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A New Look at the Economic Evaluation of Wind Energy as an Alternative to Electric and Natural Gas-Powered Irrigation

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An extension of the Guerrero et al. (2010) net present value (NPV) analysis using real options analysis (ROA) is offered to improve machinery replacement decisions. Specifically, the feasibilities of replacing natural gas irrigation systems with either electric or hybrid (electric/wind) systems are evaluated. Results indicate NPV and ROA criteria can yield opposite decisions depending on the stochastic nature of the parameters, reversibility of the investment, and flexibility of investment timing. For policy, NPV results indicate that replacing natural gas with a hybrid is on the cusp of being optimal. However, ROA indicates this NPV implication may not hold.

Key Words: electricity, irrigation, natural gas, wind energy

JEL Classifications: Q12, Q20, Q42

Wind as an alternative to natural gas is a renewable energy source for powering irrigation wells, which enhances energy security and has the potential to mitigate the impact of volatile natural gas prices. From 1997 to 2011, natural gas prices have ranged from \$3.12 to \$9.65 per thousand cubic feet (Mcf) with a mean of 5.71 and a standard deviation of 2.00 (EIA, 2012). Guerrero et al. (2010) use standard net present value (NPV) analysis to determine the feasibility of replacing natural gas irrigation systems with either electric or hybrid (electric/wind) systems. However, such replacement comes with a relatively large sunk cost in which once the option to replace is exercised, the replacement cost is irreversible. This irreversibility in conjunction with the stochastic nature of natural gas prices limits the ability of NPV analysis to determine the appropriate prices and costs to exercise the replacement option. NPV analysis assumes the underlying conditions remain stationary and definite in the future, but this assumption can be costly in the context of stochastic prices. If the replacement option is exercised and natural gas prices decline, it may have been optimal instead to delay the replacement. This is particularly relevant with the recent decline in natural gas prices from abundant supplies generated by hydraulic fracturing extraction methods.

An alternative to the NPV analysis is real options analysis (ROA), which accounts for

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stochastic prices, replacement irreversibility, and the possibility of delaying the replacement. ROA incorporates the existence of future cash flow uncertainty into capital budgeting decisions. Past applications of ROA include crop variety selection (Richards and Green, 2003), grower investment behavior (Elmer et al., 2001), and fuel choice (Tareen, Wetzstein, and Duffield, 2000). In terms of ROA for irrigation, Carey and Zilberman (2002) look at its effect on adoption delay, McClintock (2010) is concerned with evaporation mitigation systems, Michailidis and Mattas (2007) investigate dam investment, and Seo et al. (2008) consider efficient irrigation systems. Mezey and Conrad (2010) provide a general review of ROA in resource economics and in particular water.

The objective of this study is to illustrate through re-evaluating the Guerrero et al. (2010) study the advantages of using ROA in agricultural production decisions when facing highly uncertain input energy markets specifically and any input price uncertainty in general. In particular, ROA has a natural advantage over NPV analysis in cases in which investment costs and returns are highly uncertain and involve substantial irreversible initial costs. This is generally characteristic of alternative energy investments and in particular wind energy investments.

ROA is not a new investment aid for evaluating wind energy projects. In terms of large wind energy farms, Venetsanos, Angelopoulou, and Tsoutsos (2002) used ROA for evaluating wind energy systems and then designed an outline to evaluate renewable energy power projects by considering underlying uncertainties that are inherent to energy production. Their research was followed by Luna, Assuad, and Dyner (2003), Dykes and Neufville (2008), Munoz et al. (2009), and Lee and Shih (2010) who all used ROA for wind energy farms. However, all these applications of ROA are with stochastic energy output prices. In contrast, the irrigation wind system involves stochastic energy input prices. Thus, the objective is to demonstrate the application of ROA for agricultural producers using energy in their food and fiber enterprises.

Real Options Analysis

The theory of options pricing dates back to the 1900s with Louis Bachilier who inferred an option pricing formula based on the assumption that stock prices follow a Brownian motion with no drift (random movements). A theoretical framework was developed by Black and Scholes (1973) and Merton (1973) as a tool to value financial options based on the volatility of returns. The framework of real options assessed by Myers (1977) proposed that after making an investment decision, a company can obtain the right to buy or sell an investment alternative or physical asset at some future time, thus seeing investment opportunities as involving options (to buy or sell) on real assets and coining the term real options. An investment project presenting high uncertainty should equal the net present value plus the value of the future option. Opportunities to invest are viewed as holding a call option in which the investment decision can be made at some future time. When an irreversible decision is exercised, the option to invest at a future date is lost as well as the possibility of waiting for new information that may impact the decision. Therefore, the concept of keeping your options open through waiting has value. Under this framework, the value of waiting is weighted against the opportunity cost of current profit over the period of waiting. The real options criterion provides a trigger threshold in which conditions are ripe for the decision-maker to invest.

The ROA outlined subsequently was originally developed by McDonald and Siegel (1986) and is based on the theory of optimal investment adoption by Dixit and Pindyck (1994). The energy ROA literature is growing with Gonzalez, Karali, and Wetzstein (2012) providing a review of the recent literature. The decision problem facing an agricultural producer is when to invest in an electric or hybrid alternative fuel source to propel quarter-mile irrigation systems. The capital investment cost, I, is known and constant and includes the initial sunk cost associated with the energy investment along with the operational cost net of energy costs discounted through the time horizon. The value of the investment, V, is stochastic based on energy input prices following a geometric Brownian motion.[1] Because future values of the project are unknown yielding a premium for holding investment options, the critical value of V, V^*, exceeding I is larger than the net present value rule of $V > I$. There is a value to waiting before undertaking an investment. The expected future value may decline in the next period, so it would not have been optimal to invest in the current period where $V > I$. This value of waiting is lost if the investment is undertaken in the current period and should be considered.

Assume the initial investment in adopting an alternative energy source is equal to the cost difference between energy sources

$$I_a = I_N - I_E, \tag{1a}$$

$$I_b = I_N - I_H, \tag{1b}$$

$$I_c = I_E - I_H, \tag{1c}$$

where subscripts N, E, and H represent natural gas, electricity, and hybrid (wind/electric) energy sources, respectively. It is assumed the producer will invest in an irrigation system, so the capital investment costs are the difference in the alternative systems, I_a, I_b, and I_c. If these capital investment costs are lower for natural gas followed by electric and hybrid, then I_a, I_b, and I_c in equation (1) are all negative (costs).[2]

An investment has potential value added relative to an alternative investment represented as

$$V_a = V_N - V_E, \tag{2a}$$

$$V_b = V_N - V_H, \tag{2b}$$

$$V_c = V_E - V_H. \tag{2c}$$

The energy costs of operating the alternative irrigation systems are lowest for the hybrid followed by the electric and then the natural gas, so V_a, V_b, and V_c in equation (2) are all positive (returns). The investment decision is based on the increased cost savings of operation over the life of the system versus the higher capital investment costs. Equations (2) incorporate the stochastic annual energy cost–price difference

$$C_a = (IR_N \times E_N \times P_N) - (IR_E \times E_E \times P_E), \tag{3a}$$

$$C_b = (IR_N \times E_N \times P_N) - (IR_H \times E_H \times P_H), \tag{3b}$$

$$C_c = (IR_E \times E_E \times P_E) - (IR_H \times E_H \times P_H), \tag{3c}$$

where IR_j is the amount of irrigation, E_j is the energy coefficient, and P_j is the price of energy, for $j = N,E,H$. It is assumed C_i, $i = a, b, c$, evolves according to the following Brownian motion:

$$dC_i = \alpha_i C_i dt + \sigma_i C_i dz_i, \tag{4}$$

where α_i is the drift rate, the rate at which the energy cost differences change, σ_i is volatility, and dz_i is the increment of a Brownian motion. The drift rate is the rate at which the average changes and volatility is a measure of the variation over time. Like with equation (2), the energy costs of operating the alternative irrigation systems are lowest for the hybrid followed by the electric and then the natural gas, so C_a, C_b, and C_c in equation (3) are all positive (returns).

The value of the replacement opportunity is $F(C_i)$. With the payoff from investing at time t $V_{it} + I_i$, the problem is maximizing its expected present value

$$F(C_i) = \max \mathrm{E}\left[(V_{it} + I_i)e^{-\rho T}\right], \tag{5}$$

where E denotes the expectation operator, T is the (unknown) future replacement time, and ρ is the discount rate. The stochastic cost savings from investment (equation [3]) at time t are compared with the capital investment costs (equation [1]) and discounted at the time of replacing the irrigation system. The replacement decision is either self-replacement (natural gas replacing natural gas) or an alternative replacement (electric or hybrid replacing natural gas or a hybrid replacing electric).

The replacement opportunity $F(C_i)$ yields no cash flow up to the time T, so the only return

[1] In addition to assuming stochastic energy prices, further stochastic elements, including variable capital investment cost, pump life, and wind speed, could be incorporated into a ROA.

[2] In the analysis $I_a > 0$, natural gas capital investment cost is greater than for electricity.

from holding the investment is the capital appreciation. This results in the Bellman equation

$$\rho F dt = E(dF), \tag{6}$$

requiring total expected returns on the investment opportunity, ρFdt, to have the same value as the expected rate of capital appreciation (Dixit and Pindyck, 1994). Specifically, if the value of waiting measured by the expected rate of capital appreciation is greater than the expected return from not waiting, then it is optimal to wait. The threshold of when to exercise the option (stop waiting and invest) is represented by equation (6). Using Ito's lemma, dF can be expanded as

$$dF = F'(C_i)dC_i + {}^1\!/_2 F''(C_i)(dC_i)^2. \tag{7}$$

Substituting equation (4) into dCi and dividing through by dt, the Bellman equation is then

$$\begin{aligned} &{}^1\!/_2 \sigma^2 C_i^2 F''(C_i) + (\rho - \delta_i)C_i F'(C_i) \\ &\quad - \rho F(C_i) = 0, \end{aligned} \tag{8}$$

where $\delta_i = \rho - \alpha_i$. The general solution to equation (8) is

$$F(C_i) = A_{1i}C_i^{\beta_{1i}} + A_{2i}C_i^{\beta_{2i}}, \tag{9}$$

where A_{1i} and A_{2i} are constants and β_{1i} and β_{2i} are the roots of equation (8) depending on parameters ρ, σ, and δ. As discussed by Dixit and Pindyck (1994), $\beta_1 >$ one and $\beta_2 < 0$. A small value of C_i indicates the probability of it rising to a point of exercising the option (adopting electric or hybrid over natural gas or hybrid over electric) is small. Thus, the replacement opportunity, $F(C_i)$, should be worthless at this extreme, so to ensure that $F(C_i)$ approaches zero as C_i goes to zero, set the coefficient associated with β_2, A_{2i}, to zero.

As discussed by Dixit and Pindyck (1994), $F(C_i)$ must also satisfy the value-matching and smooth-pasting conditions. The root β_{1i} along with the optimal switching cost threshold can then be solved as

$$C_i^* = \frac{\beta_{1i}}{\beta_{1i} - 1} \times \delta I_i, \tag{10}$$

where

$$\begin{aligned} \beta_{1i} = \frac{1}{2} - \frac{\rho - \delta_i}{\sigma_i^2} \\ + \sqrt{\left(\frac{\rho - \delta_i}{\sigma_i^2} - \frac{1}{2}\right)^2 + 2\frac{\rho}{\sigma_i^2}} > 1. \end{aligned} \tag{11}$$

The optimal decision rule attained through the ROA is to replace the existing energy system with an alternative (electric or hybrid system) when the difference between energy costs is larger than the threshold in equation (10) and maintain the status quo system otherwise. If the current energy cost savings, $\overline{C}_i$, is greater than C_i*, then it is optimal to replace. This is compared with the threshold achieved with NPV

$$C_i' = \delta I_i. \tag{12}$$

If $\overline{C}_i > C_i'$, then replace the existing energy system with an alternative. A comparison of NPV and ROA can be made by considering the minimum acceptable rate of return or hurdle rate, which is the minimum return a producer is willing to accept for exercising the option to replace the existing energy system. Under ROA this hurdle rate accounts for the stochastic nature of energy prices, irreversibility, and the flexible timing of the replacement. The hurdle rate is defined as $(C_i^*/\overline{C}_i) - 100\%$. In contrast, the NPV criterion does not consider this minimum rate of return.

Energy Requirements

For a comparison of ROA with NPV analysis in Guerrero et al. (2010), the same three crops (corn, wheat, and sorghum) were investigated along with retaining their underlying assumptions and methodology (although the replacement and energy costs are updated). The identical Texas and Kansas study areas were considered over a 20-year time horizon for 200- and 500-feet pumping lifts; horsepower requirements were determined using their listing of energy use per acre-inch. Refer to Guerrero et al. (2010) for calculations of horsepower, total head, natural gas and electricity energy use, the ratio of wind speeds at various heights, and the air density ratio. The amount of natural gas and electricity required for each acre-inch of pumping at the specific depths is listed in Table 1.

Table 1. Energy Use per Acre-Inch for the Study Area

	Texas		Kansas	
Energy source 200′ lift	500′ Lift	200′ Lift	500′ Lift	
Natural gas (Mcf)	0.77	1.13	0.80	1.15
Electricity (kW)	46.52	80.24	48.22	81.60

Source: Guerrero et al., 2010.

The updated fixed and variable irrigation pumping costs are listed in Table 2. As indicated in the table, Kansas investment costs are higher as a result of a higher flow rate of 1200 gallons per minute (GPM) compared with 600 GPM in Texas, which requires larger horsepower. Based on these parameters, Table 2 lists the investment and operating costs by state, lift, and energy system.[3]

Energy Price Data

The data are from the U.S. Energy Information Administration (EIA) consisting of monthly Texas and Kansas industrial energy prices averaged to an annual basis for electricity and natural gas. During the sample period (1997–2011), natural gas prices varied between $3.12 and $9.65 per Mcf and electricity prices between $0.044 and $0.069 per kWh. Summary statistics on the energy prices are listed in Table 3.[4]

Buyback rates developed by Guerrero et al. (2010) were also investigated. The buyback rate for electricity in Texas varies depending on hourly surplus or shortage. For analysis, an average Texas (Kansas) buyback rate of 65% (27%) of the electricity price is used. Credit from selling excess electricity back to the grid from the hybrid system corresponds to the average buyback rates by state. This credit is determined by net metering, which allows producers to offset their electrical cost by banking excess electricity produced until used. Under a monthly net metering scenario, producers bank excess electricity for a month at a time. Within the month, the producer is charged the net amount of electricity used. A more flexible alternative policy is annual net metering, in which producers can bank for a year instead of month-to-month. Net metering programs provide an incentive for alternative electrical generation; however, not all electric utility companies have net metering programs (Guerrero et al., 2010).

Energy system cost differentials calculated by equation (3) are presented in Table 4. These cost differentials vary by crop, lift, and state. Of particular interest is the differentials are all positive, which indicates a potential cost saving from replacing a natural gas pump with either an electric or a hybrid. An important result is these cost differentials do not vary much across crop or lift for the electric to hybrid systems. This is the result of the energy coefficient not varying much for electric pumps by crop and lift. As a result, the drift and volatility estimates in Table 5 do not vary for electricity to hybrid. In contrast, for natural gas to electric or hybrid, the energy cost differential does vary by crop and lift. Figure 1 illustrates the energy cost differentials for Texas corn with a 500′ lift between 1997 and 2011. Replacing natural gas with a hybrid offers a higher cost savings relative to electricity replacing natural gas or a hybrid replacing electric. The volatility in the cost differentials associated with natural gas replacements is the result of natural gas price instability relative to electricity prices over this period. As indicated in Table 3, the coefficient of variation for natural gas prices is considerably higher than the variation in electricity prices. Similar figures occur for wheat, sorghum, a 500′ lift, and the state of Kansas.

The Brownian motion (equation [4]) assumes the statistical properties including the drift and volatility are all constant over time. This requires a stationary series in which its

[3] For a more detailed description of the fixed and variable irrigation pumping costs, refer to Lima (2012).

[4] As a result of their competitive nature, Texas and Kansas natural gas (electricity) prices track together with little variation in their differences.

Table 2. Investment and Operating Costs by State, Lift, and Energy System

	Texas			Kansas		
Item	Natural Gas	Electric	Hybrid	Natural Gas	Electric	Hybrid
Engine/motor cost investment						
Lift						
200′	$10,997	$12,342	$228,067[a]	$35,940	$24,275	$240,000
	7.64[b]	6.86	95.03	24.96	13.49	100.00
500′	35,940	24,275	240,000	43,550	42,170	257,895
	24.96	13.49	100.00	30.24	23.42	107.46
Useful life (years)						
200′ and 500′	10	15	15/20[e]	10	15	15/20[e]
Salvage value (% of investment)						
200′ and 500′	10	10	10/0[e]	10	10	10/0[e]
LMR[c]						
200′	1084	450	1,910	1480	930	2,440
	9.03[b]	3.75	15.92	9.03	7.75	20.33
500′	1,480	774	2,234	2,178	1,416	2,926
	12.33[b]	6.45	18.62	18.15	11.80	24.38
Investment and operating costs[d] (corn, wheat, and sorghum)						
200′	239.78	150.40	2,108.49	590.20	293.91	2,257.09
500′	584.89	269.74	2,228.81	761.73	503.53	2,466.70

[a] Turbine, motor, and conversion.
[b] Annual costs per acre.
[c] LMR denotes lubrication, maintenance, and repair.
[d] The investment and operating costs, I, include the initial sunk cost along with the annual operation cost associated with the energy system discounted at 6% through the time horizon.
[e] Motor/tubine.

statistical properties are the same in the future as they were in the past. It assumes there is no unit root where the mean and volatility may depend on time. Thus, natural gas and electricity cost data series were tested for the presence of unit roots. An augmented Dickey-Fuller test was performed, in which the null hypothesis is the existence of a unit root and the alternative is a stationary process. The Dickey-Fuller test was applied to the difference between energy source costs converted into logarithm with one lag difference. The results indicate the null hypothesis of a unit root can be rejected at the 5% significance level.

Real Options Analysis

Parameters for the geometric Brownian motions (equation [4]) were estimated for the data period 1997–2011. For determining drift, α_i, and volatility, σ_i, parameters in equation (4) denote the first difference in the log of the cost variable C_i as $r_i = lnC_{it} - lnC_{it-1}$. According to Ito's lemma, r_i follows a geometric Brownian motion with drift

$$dr_i = \left(\alpha_i - \tfrac{1}{2}\sigma_i^{\,2}\right)dt + \sigma_i dz. \tag{13}$$

The maximum-likelihood estimators for the drift, α_i, and volatility, σ_i, are

Table 3. Summary Statistics for Natural Gas and Electricity Prices (1997–2011)

	Mean	Minimum	Maximum	Standard Deviation	Coefficient of Variation
Natural gas[a]	$7.705	$3.120	$9.650	$2.000	0.260
Electricity[b]	0.055	0.044	0.069	0.009	0.164

[a] Per Mcf.
[b] Per kWh.

Table 4. Summary Statistics for Energy Cost Differentials[a]

Crop	Lift	Statistic	Texas			Kansas		
			$C_N - C_E$	$C_N - C_H$	$C_E - C_H$	$C_N - C_E$	$C_N - C_H$	$C_E - C_H$
Corn	200′	Mean	$34.47	$82.77	$48.31	$37.30	$62.04	$24.74
		Maximum	81.73	140.66	59.79	88.45	118.63	30.62
		Minimum	6.56	44.92	38.22	7.10	26.83	19.58
		Standard deviation	25.08	29.37	8.30	27.14	29.08	4.25
	500′	Mean	37.93	86.13	48.31	40.28	64.90	24.74
		Maximum	104.39	163.32	59.79	110.84	141.02	30.62
		Minimum	0.26	37.96	38.22	0.28	19.17	19.58
		Standard deviation	35.87	39.62	8.30	38.09	39.89	4.25
Wheat	200′	Mean	21.68	69.74	48.06	33.70	57.85	24.15
		Maximum	51.41	110.03	59.48	79.93	109.39	29.89
		Minimum	4.12	42.24	38.02	6.41	25.66	19.11
		Standard deviation	15.77	20.49	8.25	24.53	26.44	4.15
	500′	Mean	23.86	71.84	48.06	36.39	60.44	24.15
		Maximum	65.66	124.28	59.48	100.16	129.62	29.89
		Minimum	0.16	37.86	38.02	0.25	18.75	19.11
		Standard deviation	22.56	26.63	8.25	34.42	36.18	4.15
Sorghum	200′	Mean	21.68	69.01	47.34	33.70	57.31	23.61
		Maximum	51.41	109.15	58.59	79.93	108.72	29.22
		Minimum	4.12	41.67	37.45	6.31	25.24	16.68
		Standard deviation	15.77	20.40	8.13	24.53	26.39	4.05
	500′	Mean	23.86	71.12	47.34	36.39	59.89	23.61
		Maximum	65.66	123.40	58.59	100.16	128.69	29.22
		Minimum	0.16	37.29	37.45	0.25	18.32	18.68
		Standard deviation	22.56	26.55	8.13	34.42	36.14	4.05

[a] C_N, C_E, and C_H are natural gas, electricity, and hybrid annual energy costs, respectively. The stochastic nature of these costs is based on the 1997–2011 period. The mean prices for natural gas and electricity are $5.705 per Mcf and $0.055 per kWh, respectively. The energy coefficients are: 0.77 for Texas 200′ lift natural gas, 46.52 for Texas 200′ lift electricity, 1.13 for Texas 500′ lift natural gas, 80.24 for Texas 500′ lift electricity, 0.80 for Kansas 200′ lift natural gas, 48.22 for Kansas 200′ lift electricity, 1.15 for Kansas 500′ lift natural gas, and 81.60 for Kansas 500′ lift electricity. The amount of irrigation varied by state and crop and was determined using the distribution of crop growing seasons.

(14) $$\sigma_i^2 = \sum_{t=1}^{n} \left(\frac{r_{it} - \mu_i}{n}\right)^2$$

and

(15) $$\alpha_i = \mu_i + \frac{\alpha_i^2}{2},$$

where n is the number of observations and $\mu_i = \sum_{t=1}^{n} \left(\frac{r_{it}}{n}\right)$. As a foundation for the feasibility analysis, Table 5 lists the estimated drift and volatility parameters for converting from a natural gas to a hybrid and electricity to a hybrid pump. The cost differentials across crops and lifts are similar resulting in the same drift and volatility parameters for the electricity to hybrid replacement. As noted, this electric to hybrid result occurs given similar energy efficiencies across crops and lift yielding comparable energy cost differentials (Table 4). In contrast, the drift and volatility for natural gas to hybrid do vary across lifts, but only some across crops.

The average differences from 2007 to 2011 for each energy replacement combination in equation (3), $\overline{C}_i$, were used to compare energy replacements across crops, locations, and lifts. Cash flow streams accounted for the taxes, insurance, buyback rates, inflation, and discount rates. Similar to Guerrero et al. (2010), taxes are set at 1% of the value achieved through the tax assessment ratio of 0.20 and insurance costs are set at 0.6% of the investment cost. A tax credit that reflects depreciation of certain business investments is approximated using the Modified Accelerated Cost-Recovery System

Table 5. Drift and Volatility Estimates

Crop	Lift (feet)	Drift	Volatility
Natural gas to hybrid			
Kansas			
Corn	200	0.086	0.365
	500	0.148	0.524
Wheat	200	0.082	0.354
	500	0.139	0.505
Sorghum	200	0.083	0.357
	500	0.141	0.511
Texas			
Corn	200	0.056	0.255
	500	0.083	0.357
Wheat	200	0.045	0.196
	500	0.060	0.270
Sorghum	200	0.045	0.198
	500	0.060	0.273
Electricity to hybrid			
Kansas and Texas			
Corn, wheat, and sorghum	200′ and 500′ lift	0.031	0.038

over 5 years at a 15% marginal tax rate. All costs after the first year are adjusted at 3% per year and the net operational cost stream suffered a 6% discount rate.

Natural Gas to Electricity

As indicated in Tables 2 and 4 for all crops, lifts, and states, the changes in investment cost $I_a = (I_N - I_E)$, (equation [1a]) and energy costs C_a (equation [3a]) are both positive. This implies replacing a natural gas pump with an electric pump requires lower investment cost I_a and yields a lower stream of energy costs C_a. Thus, with both investment and energy costs lower, it is optimal to replace natural gas with electrical pumps. When access to electric power is available, an electric pump system should be used once a current natural gas system requires replacement.

Natural Gas to Hybrid

In contrast to a replacement with electricity, replacement with a hybrid is not as clear-cut. As indicated in Table 2 across crops, lifts, and states, hybrid replacements cost considerably more than natural gas. This cost differential must then be offset by hybrid energy savings for a hybrid pump to be adopted. Specially, the NPV criterion (equation [12]) represents the threshold where a hybrid pump becomes optimal. In terms of NPV, if $\overline{C}_i > C_i'$, then replace a natural gas pump with a hybrid. Alternatively, using ROA, if $\overline{C}_i > C_i^*$, then switch to the alternative.

The feasibility results by crops, lifts, and states for replacing natural gas with a hybrid pump at a 6% discount rate are represented in Table 6. For Texas, the NPV cost savings, C_i', are relatively close to the threshold value, $\overline{C}_i$. For corn, a 500′ lift with metering crosses the threshold indicating adopting a hybrid replacement. In contrast, the Kansas average costs, $\overline{C}_i$, are lower than for Texas resulting in NPV analysis not triggering a hybrid replacement. However, the use of net metering in Kansas has a much larger impact on NPV than for Texas. This results in the annual net metering NPVs being close to the threshold value $\overline{C}_i$. In fact, for Kansas corn with a 500′ lift, annual net metering triggers a hybrid replacement. The NPV criterion considering a 5% discount rate triggers further replacement of natural gas with a hybrid pump. For both Texas and Kansas across all three crops, annual net metering

Table 6. Feasibility of Natural Gas to Hybrid (6% discount rate)[a]

	Lift					
	Corn		Wheat		Sorghum	
State	200′	500′	200′	500′	200′	500′
Texas						
Average energy cost, $\bar{C}$	\$96.19	\$98.57	\$81.79	\$83.29	\$80.92	\$82.42
Net present value, C'	112.12	98.64	112.12	98.64	112.12	98.64
Metering						
Monthly	110.52	96.69[a]	110.52	96.69	110.52	96.69
Annual	105.01	87.56[a]	105.01	87.56	105.01	87.56
Real options, C^*	175.42	185.47[b]	155.83	158.86	156.41	159.65
Metering						
Monthly	172.92	181.80	151.51	151.38	153.48	155.70
Annual	164.30	164.64	150.58	145.74	150.58	145.74
Kansas						
Average energy cost, $\bar{C}$	70.92	72.67	68.24	67.83	65.59	67.17
Net present value, C'	100.01	102.30	100.01	102.30	100.01	102.30
Metering						
Monthly	93.78	93.30	93.78	93.30	93.78	93.30
Annual	79.66	70.99[a]	79.66	70.99	79.66	70.99
Real options, C^*	190.82	248.61[c]	187.10	241.98	188.20	243.92
Metering						
Monthly	178.93	226.72	171.09	210.31	174.84	219.19
Annual	152.00	172.53	150.63	166.86	150.63	166.86

[a] Replacement of natural gas with a hybrid pump using net present value criterion is optimal.
[b] Hurdle rate = $C^*/\bar{C} - 100\% = 88\%$.
[c] Hurdle rate = $C^*/\bar{C} - 100\% = 242\%$.

using a 500′ pump triggers a hybrid replacement. For Texas corn and wheat, even without net metering, NPV analysis triggers replacement for a 500′ lift as well as for Texas corn with a 200′ lift. In addition, annual net metering for Kansas corn and wheat with a 200′ lift triggers a hybrid replacement.

These NPV results are in a contrast to the ROA. At a 6% discount rate, ROA does not indicate the feasibility of replacing natural gas with a hybrid pump for any crop, lift, or state. The stochastic nature of energy prices results in hurdle rates in which the present value of benefits has to be substantially higher than

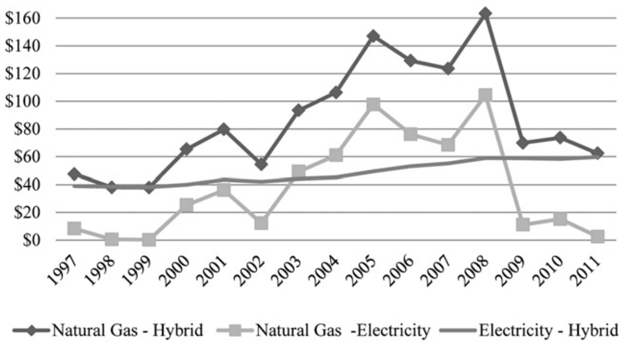

Figure 1. Texas Energy Cost Difference for Corn at 500′ Lift

investment costs before a replacement is warranted.

Figure 2 illustrates the effect that the discount rate has on replacing natural gas with a hybrid for a 500′ lift growing corn in Texas. With average energy cost, $\overline{C}_b$, of \$98.57, NPV analysis would trigger a replacement with a hybrid at slightly less than a 6% discount rate. In contrast, ROA with and without monthly or annual metering requires a lower discount rate of less than 3%. The future value of benefits associated with a hybrid must be discounted at a relatively low rate before they are lower than the initial investment costs for triggering a hybrid replacement. Similar results occur across other crops, lifts, and states, but in a number of cases, even a zero discount rate will not trigger a replacement under ROA, but a positive rate would trigger such a replacement with NPV analysis.

Electricity to Hybrid

With both NPV and ROA indicating electricity to replace natural gas, the opposite extreme results for a hybrid pump to replace electricity (electricity dominates a hybrid pump). Under the NPV criterion, for all Texas (Kansas) crops and lifts, NPV, C', is over 100% (290%) higher than the average energy cost, $\overline{C}$. Using ROA further increases this cost differential: 106% for Texas and 301% for Kansas. For Texas (Kansas) corn with a 200′ lift, average energy cost $\overline{C}$ is \$58.20 (\$29.81) compared with NPV, C', of \$117.49 (\$117.79) and ROA, C^*, of \$120.12 (\$120.44). Similar results are reported in Lima (2012) for the other crops and lifts.

Implications

Whether NPV or ROA is used, the results are similar at the extremes. The replacement option is preferred when there are no costs associated with replacement to all other options. This case is illustrated in the natural gas to electric pump results. The dominant option regardless of the investment criterion is to replace natural gas with an electric pump. At the other extreme is when the cost of replacement is so high that replacement is not feasible regardless of the replacement criteria used. An illustration of this extreme is provided in terms of a hybrid replacing an electric pump. The costs of replacement are so high that regardless of the replacement criteria used, it is not feasible to replace.

The replacement criteria become important when the decision is not at the clear-cut extremes. As indicated in the results, the NPV and ROA criteria can yield opposite replacement decisions depending on the stochastic nature of the parameters, reversibility of the investment, and flexibility of investment timing. Not considering the real option can lead to a false-positive for replacement. Thus, the criterion to replace where NPV > 0 may not be correct if the premium of holding a real option to invest is considered. The uncertainty of future net present values may result in a negative NPV, because replacement with high sunk costs such as a hybrid pump cannot be sold without suffering

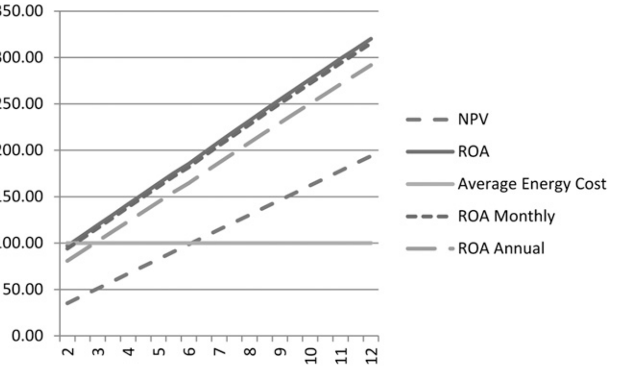

Figure 2. Option to Replace Natural Gas with Hybrid for Texas Corn with a 500′ Lift

some loss. In that case, expected NPV may have to be substantially higher than zero before replacement is considered. This wedge between NPV = 0 and the positive NPV that will trigger replacement is called the hurdle rate, which is defined as the ratio of expected net discounted benefits to costs. For many firms this hurdle rate is where the present value of benefits is two to three times cost before the firm will purchase an asset. A rule of thumb that some companies use in investment decisions is to undertake an investment only if it results in $1 back each year for every $2 spent initially (Wetzstein, 2013).

However, this comparison of NPV with ROA has implications beyond producers' replacement decisions. In terms of policy, NPV results indicate that replacing natural gas with a hybrid pump is on the cusp of being optimal if only costs could be slightly lowered. This would suggest policies that lower costs including net metering, investment tax exemptions, and research development subsidies could just be enough to tip the scale in favor of replacement. Without considering the stochastic nature of energy prices, NPV arrives at this conclusion. With the new hydraulic fracturing technologies, the U.S. proven reserves of natural gas are expanding, leading to potential substantial price declines. However, NPV is unable to account for this possible future natural gas price volatility. ROA with its associated hurdle rate can account for this price volatility and thus indicate this NPV implication may not be correct. Instead, substantial reductions in cost will be required before hybrid replacements are optimal. Major policy incentives may be required before replacement. This has a direct bearing on the types of policies adopted. Net metering and limited duration tax exemptions may not be sufficient incentives for hybrid replacement. Instead, alternative long-term more permanent policies may be warranted. One such permanent policy could be a carbon tax. Such a tax would internalize the external costs of fossil energy and allow the cost of fossil fuels to reflect its total social and private costs.

It is up to applied economists to provide policymakers with analysis that correctly models producer decision processes. As such, ROA offers improved analysis that will aid policymakers in developing programs to mold our future energy portfolio. The model and results presented offer an outline for such improved analysis when considering the stochastic nature of energy costs as inputs into an agricultural production system.

Conclusion

As addressed by Gonzalez, Karali, and Wetzstein (2012), with the continued expansion of renewable energy, the relatively low-cost technologies leading to highly feasible investments will be exhausted first. In these cases, NPV analysis instead of ROA would generally be adequate. However, after highly feasible investment opportunities are exhausted, less favorable options will come into play. An example, addressed in this analysis, is replacing natural gas irrigation pumps with hybrid systems. In such cases, ROA could be used providing a method of considering uncertainty, irreversibility, and flexibility parameters.

Results suggest that using NPV will result in more aggressive replacement: replace the existing system with a hybrid when benefits are just above costs rather than wait until benefits exceed costs to account for uncertainty, irreversibility, and flexibility. ROA provides quantifiable estimates for considering the stochastic nature of natural gas and electricity prices, the irreversibility of replacement, and suggesting the possibility of delaying the replacement decisions may be the optimal solution. This provides empirical support for greater caution where the inaction gap is larger under the ROA. As the results indicate, the natural gas replacement threshold for a hybrid pump in Kansas growing corn with a 500′ lift is over twice as high under ROA as under NPV (Table 6).

Overall improvements in risk management and capital valuation methods are necessary to minimize risk in alternative energy investments. ROA can provide a tool that both limits downside risk and takes better advantage of upside potential. The results suggest using ROA as a decision-making tool would yield improved and better timed investment decisions relative to the NPV approach.

For developing an effective set of policies that promote rather than hinder increased alternative energy production, existing and new creative policies should be assessed in terms of how they affect the underlying barriers of renewable energy investments. Incorporating feasible alternative sets of policies into a ROA will estimate the investment conditions for firms considering renewable energy. In contrast to NPV, ROA will reveal how policies affect the uncertainty, irreversibility, and flexibility of renewable energy investments. Based on this investigation and the objectives of policymakers, an efficient set of feasible policies can be developed yielding an enhanced sustainable renewable energy system.

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