standard geometric Brownian motion.

### 3. Renewable Resource Model

A new model for evaluating renewable resource investments is derived, based upon the seminal Brennan and Schwartz (1985) framework, but involves recasting that framework to suit assets that have a renewable inventory under the assumption that the rate of extraction does not exceed the rate at which the resource is replenished. An integral part of the derivation of the new model is the specification of boundary conditions similar to, albeit mathematically distinct from, the boundary conditions of the original framework. More generally, the new model is derived and analysed through the application of the concept of analytic continuation (Harris, 1992), which involves extending the basic functions and equations of the model, continuously to first derivatives, over the entire phase space of the parameters. It will be shown that the resultant analytically continued model's equations can be solved to produce closed form solutions. Specific solutions can only be calculated via numerical techniques and consequently computational implementations of general solutions for the final model are developed.

The Brennan and Schwartz (1985) model consists of two differential equations which describe the value of a mine based upon the current spot price and a number of other model parameters. The original model for a finite life, diminishing inventory (when being operated) asset is:

$$\max_{q \in (\underline{q}, \bar{q})} \left[ \frac{1}{2} \sigma^2 s^2 v_{ss} + (r - \kappa) s v_s - q v_Q + q(s - a) - \tau - (r + \lambda_1) v \right] = 0 \quad (\text{open mine})$$

$$\frac{1}{2} \sigma^2 s^2 w_{ss} + (r - \kappa) s w_s - f - (r + \lambda_0) w = 0 \quad (\text{closed mine})$$

Where:

$$\tau = t_1 q s + \max [t_2 q [s(1 - t_1) - a], 0]$$

$$r = \rho - \pi \quad \text{is the real interest rate}$$

subject to the boundary conditions:

$$w(s_0^*, Q) = 0$$

$$v(s_1^*, Q) = \max [w(s_1^*, Q) - k_1(Q), 0]$$

$$w(s_2^*, Q) = v(s_2^*, Q) - k_2(Q)$$

$$w(s, 0) = v(s, 0) = 0$$

$$w_s(s_0^*, Q) = 0;$$

$$v_s(s_1^*, Q) = \begin{cases} w_s(s_1^*, Q) & \text{if } w(s_1^*, Q) - k_1(Q) \geq 0, \\ 0 & \text{if } w(s_1^*, Q) - k_1(Q) < 0; \end{cases}$$

$$w_s(s_2^*, Q) = v_s(s_2^*, Q).$$

The development of a real options model applicable to evaluating renewable resource assets, based on the Brennan and Schwartz theory, involves the use of analytic continuation. Analytic continuation is a well-known technique in the area of complex function analysis mathematics (Harris, 1992). The technique involves extending the domain of an analytic function beyond its original (or defined) range in a manner which keeps that function continuous to first derivative into the extended domain. The practical implications of the use of the method of analytic continuation is that the analytically-continued function can then be used to extend the original function into a new domain where the original function initially defined becomes divergent, is undefined, has no physical meaning, or has non-analytic behaviour or form (see, for example, Harris, 1992).

In this study analytic continuation is used to cover values of the spot price lower than the abandonment option, a physically unreasonable range of the spot price domain. In their original model, Brennan and Schwartz imposed the reasonable constraint that the value of the mine is zero when the spot price is lower than the abandonment option. This causes a non-analyticity in their model (in the first derivative) and is a contributory reason to the generally accepted belief that their model is insoluble analytically.

We produce an analytically continued version of the real options Brennan and Schwartz (1985) functions  $v(s, Q)$  and  $w(s, Q)$  by allowing the functions to continue smoothly beyond their boundary endpoints and into regions of the spot price phase space where they strictly (according to Brennan & Schwartz, 1985) are not defined. That is, the real options functions  $v(s, Q)$  and  $w(s, Q)$  are smoothly continued into the lower spot price region  $s < s_0^*$  and the upper spot price region of  $s > s_2^*$ . Achieving an analytic solution to a version of this model provides a more complete coverage of phase space thus furthering conventional insight into the behaviour of the model. Necessarily this requires a reworking of the currently discontinuous boundary conditions specified by Brennan and Schwartz (1985).

The model equations are smooth and continuous over their entire range of spot prices and are not modified, even beyond the physical limits imposed by the boundary conditions. This is in stark contrast to the boundary conditions originally specified which contains embedded discontinuities and discontinuous behaviour. In the case of an asset with a renewable inventory, the  $Q$  dependence in the boundary conditions disappears as  $Q \rightarrow \infty$ . Accordingly, the set of physical boundary conditions simplify to:

$$w(s_0) = 0 \quad (1)$$

$$v(s_1) = w(s_1) - k_1 \quad (2)$$

$$v(s_2) = w(s_2) + k_2 \quad (3)$$

$$v_s(s_1) = w_s(s_1) \quad (4)$$

$$v_s(s_2) = w_s(s_2) \quad (5)$$

Similarly, the discontinuity in the tax function  $\tau$  is replaced by a smooth tax function thus allowing for a full loss tax off-set (see Brennan and Schwartz, 1985). The tax function thus becomes

$$\tau = t_1 qs + t_2 q(s(1-t_1) - a) \quad (6)$$

Under the above assumptions the (deflated) value of the open mine  $v(s, Q)$  (when it is operating at a production rate  $q$  which does not exceed the rate of replenishment) satisfies the ordinary differential equation (ODE)

$$\frac{1}{2} \sigma^2 s^2 \frac{d^2 v}{ds^2} + (r - \kappa) s \frac{dv}{ds} + q(s - a) - t_1 qs - t_2 qs(1-t_1) + t_2 qa - (r + \lambda_1) v = 0 \quad (7)$$

We note that the ODE which values the closed asset remains unchanged from the original specification. The new model for an infinite resource asset is the following system of equations:

$$\frac{1}{2} \sigma^2 s^2 \frac{d^2 v}{ds^2} + (r - \kappa) s \frac{dv}{ds} + q(s - a) - \tau - (r + \lambda_1) v = 0 \quad (8)$$

$$\frac{1}{2} \sigma^2 s^2 \frac{d^2 w}{ds^2} + (r - \kappa) s \frac{dw}{ds} - f - (r + \lambda_0) w = 0 \quad (9)$$

Where:

$$\tau = t_1qs + t_2q(s(1-t_1) - a)$$

$$r = \rho - \pi$$

Subject to the boundary conditions:

$$w(s_0) = 0$$

$$v(s_1) = w(s_1) - k_1$$

$$v(s_2) = w(s_2) + k_2$$

$$v_s(s_1) = w_s(s_1)$$

$$v_s(s_2) = w_s(s_2)$$

This model has the advantage of being smooth and twice-differentially continuous over the entire spot price phase space. This ensures that conventional solution techniques can now be applied to this system of equations.

#### **4. Application to Corn-Cropping Investments under Uncertainty**

The Renewable Resource Model (RRM) is applied to price cropland assets across the U.S. Corn Belt as well as to outline the appropriate operational policy that farmers should follow to manage these assets optimally. Whereas some previous related studies have examined entry and exit decisions regarding new investments in agricultural assets (see, for example, Tauer (2006)), this research evaluates the managerial options available to a particular perennial agricultural operation whereby the initial decision to invest has already been made. The RRM has practical implications that may assist farmers to make optimal decisions regarding whether or not to plant their field crops for the current season and at which price it is worth considering alternative uses for their crop land such as rotating their crops or converting their land for other industrial uses. These managerial decisions have significant implications for valuing agricultural assets that are difficult to incorporate into DCF valuations.

For instance, following the Brennan and Schwartz (1985) example of a copper mine, should the price of copper fall to a sufficiently low level (the critical price  $S_1$ ), then the mine owner should cease operating the mine and incur the costs of closure and annual maintenance on the mine. A farmer faces a similar dilemma as the resource miner regarding their decisions to choose the

appropriate operational policy that optimises the value of their investment. Each year farmers must consider whether or not the current spot price is appropriate to warrant exercising the option to outlay the costs to plant their fields for the coming season. Thus for this case study the option associated with the price  $S_1$  is interpreted as one where the farmer should forego planting for the current season whilst maintaining the crop land until prices improve and reach the critical price  $S_2$ . At the critical price  $S_2$ , it is appropriate to outlay the costs of production to plant the crop. If, however, the option to delay planting has already been exercised, and the price should continue to fall further to the critical price  $S_0$ , then the farmer should allow the land to lay fallow whilst considering alternative uses for their cropland.

We selected corn as a suitable agricultural commodity to illustrate the application of the model for several reasons. First, corn is the largest component of the world's coarse grain trade and is therefore an economically important soft commodity that is cultivated for a variety of purposes including food, feed and industrial uses (United States Department of Agriculture (USDA), 2011a). Second, since corn is a perennial crop (as such its inventory may be harvested and subsequently replenished on an annual basis), and has well-developed markets, it is deemed appropriate to fit with various assumptions underpinning the model's applicability to a real-world setting. Moreover, if the tenancy of the farm is free from constraints imposed by any specific lease period the investment horizon can be assumed to be infinite (thus satisfying a key assumption of the model). Third, a real options analysis is appropriate for assets such as perennial crops because the farmer holds various operational options over these assets which, as previously discussed, may be exercised at the farmer's discretion.

Accordingly, we focused the case study application of the renewable resource model to evaluate hypothetical investments in corn production assets across the Heartland States of Illinois, Indiana, Iowa, Missouri and Ohio. Valuations are calculated based on cropland consisting of 250 and 1000 acres for which the total area is assumed amenable to crop production. Parameters used in the study are average values calculated using data sourced from various U.S. Government agencies over the 10-year period 2000 to 2009. The parameters used in this study are estimated using USDA census data.

The model requires the variance of the corn price to be calculated. A key assumption of the renewable resource options model is that the prices of the underlying commodity follow a random walk and are log-normally distributed . Thus, using monthly U.S. corn prices data from January

2000 to December 2009, the statistic  $d_t = \ln\left(\frac{S_{t+1}}{S_t}\right)$  is calculated and annualised by multiplying by 12. This resulted in an annually adjusted mean ( $d_t$ ) of 0.0057 and standard deviation of 0.1891, hence a variance rate of 0.0358.

Whether the long-term average price of corn is stationary was tested using a Dickey-Fuller test. Using USDA data for average monthly corn prices received by U.S. farmers over the period January 1975 to December 2010 yields 420 observations. The null hypothesis that the corn price is stationary could not be rejected at the 95% confidence.

The model requires estimates for the average rates of production and the associated costs per bushel of corn. The USDA publishes a detailed breakdown of cost data consisting of both the variable and fixed cost components of corn farm production compiled on a regionalised basis. The latest estimates for average total economic costs reported by the USDA for the Heartland Region are for the year 2009, which is \$555.15 per planted acre (USDA 2011c). The average production costs for each of the states is calculated by dividing the total costs by the average yields reported for each state over the decade 2000 to 2009 (USDA 2011d). Calculations for the annual rates of production and the resulting production costs per bushel of corn are presented below in Table 1.

The results of these calculations show that farmers with corn crops located in the Heartland States of Iowa and Illinois are relatively low-cost producers, while farmers in Missouri have relatively high costs of production. It is not surprising that farms located in the States of Iowa and Illinois typically produce in excess of one-third of the total U.S corn crop (USDA, 2011a).

### Insert Table 1 here

Since the actual risk-free rate is not readily observable (and thus known) the standard approach in the literature is to use the yield on U.S. Treasury securities as a proxy for the risk-free rate. The 10-year U.S. Treasury bond rate was chosen for use in this study.

A key assumption of the model is that the future price of a commodity is a function of the spot price and time to maturity. Because the model assumes the net convenience yield to be proportional to the price it may be estimated directly from the following relationship:

$$F(T) = S(t)e^{(r-\kappa)(T-t)}$$

where  $F(T)$  is the futures price,  $S(t)$  is the spot price,  $r$  is the nominal interest rate and  $\kappa$  is the convenience yield. Thus monthly convenience yields are calculated and annualised following the approach adopted by Gibson and Schwartz (1990):

$$\kappa = r - \frac{1}{\Delta t} * \ln \left[ \frac{F(T)}{S(t)} \right]$$

where  $\Delta t$  is equal to 1/12.

The average annualised convenience yield over the period January 2000 to December 2009 was calculated to be 4.39%.

The final estimates for the analysis are estimates for federal income taxes, state property taxes and the royalty rate and maintenance costs, costs of closure and costs of reinstating operations. According to Durst (2009), 99% of U.S. farm income is taxed at the individual tax rate rather than the corporate tax rate since most farms are operated as sole proprietors, partnerships, or small business corporations. For this study we apply a tax rate of 15% which is reported by the USDA as the average effective Federal income tax rate for 2004. The average state property tax rates for each state is taken from a 2007 article in The New York Times: Illinois (1.79%), Indiana (2.12%), Iowa (2.15%), Missouri (1.42%) and Ohio (1.81%). Royalty rates do not apply and are set to zero per cent.

Costs for cropland that is currently being maintained are estimated by including only those recurring annual costs of the farm published by the USDA for the Heartland Region. Our estimates include non-real estate taxes and insurance and general farm overhead. These costs are reported by the USDA to total \$24 per planted acre for 2009. Costs associated with exercising the option to temporarily delay operations,  $k_1$ , may include the costs of storing machinery (and silage if appropriate), paying out relevant redundancies and termination payments on current contracts, as well as any outstanding general liabilities. While the costs to exercise the option to reinstate operations,  $k_2$ , may involve hiring and training costs and other miscellaneous recommissioning costs due on the farm. For this study we assume the costs of transitioning between each operating state to be \$10,000 each. Costs of abandoning the crop to let the land lie fallow are assumed to be zero.

Having now calculated all of the required parameters for use in the model, a summary of the parameters are detailed in the following Table 2.

**Insert Table 2 here**

Table 3 presents the results for the calculations of cropland value as a function of the corn price for the various States. The results show that cropland values per planted acre vary significantly according to location in the U.S. while the size of the cropland has a rather smaller impact. It can be seen that cropland located in the States of Iowa and Illinois have the highest values per-acre at each price interval, while values in Indiana and Ohio constitute an apparent mid-range across all states, and values calculated for Missouri are significantly lower. This is unsurprising given that farms in Iowa and Illinois have relatively low production costs while Missouri farms have higher costs.

**Insert Table 3**

Note that although the hypothetical spot price \$3.50 is below the actual average costs of production for several states (i.e. on average farmers in these states are currently out-of-the-money) the option values of the cropland remain positive at this price. Importantly, this result illustrates a key distinction in using option pricing to evaluate investments compared

with conventional Net Present Value valuation techniques, whereby the investment decision would be rejected. This implies that investors may inadvertently forego an otherwise potentially profitable investment.

It is of interest to compare these model results with the official estimates of average cropland value published by the USDA for each State. The USDA estimates are calculated using a complete, probability-based land-area sampling frame based on annual survey data which includes a stratified sample of land areas averaging approximately one square mile in size gathered during the first two weeks of June (USDA, 2011e). Table 4 shows the cropland values reported by the USDA for the years 2006 to 2010.

#### **Insert Table 4**

Unfortunately, the USDA does not disaggregate their data to distinguish between specific uses of cropland (for example, corn, sorghum, or wheat) within each of the States. Nevertheless, it is noted that a similar pattern can be observed between the USDA values and the model values, in that Illinois and Iowa have the highest cropland values, while Missouri has significantly lower values. This raises an interesting question: what is the appropriate spot price at which the values obtained by implementing the renewable resource model match the official USDA estimates? In Table 5 we report the appropriate spot price at which the model produces cropland values equivalent to those reported by the USDA for 2010.

#### **Insert Table 5**

Table 5 indicates that a spot price in the range \$5.45 to \$6.12 would match the official cropland values published by the USDA for 2010. Figure 1 illustrates that, during 2010, corn prices were significantly below the calculations of the appropriate prices at which the model matches the USDA values. However, prices observed in 2011 from April to June are found to be higher than these “benchmark” prices.

Under the RRM, it is optimal to continue perennial corn farming operations on the crop land until the price falls to the critical price  $S_1$ . If the price falls below this level, it is optimal to delay planting for the coming season and instead incur the costs of closure and maintenance of the land

to minimise operational losses which would have resulted from going ahead with planting. It is optimal to abandon production of corn entirely when the price falls to  $S_0$  where the option value to operate a corn crop on this land is zero. Conversely, if the crop land is currently not operational (that is the spot price has been low enough to warrant delaying planting this seasons corn crop), and the price rises above the critical price level  $S_2$ , it is optimal to return to normal operating conditions and incur the associated production costs. The results of the calculations for these critical prices are presented below in Table 6 below.

### **Insert Table 6**

## **5. Discussion**

The results of the evaluation can be interpreted in at least several ways. First, they suggest that, if the RRM's assumptions hold, and if the model parameters adopted above are a valid representation of the true situation, then the market valuations of corn cropland in the states studied may have involved some over-valuation during 2010; in that the corn prices which prevailed during the period implied (according to the model) lower cropland values. By the same token, the market valuations in much of 2011 appear to have been somewhat lower than indicated by the model.

Second, the above characterisation of over- and under-valuation needs to be qualified by the fact that USDA valuations of cropland related to the average for all crops, whereas the model-generated valuations are geared to corn croplands only. It is possible, for example, that during 2010 the returns on crops other than corn may have been, and were expected to remain, higher than returns on corn, so that market values of all croplands combined would be higher than those for corn croplands. In that case, market values of corn croplands may have been far closer to the model-based values than the above comparison may suggest.

Third, the discussion in the above two paragraphs notwithstanding, it is of interest to note how close the model's calculations turn out to be relative to market valuations, as indicated by USDA estimations. Recall that in parameterising the model and implementing the solution methods in this case study, we have had to make a number of simplifying assumptions and work with "ballpark" estimation, such as those for production costs. Despite these approximations, the results turn out to be certainly quite close to USDA estimates. This suggests that, in a real-world

situation, it may well be worth investing additional resources into refining the estimates of the relevant model parameters in order to obtain more accurate model valuations. In particular, compiling cost and tax data that is more specific for individual farms would provide a more robust empirical analysis, and would seem a worthwhile avenue for future research.

Results further indicated that Illinois and Iowa are found to have lower price thresholds at which it becomes optimal to exercise the various operational options over a farm. This can be expected given that our calculations showed farmers in these states to have the lowest costs of production in the Heartland Region. It can be seen that the larger the farm size, the lower the critical price, S1, at which it becomes optimal to abandon corn-farming operations. Similarly, a larger farm size reduces the critical price to reinstate operations, S2, over a previously mothballed crop. A larger farm size, on the other hand, increases the price at which it becomes optimal to temporarily delay corn farming. In other words, the larger the corn crop size, the smaller the price range between critical prices S1 and S2, and the larger the price range between critical prices S0 and S1.

There were no instances where the corn price fell below the highest calculated abandonment price of \$3.14 (for both small and large farms) using the monthly USDA data for average U.S. corn prices received by farmers over the period January 2009 to May 2011. In fact, the last time the monthly price was below this level was in January 2007. The monthly corn price fell below the critical price to cease production, S1, for both small and large farms in Missouri in 2009 during the months of August and September. Similarly, in 2010, the price fell below these prices for large farms on consecutive months from February to July.

Farmers may stockpile inventory for future delivery when market conditions improve. Furthermore, for many farms, the decision to continue unprofitable operations may be influenced by both contractual obligations with various end-users of corn and with efforts to ensure marketing networks are maintained. Investigating how these relatively low prices affected farming operations amongst individual farms in Missouri (as the model suggests was appropriate) and, more generally, looking for evidence of hysteresis inertia in output level affecting operational decision-making in agriculture, would be an interesting avenue for further research.

Durst (2009) notes that nearly three-quarters of farm sole proprietors in the U.S. reported a farm loss in 2006 and that for small residential farms in particular the return to farming from the tax code may partially explain continued farm production despite the persistence of farm losses. Losses from farming are used to reduce taxes on other income, which is especially the case for individuals who report their primary occupation to be something other than farming. Similarly, large commercial farms may not be stand-alone businesses, but rather part of a broader portfolio of assets for which losses may be offset against other parts of the firm (see Moel & Tufano, 2002). This implies that for large, well-diversified firms, operating policy decisions may be made at the firm level rather than at the operational level. Other non-financial considerations may also influence the investment decision process. For instance, Tauer (2006) posited that farmers often hold optimistic expectations of the future in that next month's price might be better than that at present and thus continue operations despite an objective financial analysis indicating that it would be appropriate to do otherwise.

## **6. Conclusion**

This paper derived a new model for evaluating agricultural enterprises taking into account price volatility and managerial flexibility. This Renewable Resource Model (RRM) extends the Brennan and Schwartz (1985) model framework developed to evaluate natural resource assets by recasting that framework to suit assets that have a renewable inventory, under the assumption that the rate of extraction does not exceed the rate at which the resource is replenished. An application of the RRM was presented, which evaluated investments in corn cropping across various US Corn Belt states. These valuations were found to be relatively consistent with official estimates of cropland values published by the USDA, although there were differences that can be explained in terms of fairly plausible factors, and which should be further investigated in the future. Our results further indicate significant differences between optimal operational decision-making for relatively small and large corn farms.

The location and relative size of corn croplands were found to be important factors affecting the critical prices at which to exercise various operational options in order to manage operations optimally. Relatively low-cost producers were found to have lower price thresholds at which it becomes optimal to exercise all three options and larger croplands were found to have lower

critical prices at which it becomes optimal to abandon corn-farming operations than smaller croplands. Larger croplands were also found to have higher prices at which it becomes optimal to temporarily cease corn farming in all cases. The relatively larger price ranges between the critical prices to shut down and abandon show that it is optimal to exercise the option to cease operating larger croplands at a higher price but abandon at a lower price than for small croplands. Conversely, smaller croplands had higher critical prices to exercise the option to commence operations. Although small farms require higher price thresholds at which it becomes optimal to commence operating their croplands, should the price fall once operations begin, it is optimal to sustain operations at lower price thresholds before exercising the option to cease operations. While RRM provides an objective approach to determining the appropriate operating policy for these farmers, however, their decisions may ultimately be affected by considerations that include subjective factors outside the scope of the model.

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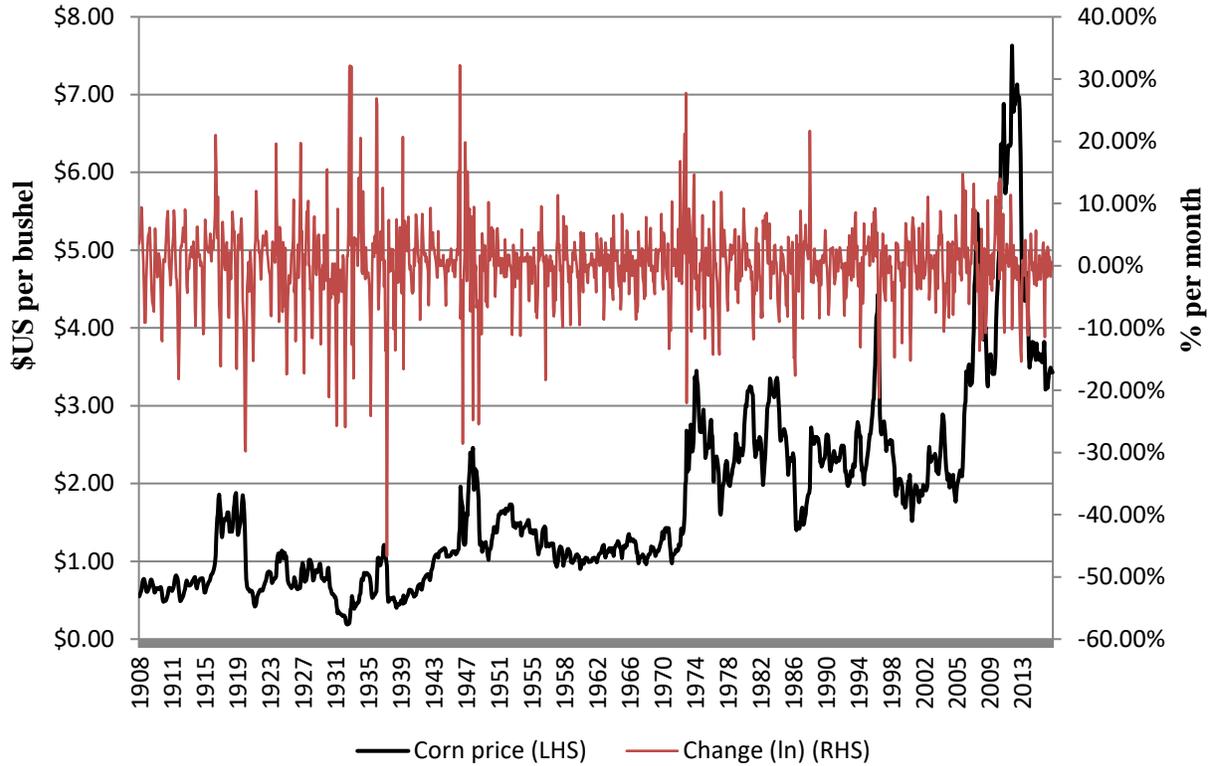
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**Figure 1: U.S. Average Monthly Corn Prices**



Source: USDA, 2011b.

**Table 1: US Corn Belt Average Annual Harvest Yields, 2000-09**

Year	Illinois	Indiana	Iowa	Missouri	Ohio
2000	151	146	144	143	147
2001	152	156	146	133	138
2002	135	121	163	105	89
2003	164	146	157	108	156
2004	180	168	181	162	158
2005	143	154	173	111	143
2006	163	157	166	138	159
2007	175	154	171	140	150
2008	179	160	171	144	131
2009	174	171	181	153	171
2010	157	157	165	123	160
2011	157	146	172	114	153
2012	105	99	137	75	120
2013	178	177	164	136	174
2014	200	188	178	186	176
2015	175	150	192	142	153
2016	197	173	203	163	159
2017	188	173	188	162	171
<b>Average</b>	165	155	170	135	150
<b>Production Costs \$/bu</b>	3.21	3.42	3.08	4.02	3.49

**Table 2: Data Parameters Summary**

<b>Parameter</b>	<b>Value</b>
<b>Real Interest Rate</b>	2.39% per year
<b>Annual Volatility*</b>	18.91% per year
<b>Average Convenience Yield</b>	4.39% per year
<b>Average Annual Yield</b>	
<b>Illinois</b>	162.5 bu/planted acre
<b>Indiana</b>	153.7 bu/planted acre
<b>Iowa</b>	166.1 bu/planted acre
<b>Missouri</b>	133.8 bu/planted acre
<b>Ohio</b>	145.3 bu/planted acre
<b>Average Production Cost</b>	
<b>Illinois</b>	\$3.42 per bushel
<b>Indiana</b>	\$3.61 per bushel
<b>Iowa</b>	\$3.24 per bushel
<b>Missouri</b>	\$4.15 per bushel
<b>Ohio</b>	\$3.82 per bushel
<b>Maintenance Cost</b>	\$24 per planted acre
<b>Cost to Temporarily Close</b>	\$10,000
<b>Cost to Reinstate Operations</b>	\$10,000
<b>Federal Income Tax Rate</b>	15%
<b>State Propoerty Tax Rate</b>	
<b>Illinois</b>	1.79% per year
<b>Indiana</b>	2.12% per year
<b>Iowa</b>	2.15% per year
<b>Missouri</b>	1.42% per year
<b>Ohio</b>	1.81% per year
<b>Royalty Rate</b>	0%

\* Variance = 0.0358

**Table 3: Real Options Evaluation of Corn Cropland**

250 acres	Illinois	Indiana	Iowa	Missouri	Ohio
Spot Price (\$/bu)	Crop Value (\$/acre)				
\$3.50*	840	560	960	200	400
\$4.00**	1520	1160	1680	640	920
\$4.50	2280	1800	2440	1160	1560
\$5.00	3120	2520	3280	1800	2240
\$5.50	4000	3320	4160	2480	2960
\$6.00	4920	4120	5080	3200	3760
1000 acres	Illinois	Indiana	Iowa	Missouri	Ohio
Spot Price (\$/bu)	Crop Value (\$/acre)				
\$3.50*	890	630	1020	260	470
\$4.00**	1560	1200	1720	690	980
\$4.50	2330	1850	2500	1230	1600
\$5.00	3160	2580	3330	1850	2280
\$5.50	4030	3350	4210	2520	3010
\$6.00	4950	4150	5110	3240	3790

\* Spot price is below average cost of production for Indiana, Missouri and Ohio  
 \*\* Spot price is below average production cost for Missouri

**Table 4: USDA Average Cropland Values by State**

Year	AG Land, Cropland - Asset Value, Measured in \$ / acre					
	Illinois	Indiana	Iowa	Missouri	Ohio	Corn Belt
2006	\$ 3,640	\$ 3,250	\$ 3,100	\$ 2,010	\$ 3,470	\$ 3,090
2007	\$ 4,150	\$ 3,640	\$ 3,600	\$ 2,330	\$ 3,820	\$ 3,530
2008	\$ 4,850	\$ 4,140	\$ 4,260	\$ 2,500	\$ 4,140	\$ 4,030
2009	\$ 4,590	\$ 3,890	\$ 3,980	\$ 2,490	\$ 3,830	\$ 3,840
2010	\$ 4,720	\$ 4,270	\$ 4,450	\$ 2,600	\$ 3,900	\$ 4,090
2011	\$ 5,480	\$ 5,070	\$ 5,600	\$ 2,790	\$ 4,160	\$ 4,810
2012	\$ 6,300	\$ 5,840	\$ 6,810	\$ 3,120	\$ 4,640	\$ 5,600
2013	\$ 7,190	\$ 6,590	\$ 8,000	\$ 3,500	\$ 5,190	\$ 6,470
2014	\$ 7,700	\$ 7,050	\$ 8,750	\$ 3,810	\$ 5,650	\$ 7,000
2015	\$ 7,650	\$ 7,000	\$ 8,200	\$ 3,810	\$ 5,850	\$ 6,840
2016	\$ 7,450	\$ 7,000	\$ 8,000	\$ 3,770	\$ 5,800	\$ 6,710
2017	\$ 7,350	\$ 6,700	\$ 8,100	\$ 3,820	\$ 5,780	\$ 6,670

Source: United States Department of Agriculture (USDA), 2017, National Agricultural Statistics Service: Quick Stats, available at <https://quickstats.nass.usda.gov/>

**Table 5: Results for the Appropriate Corn Prices at which the Model matches the USDA estimates for Cropland Values**

Crop Size	Spot Prices (\$/bu)				
	Illinois	Indiana	Iowa	Missouri	Ohio
250 acres	\$5.95	\$5.95	\$5.45	\$5.64	\$6.12
1000 acres	\$5.93	\$5.93	\$5.44	\$5.60	\$6.10

**Table 6: Real Options Analysis of Critical Option Prices**

250 acres	S0*	S1**	S2***
Illinois	\$2.59	\$2.78	\$3.90
Indiana	\$2.74	\$2.93	\$4.12
Iowa	\$2.48	\$2.62	\$3.70
Missouri	\$3.14	\$3.37	\$4.74
Ohio	\$2.89	\$3.10	\$4.36
1000 acres	S0	S1	S2
Illinois	\$2.55	\$2.94	\$3.63
Indiana	\$2.69	\$3.10	\$3.83
Iowa	\$2.44	\$2.77	\$3.44
Missouri	\$3.08	\$3.56	\$4.41
Ohio	\$2.84	\$3.28	\$4.06

\* S0 - abandon

\*\* S1 - temporarily cease production

\*\*\* S2 - recommence production