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When to Get In and Out of Dairy Farming: A Real Option Analysis

Loren W. Tauer

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Abstract

The Dixit entry/exit real option model, modified to accommodate a milk price support regime, was applied to the entry/exit decisions of New York dairy farmers. Results varied by farm size, but for the 500-cow farm the entry milk price is $19.09 and the exit milk price is $11.66 when farmers were allowed to continuously enter and exit the industry. With no option to ever return to dairy farming, the exit milk price falls to $10.00.

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Introduction

Over forty years ago Glenn Johnson discussed how supply response in agriculture was nonsymmetric such that supply elasticity empirically often appeared to be lower for a price decrease than for a price increase. He postulated this was due to fixed investment in land and labor, such that the opportunity costs were too great for exit except at very low prices. At that time the economic theory and mathematics to model this asymmetric response had not been developed, except for ad hoc approaches estimating separate output responses to price increases and decreases. Beginning with McDonald and Siegel (1985, 1986) among others, and developed and popularized by Dixit and Pindyck, entry and exit into an industry can now be modeled using real option concepts. Essentially, this approach uses financial option theory applied to physical assets rather than financial assets, with the realization that the entry decision can be modeled as a call option and the exit decision can be modeled as a put option.

This article uses the model developed by Dixit to model the entry and exit decision of the dairy farmer. In recent years the price of milk has begun to fluctuate much more than in the past with resultant extreme variations in the profits earned by dairy producers. Many times the price has fallen and held for an extended period such that only the most efficient producers would have been able to earn a positive return. Yet, we continued to observe only the normal trend exodus of dairy farms. At other times many more dairy farms exited.

The model requires that milk prices evolve as a Geometric Brownian Motion, which generates a lognormal price distribution with a lower price bound of zero and an

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upper price bound of infinity. The price of milk could approach infinity at some minute probability; but given the existence of a milk price support mechanism in the U.S., the price of milk could never approach zero. Thus, we modify the Dixit model so that the milk price above the support price is modeled as a Geometric Brownian Motion resulting in a lognormal distribution of milk price minus the support price. This is accomplished by subtracting milk support prices from observed empirical milk market prices.

Using data collected from New York Dairy Farm Business Summary participants, we determine what milk prices should encourage farmers to exit and enter the industry given the investment and cost structure of different dairy farms. What we find is that there are lower and upper prices such that exit does not occur until milk price moves below the lower price bound, and entry does not occur until milk price moves above the upper price bound, producing hysteresis between the price bounds. Since dairy producers have different costs of production, these price bounds vary by type of farm, although all may have the same milk price movement expectation.

The Dixit model allows the farmer to enter and exit repeatedly. Yet, most farmers when they exit never return.[1] That phenomenon is modeled as an exit/no-return option and compared with the entry/exit combination. We find that if the farmer is not able or willing to re-enter then the exit milk price is much lower than with exit/entry. Essentially, without the option to re-enter later, the farmer is more reluctant to exit.

There have been applications of real option concepts to agricultural investment decisions, including Richards and Patterson, and Carey and Zilberman, among many others. For dairy investment decisions, Purvis, Boggess, Moss and Holt modeled the freestall housing investment as a real option problem and found that the present value of the investment would have to be much greater than the investment cost before the investment would be made. Engel and Hyde found the same for the adoption of robotic milking systems.

[1] Two colleagues in my academic department exited dairy farming and became college professors. They never re-entered dairy farming even when milk prices set all-time high prices a number of times during their professional careers. A switching option specification (between careers) might be used to analyze their decisions.

The Farming Entry and Exit Decisions as Options

Why a farmer may not get out of farming, even when he is currently experiencing losses, is easily expressed by any farmer. Next year might be better, and he is keeping his options open. Why someone may also hesitate to get into farming can also be expressed in option terminology. There may be profit today but it might be wise to see if profitability continues before making the investment. The exit decision is viewed as a put option and the entry as a call option, with the farmer as a holder (buyer) of these options. These options have value.

The standard economic operating decision, given perfect information and no adjustment costs, is to invest when the product price is above the sum of fixed and variable cost. In a multi-period setting, that would be when NPV is positive. The decision to shut down is when the product price is below variable cost. Given positive fixed and variable costs, this would generate both a lower and upper milk price band such that new investment would not occur until the upper milk price is reached, and exit would not happen until the lower milk price is reached. The call and put options further increase the upper price and decrease the lower price. That is because if the upper price band is reached and you make the investment, you kill your option value to wait. Thus, it takes an even higher milk price than the sum of fixed and variable costs before you make the investment. In contrast, when you exit you kill the option to continue operating, and this takes a lower milk price than the variable cost alone.

The basic Dixit model assumes that the original investment is lost and there may be additional costs to exit. Yet for many dairy farms a significant amount of the initial investment can be recovered upon exit. Cows are liquid and land always has value. If that is the case, the Dixit model can be modified with a negative exit cost, reflecting what the farmer may recover of the original investment. A current farmer may then find it optimal to exit while the milk price is even greater than variable cost. Although the farmer may be covering variable cost, he may not be covering total cost, and the stochastic price may go even lower than the current price. It might be best to "get out while you are ahead – if you can get back in at little cost". If you can recover all investment and re-enter at no cost, you will exit when price falls below total cost and re-enter when price moves above total cost. The problem is that many farmers never re-enter. Farmers who participated in the Federal Dairy Buy-Out Program generally did not return to dairy farming after the required 5-year exodus, even when they kept the land and buildings. Farmers who sell everything and leave agriculture often sell a farm that has been in the family for generations. This family farm is not replaceable and the re-entry option is gone. By excluding the option to re-enter, the exit milk price is even lower.

It is interesting that the uncertainty of the milk price is what determines these costs, and it is not necessary for the producer to be risk averse. In fact, most analysis is done assuming that the farmer is risk neutral. Simply the existence of price variability and entry and/or exit costs produce option value.

An important assumption of the model is that delayed investments remain available in the future. That is easily the case for proprietary investment, but obviously might not be the case in a competitive industry such as agriculture. If an investment is profitable and a farmer does not make the investment, some other farmer might. Leahy addressed this issue and showed that the investment strategy using these real options models is still optimal in competitive equilibrium even though the price process is endogenous. The introduction of competition reduces the value of investment options but does so by reducing the value of the invested capital. Since competition reduces the value of actual and potential capital at the same time, the trade-off between the two is unaffected. Farmers may treat the price process as an exogenous diffusion process whose mean and variance are a fixed function of the price level.

Mathematics of the Entry and Exit Option Model

The Dixit model requires assumptions concerning the characteristics of the investment. First is that the investment has an infinite life and is nondepreciating. Land has an infinite life and buildings have long lives. It is clear that components of the dairy farm do depreciate, although land does not, and buildings depreciate slowly. Depreciation can be included into the model by one of two methods. If the investment depreciates and that depreciation is not restored, then depreciation can be modeled like a stock dividend by adjusting the discount rate. If depreciation is restored by replacement, then the depreciation necessary to maintain the investment is added to the constant operating cost.

We elect to add depreciation to the operating cost presuming most farmers replace depreciated equipment.

Assume that the price of milk follows a Geometric Brownian Motion specified as:

$dP = \mu P dt + \sigma P dz$ (often rewritten as $dP/P = \mu dt + \sigma dz$) (1)

where:

P is the price of milk minus the milk support price,

μP is the expected drift rate of P,

$\sigma^2 P^2$ is the variance rate of P, and

dz follows a Wiener process, i.e., $dz = \varepsilon\sqrt{dt}$, with ε being a random draw from a standardized normal distribution ($E(\varepsilon) = 0$ and standard deviation of ε is 1).

Using the square root of time allows the process to be Markovian. Note that in keeping with conventional notation the variable P is used to represent the stochastic market price of the product, but in this case that variable represents the milk market price minus the milk support price.

If the cost of production is assumed to be constant, or at least not extremely variable over time, then the value of the farm is strictly a function of the milk price and a stochastic component represented by time, expressed as $V(P,t)$. If cost is expected to vary significantly over time, then it can be entered as an additional stochastic variable which makes the mathematics more complex; or alternatively, the price variable P can be altered to represent an annual net operating return variable (NR). The modeling approach of price variable and cost constant is used since the price of milk is a transparent and published statistic while net return is not. However, we will also model and solve using net operating return.

A Taylor expansion of the function $V(P,t)$ around the variables P and t produces:

$dV = \partial V/\partial P\, dP + \partial V/\partial t\, dt + 1/2\, \partial^2 V/\partial P^2\, (dP)^2 + \ldots,$ (2)

where terms $(dt)^2$, $(dP)^3$ and higher vanish in the limit. In ordinary calculus the term $(dP)^2$ would also vanish but not in this case since dP follows a Brownian Motion.

Inserting equation (1) for dP and the square of equation (1) for $(dP)^2$ into equation (2) produces the following Ito process:

$$dV = \left(\frac{\partial V}{\partial P} \mu P + \frac{\partial V}{\partial t} + \frac{1}{2} \frac{\partial^2 V}{\partial P^2} \sigma^2 P^2 \right) dt + \frac{\partial V}{\partial P} \sigma P dz \qquad (3)$$

Since this is an infinite horizon problem, the variable t is not a decision variable and the derivative $\frac{\partial V}{\partial t}$ can be deleted.

Denote $\frac{\partial V}{\partial P} = V'(P)$, $\frac{\partial^2 V}{\partial P^2} = V''(P)$ for notational simplification, then (3) can be re-written as:

$$dV = \left(V'(P) \mu P + \frac{1}{2} V''(P) \sigma^2 P^2 \right) dt + V'(P) \sigma P dz$$

Taking the expected value of both sides of the equation yields

$$E\,(dV) = \left(V'(P) \mu P + \frac{1}{2} V''(P) \sigma^2 P^2 \right) dt \qquad (4)$$

since the expectation of dz, a normal standard deviate, is zero.

Deriving the Functional Form of the Value of an Idle Project

In equilibrium the expected capital gain of an idle project (denoted by $dV_0(P)$) should equal the normal return from the value of the investment ($= \rho V_0(P)dt$), where ρ is the discount (interest) rate. We use a risk-adjusted interest rate rather than the risk-free rate appropriate under contingent valuation (Dixit and Pindyck). There are short-term milk futures but these would not completely span the future, so long-term risk could not be hedged. Equating produces:

$$[V_0'(P)\ \mu P + \frac{1}{2} V_0''(P)\ \sigma^2 P^2\,]dt - \rho V_0(P)dt = 0$$

Dividing the above equation by dt, produces the differential equation:

$$V_0'(P)\ \mu P + \frac{1}{2} V_0''(P)\ \sigma^2 P^2 - \rho V_0(P) = 0$$

As shown by Dixit, the general solution for this differential equation is of the form: $V_0(P) = AP^{\alpha} + BP^{\beta}$

where:[2]

$$\alpha = \frac{\sigma^2 - 2\mu - ((\sigma^2 - 2\mu)^2 + 8\rho\sigma^2)^{1/2}}{2\sigma^2} < 0 \tag{5}$$

$$\beta = \frac{\sigma^2 - 2\mu + ((\sigma^2 - 2\mu)^2 + 8\rho\sigma^2)^{1/2}}{2\sigma^2} > 1 \tag{6}$$

assuming $\rho > \mu$, and A and B are constants to be determined.

For an idle project, the value of an investment should go to zero as the price P goes to zero. Since $\alpha < 0$ and $\beta > 1$, $V_0(P) = AP^{\alpha} + BP^{\beta}$ goes to zero when P goes to zero only if $A = 0$. So the functional form of the value of an idle project (denoted by V_0) becomes

$$V_0(P) = BP^{\beta} \tag{7}$$

Deriving the Functional Form of the Value of an Active Project

In equilibrium the following condition holds for an active project:

Normal return = expected capital gain + net revenue flow. This is stated as:

$$\rho V_1(P)\, dt \;=\; E[dV_1] \;+\; (P - C)dt$$

where C is variable cost above the milk support price per hundredweight of milk produced since P is the milk price above the support price.

Substituting $E\,[dV] = \left(V'(P)\mu P + \frac{1}{2}V''(P\;)\sigma^2 P^2\right)dt$ from (4) into the equation above, dividing both sides by dt, and rearranging the equation produces:

$$V_1'(P)\,\mu P + \frac{1}{2}\,V_1''(P)\,\sigma^2 P^2 - \rho V_1(P) + P - C = 0.$$

The general solution for this differential equation is:

$$V_1(P) = P/(\rho - \mu) - C/\rho + AP^{\alpha} + BP^{\beta}$$

where:

$P/(\rho - \mu) - C/\rho$ is the present value of the net revenue.

$AP^{\alpha} + BP^{\beta}$ is the value of the option to abandon the project.

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[2] In Dixit, equation (5) is defined and used as $-\alpha$ in further derivations since it has a negative value. In Dixit and Pindyck, they keep $\alpha < 0$ but use β_2 for notation.

Clearly, as the price P goes to infinity, this option value of abandonment goes to zero. Since $\alpha < 0$ and $\beta > 1$, $AP^{\alpha} + BP^{\beta}$ goes to zero when P goes to infinity only if $B = 0$. Therefore, the functional form of the value of an active investment project becomes

$$V_1(P) = P/(\rho - \mu) - C/\rho + AP^{\alpha} \tag{8}$$

Deriving the Investment Trigger Point and Abandonment Point

At the investment trigger point H, the value of the option (the value of the idle project) must equal the net value obtained by exercising it (value of the active project minus sunk cost of investment, represented by K). So we must have:

$$V_0(H) = V_1(H) - K \text{ or}$$

$$V_1(H) - V_0(H) = K \tag{9}$$

This is the value-matching condition.

The smooth-pasting condition requires that the two value functions meet tangentially:

$$V_1'(H) - V_0'(H) = 0 \tag{10}$$

Similarly, at the abandonment point L we have:

$$V_1(L) - V_0(L) = -X \qquad \text{(value-matching condition)} \tag{11}$$

$$V_1'(L) - V_0'(L) = 0 \qquad \text{(smooth-pasting condition)} \tag{12}$$

where X is the cost of abandoning the investment K, which is assumed worthless. If some of the original investment K is recovered, such that value remains after liquidation costs, then those net proceeds are entered as a positive X value.

Substituting the functional form of V_0 and V_1 from equations (7) and (8) into equations (9), (10), (11), (12) produces the following system of differential equations:

$$H/(\rho - \mu) - C/\rho + AH^{\alpha} - BH^{\beta} = K \tag{13}$$

$$1/(\rho - \mu) + \alpha AH^{\alpha-1} - \beta BH^{\beta-1} = 0 \tag{14}$$

$$L/(\rho - \mu) + AL^{\alpha} - BL^{\beta} = -X \tag{15}$$

$$1/(\rho - \mu) + \alpha AL^{\alpha-1} - \beta BL^{\beta-1} = 0 \tag{16}$$

In this system of equations, ρ, μ , σ^2 are parameters which can be estimated directly from empirical data. Then α, β can be calculated by applying formula (5) and (6). Finally, the four unknowns A, B, L, H can be obtained numerically as a simultaneous solution to the four equation system (13-16). This is done with the use of Mathcad software.

Deriving the Solution for Exit Only

Dairy farmers currently operating who are not able to re-enter if they exit, only have the exit option. The impact of that single option can be determined.

Equation (8) provides the value of an active project. If the farmer is currently invested, then the value of leaving the business is:

$$V_2(P) = X > 0, \text{ where } X \text{ is the sales value.} \tag{17}$$

The value matching condition equating equations (8) and (17) becomes:

$$P/(\rho - \mu) - C/\rho + AP^{\alpha} = X \tag{18}$$

The smooth pasting condition, which is the derivative of (18) wrt P becomes:

$$1/(\rho - \mu) + \alpha AP^{(\alpha+1)} = 0 \tag{19}$$

Solving for A in the smooth pasting equation (19), inserting into the value matching equation (18) and solving for P produces:

$$P = (\alpha/(\alpha+1))^* ((\rho - \mu)/\rho)^* (\rho X+C) \tag{20}$$

This closed form solution for P can be used to map out the exit milk prices.

Estimating the Entry and Exit Price of Milk

Parameter Estimates

The Department of Applied Economics and Management at Cornell University collects annual farm business data on a group of cooperating farms, which provides information on investment and cost of production (Knoblauch, Putnam, and Karszes). The average annual price of milk received by Dairy Farm Business Summary (DFBS) participants and their operating costs per hundredweight of milk produced over the last 10 years are shown in Table 1 and plotted in Figure 1. It appears that the price of milk is much more variable than operating cost, especially during the last 7 years. During the last seven years the annual average price of milk has ranged from \$13 to \$16 dollars per hundredweight, while the operating costs of producing milk have ranged from \$11 to \$12. It would be possible to use these annual milk prices to estimate both μ and σ^2 for the option model since prices that are a random walk at the monthly level would also display a random walk at the annual level. However, monthly prices are available from USDA surveys and provide many more observations to estimate volatility. Monthly cost data are not available from any source, so these annual DFBS investment and cost of production data are used.

Table 1. Milk Price and Operating Costs for New York DFBS Farms

Year	*Milk price $/cwt.*	*Operating Costs Reported $/cwt.*
1993	13.14	10.18
1994	13.44	10.47
1995	13.03	10.40
1996	14.98	12.00
1997	13.65	11.76
1998	15.60	11.50
1999	14.91	11.22
2000	13.38	11.31
2001	15.98	11.87
2002	12.98	11.01

The premise underlying option pricing is that the stochastic price variable follows a random walk. The option model developed further assumes that milk prices are log normally distributed with a lower bound of zero and an upper bound of infinity. It is possible that the milk price can approach infinity. However, the dairy industry in the U.S. operates with a Federal support price mechanism, preventing the price of milk from reaching zero. Given this phenomenon, the lower bound of the milk price is the milk support price and, thus, subtracting support prices from market milk prices produces a lower bound of zero.[3] Monthly milk support prices were subtracted from monthly milk prices received by New York farmers over the period 1993 through the end of 2003 producing 120 observations. These are plotted in Figure 1.

[3] Given the operational complexity in maintaining a support price, the market price of milk to a farmer can dip below the support price, although this did not happen to any of the monthly New York prices.

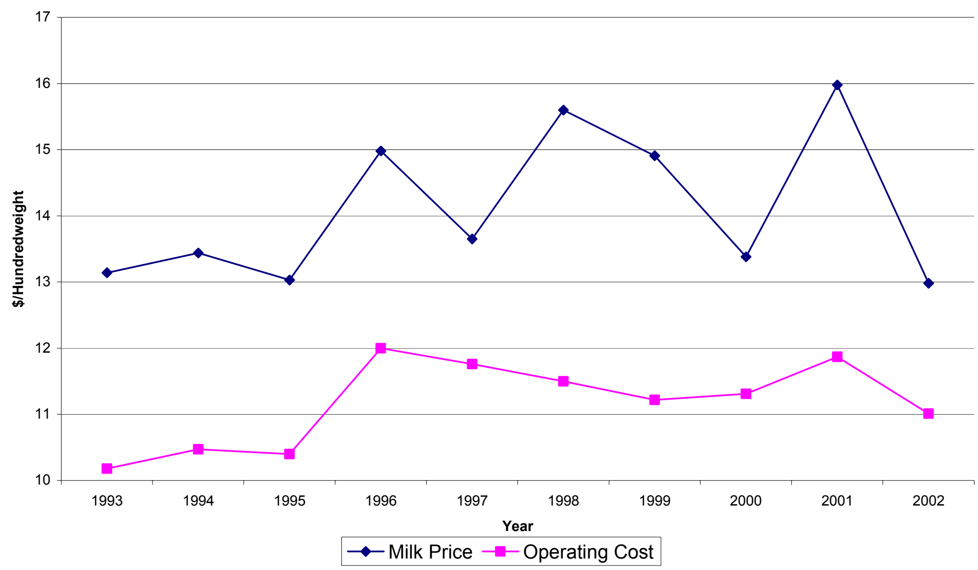

Figure 1. New York Milk Prices and Operating Costs Over 10 Years

To calculate mean and variance of the milk price above the support price, the statistic $d_t = ln(P_t/P_{t-1})$ was calculated which is distributed as $d_t \sim N(\nu - ½\, \sigma^2, \sigma^2)$. The mean ν of this distribution must be corrected to $\mu = \nu + ½\, \sigma^2$ where σ^2 is the variance of the distribution. This resulted in an annually adjusted mean of 0.014 and variance of 0.33236.[4]

Whether New York milk price minus the support price is a random walk was tested with a Dickey-Fuller test. Regressions were estimated for a unit root with a drift (intercept) and trend, with a drift and no trend, and with no drift and no trend. The Durbin-Watson statistic initially indicated that errors in each equation were not strictly white noise, so lagged differences were included beginning with five terms, and deleting

[4] In financial options, daily prices are often used such that the variance is much larger than the mean estimate, with the mean often being ignored or set to zero, especially since it is not required in the Black-Sholes Formula because of risk-free arbitrage. Mean returns are also difficult to accurately estimate (Luenberger). Even if the mean is not zero, most financial options have short lives such that the volatility overwhelms any modeled mean price increase. In our application there is no option expiration.

those not statistically significant. The Durbin-Watson statistics of the final models imply the remaining errors are white noise. In only the random walk equation with no drift and no trend could the null hypothesis of a unit root not be rejected, allowing the weak conclusion of the existence of a unit root and a random walk. It appears, however, that there is drift in the monthly milk price minus support price, but no trend; and in that equation the null hypothesis of a unit root was rejected, implying that the milk price does not follow a random walk. However, Tomek concludes that since the data generating processes for commodity prices are complex and difficult to forecast, and given the costs of arbitrage, any systematic behavior of prices cannot be used to make profitable forecasts. It is thus reasonable to assume that farmers act as if prices do follow a random walk.

A trend line fitted through the DFBS annual operating cost data leads to the rejection of any trend in costs.[5] The fact that operating costs per cwt. essentially have not increased might surprise some since the cost of inputs has increased; but offsetting input price increases is the continuous increase in milk production per cow. Thus, the mean percentage change of operating costs and variance were assumed zero in the following analysis. Assuming a constant operating cost allowed formulating the model in terms referenced to the price of milk (above the support price). Later the stochastic variable in the model is redefined as the net operating return per hundredweight of milk rather than milk price per hundredweight of milk.

Data from the year 2002 of the New York DFBS were used to estimate costs and investments (Knoblauch, Putnam, and Karszes). The reported and plotted operating costs in that annual publication include interest paid and exclude depreciation and the value of operators' labor, so interest paid was subtracted, depreciation on buildings, machinery and equipment was added, and the values of operators' labor were added to operating costs. All depreciation is assumed reinvested into the farm to maintain the investment. Operators' labor is treated as an operating cost rather than modeled as an investment. There is an active market for dairy workers and managers so little human capital would be lost. Cull cows and other receipts besides milk are produced by these farms and the cost of producing those receipts is reflected in operating cost. Thus, the value of those

[5] The change in annual operating cost was 0.0104 with a variance of 0.004.

receipts per cwt. of milk is also subtracted from operating cost to produce the variable cost of producing milk only. On average, these farms paid an interest rate of 5 percent. An additional 300 basis points provides a discount rate of 8 percent.

Although actual monthly support prices over the period 1993 through 2002 were used to estimate the distribution of the net milk price (milk price above the support price), the current support price of $9.90, effective through 2007, was subtracted from variable costs for each farm type. Model solution results were then milk price above the support price, and the support price of $9.90 was added to these solution values to obtain entry and exit market milk prices.

The other variables necessary to make the model operational are an estimate of the investment per cwt. of milk and the cost of liquidating that investment. Dividing total farm assets of various farm sizes by the total annual milk production of that farm size produced investment cost per hundredweight as shown in Table 2. Investment per cwt. of milk decreases by farm size, from a maximum of $46.65 for the 50-cow farm (data from size class 50 to 74 cows), to a low of $27.04 for the 500-cow farm (data from size class 400 to 599 cows). Liquidation costs were estimated at 50 percent of real estate value, 40 percent of machinery and equipment value, and 10 percent of cows, feed, and other assets, all of which are more liquid. Sensitivity analyses on these liquidation costs are reported. Parameters used in the option model are summarized in Table 2.

Results

Milk prices by farm size that would encourage exit and entry into milk production are shown in Table 3. It is important to remember that entry prices reflect turnkey entry of a similar type farm and not incremental investment of current farms. Also, if farmers were able to recover all investment costs upon exit, then entry and exit prices would be equal to the total cost of production – operating and fixed. There would be no cost of entering and exiting the industry and the options would have no value.

Table 2. Option Model Parameters for Various Size Dairy Operations in New York

Number of cows (range of size)	*Investment per cwt. of milk*	*Liquidation value per cwt. of milk*	*Variable cost per cwt. of milk*	*Total cost per cwt. of milk*
50 (50-74)	$46.65	$30.37	$14.66	$18.39
100 (100-149)	43.46	28.84	14.01	17.49
150 (150-199)	37.59	25.59	13.44	16.45
250 (200-299)	29.77	20.50	12.05	14.43
500 (400-599)	27.04	19.00	11.85	14.01

Data generated from Year 2002 NY Dairy Farm Business Summary Report. Future growth in the price of milk above the support price was 0.014. Variance of the percentage change in milk price above the support price was 0.33236. No projected change in operating cost, and variance of that cost is zero. A support price of $9.90 was subtracted from each listed variable cost. Discount rate of 8 percent.

Table 3. Exit and Entry Milk Price for Various Size Dairy Operations in New York

Number of cows	*Total cost per cwt. of milk*	*Variable cost per cwt.*	*Milk price to exit dairy*	*Milk price to enter dairy*	*Milk Price to exit dairy forever*
50	$18.39	$14.66	$13.56	$28.78	$10.42
100	17.49	14.01	13.16	26.80	10.30
150	16.45	13.44	12.77	24.30	10.24
250	14.43	12.05	11.80	20.15	10.01
500	14.01	11.85	11.66	19.09	10.00

Solution by real option model. Model parameters from Table 2. A support price of $9.90 was used.

The 250-cow farm has a variable cost of $12.05, and with an investment of $29.77 at 8 percent interest would have a fixed cost of $2.38, for a total cost of $14.43, producing an operating price range from $12.05 to $14.43. With the addition of exit and entry options, the operating range expands to the range of $11.80 to $20.15. If there were no option to enter with only an exit option of a current farm, that 250-cow farm would not exit until the milk price fell below $10.01.

Exit prices range from a low of $11.66 for the 500-cow dairy to a high of $13.56 for the 50-cow dairy. The lowest milk price in New York during the last 10 years has been $11.80, which is $0.14 above the lowest exit price, and thus would trigger exit, but $1.76 below the highest exit price. During those same 10 years, new entry would not have been justified because the highest milk price during that period was $0.89 less than the lowest entry price of $19.09.

There may be other financial and non-financial factors impacting entry and exit decisions. Many farmers simply are at an age to retire, and beginning farmers will enter as long as the price is reasonable. Another possibility is that the results generated are for averages within a size group, and there can be variation within an average.

The analysis assumes the farmer can recover only a fraction of the initial investment upon exit. If almost all investment can be recovered, then the entry price falls and the exit price increases. In fact, the exit price can rise above the variable cost of production but not the total cost of production. This is illustrated with the 150-cow dairy, using the parameters for that farm as shown in Table 2 but increasing the liquidation value from $25.59 to $33.83, which represents losing just 10 percent of the initial investment upon exit. The exit and entry prices then become $21.14 and $13.78. The $13.78 exit price is above the $13.44 variable cost. Setting the liquidation value to the investment value generates entry and exit prices of $16.45, which is the total cost of production.

At the other extreme the farm may become worthless upon exit. That would raise the exit/no-return price. For the 50-cow farm the exit price would increase from $10.42 to $11.80. This is still less than the variable cost of production of $14.66 for that farm, but there is the opportunity that prices might get better.

Finally, the analysis was also completed using net operating return variability from the 10 years of New York DFBS data, which is the difference between the milk price received by participants and operating cost as shown in Figure 2. This entailed using only 10 observations, but the mean annual growth in net return was 0.04520 and variance was 0.27194. Variance of net operating return is somewhat less than the

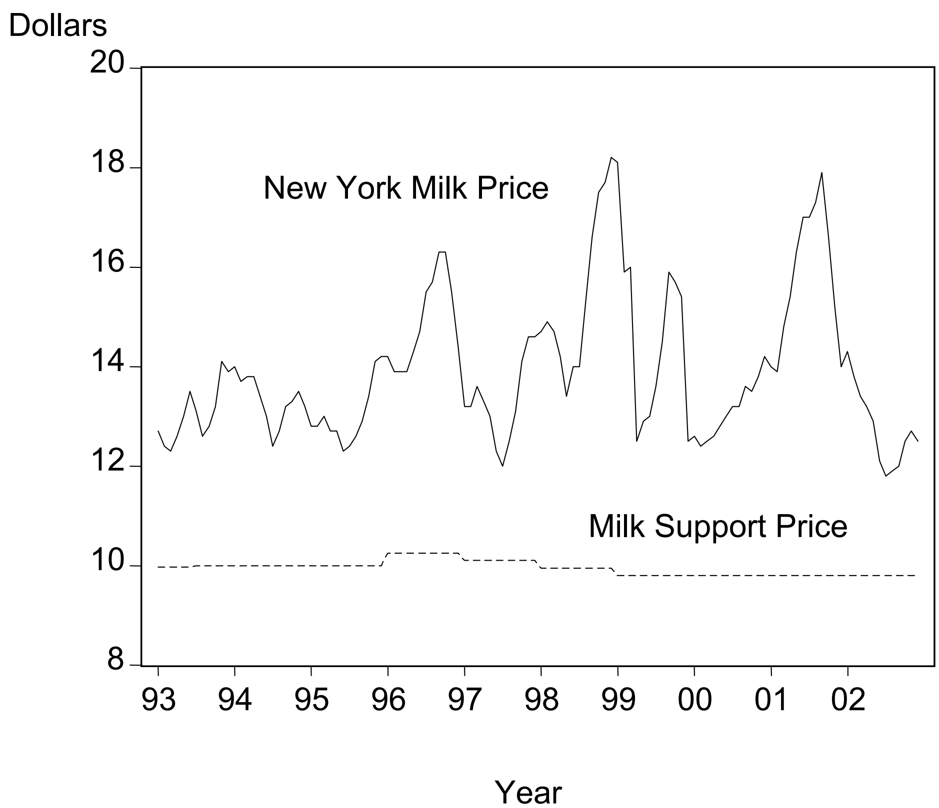

Figure 2. Monthly New York milk prices and milk support prices, 1993 through 2003

variance of the milk price minus support price. The option model was solved setting operating cost (*C*) equal to zero. Using the investment cost of \$37.59 and sales value of \$25.59 for the 150-cow farm produces an entry operating net return of \$7.18 and an exit net operating return of \$0.86. From these amounts would be subtracted a fixed cost of \$3.01 (interest rate of 0.08) resulting in entry and exit net profit of \$4.17 and -\$2.15. Since the average milk price received by these farm business summary farms over the 10-year period was \$14.11, this corresponds to an entry milk price of \$18.28 and an exit milk price of \$11.96. This compares to entry and exit milk prices of \$24.30 and \$12.77, respectively, for the 150-cow farm using milk price minus support price variability and a constant cost of production. The exit/no-return net operating return is -\$0.30, which would be -$3.31 for net profit. At a $14.11 average milk price, this generates an exit/no-return milk price of $10.80, slightly higher than the $10.24 using milk price volatility only in the model.

Conclusions

The entry and exit decisions of the dairy farm were modeled as real options. Conventional economics would dictate that a farmer should exit the industry when the milk price falls below variable cost of production. However, the milk price may recover in the future so a farmer continues to produce, essentially keeping his options open. The value of that option is computed such that the milk price before exit is lower than simply the variable cost of production. At the other end, a farmer should enter the industry when the price of milk is greater than fixed plus variable cost of production. Again, a farmer may not enter immediately since the high milk price may be transient. He wants to see if the high milk price has duration, so essentially keeps his investment option open. The milk entry price must be above not just the sum of fixed and variable cost of production but also the addition of the option value.

Estimating exit and entry milk prices using data from New York dairy producers generate exit and entry prices within the bounds of milk prices these producers have recently experienced, and yet, over that time producers have both exited and entered the industry. Those entry and exit decisions may have also entailed financial and personal considerations outside the option value of waiting. Since the price of milk has only recently become more variable after a long period of stable (but generally increasing) milk prices, producers may underestimate the future variability of milk prices. A lower assessment of volatility would produce lower option values and increase the exit price closer to variable cost and decrease entry price closer to variable plus fixed cost of production. As farmers rationally factor into their decisions greater milk price volatility, production hysteresis will increase.

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Appendix Tables

Appendix Table A1. Dickey-Fuller Test for Unit Root on Monthly New York Milk Prices from 1993 through 2002, Random Walk with Drift and Trend.

ADF Test Statistic	-4.689270	1% Critical Value*	-4.0387
		5% Critical Value	-3.4484
		10% Critical Value	-3.1491

*MacKinnon critical values for rejection of hypothesis of a unit root.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(PRSUP)
Method: Least Squares
Date: 09/02/04 Time: 14:12
Sample(adjusted): 1993:04 2002:12
Included observations: 117 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PRSUP(-1)	-0.206331	0.044001	-4.689270	0.0000
D(PRSUP(-1))	0.274589	0.086380	3.178869	0.0019
D(PRSUP(-2))	0.324992	0.090351	3.597003	0.0005
C	0.713818	0.183815	3.883342	0.0002
@TREND(1993:01)	0.001910	0.001803	1.059224	0.2918

R-squared	0.243941	Mean dependent var	0.003162
Adjusted R-squared	0.216939	S.D. dependent var	0.701192
S.E. of regression	0.620490	Akaike info criterion	1.925181
Sum squared resid	43.12088	Schwarz criterion	2.043222
Log likelihood	-107.6231	F-statistic	9.034135
Durbin-Watson stat	1.903055	Prob(F-statistic)	0.000002

The model is: $z_t = \mu + \beta t + z_{t-1} + u_t$
Estimated as: $z_t - z_{t-1} = \mu\gamma + \beta(\gamma-1)t + (\gamma-1)z_{t-1} + u_t$, where the null hypothesis is $\gamma = 1$.
The Dicky-Fuller test is $(\gamma-1) = 0$, or by default $\gamma = 1$.

Appendix Table A2. Dickey-Fuller Test for Unit Root on Monthly New York Milk Prices from 1993 through 2002, Random Walk with Drift

ADF Test Statistic	-4.594175	1% Critical Value*	-3.4870
		5% Critical Value	-2.8861
		10% Critical Value	-2.5797

*MacKinnon critical values for rejection of hypothesis of a unit root.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(PRSUP)
Method: Least Squares
Date: 09/02/04 Time: 14:15
Sample(adjusted): 1993:04 2002:12
Included observations: 117 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PRSUP(-1)	-0.190999	0.041574	-4.594175	0.0000
D(PRSUP(-1))	0.265407	0.085990	3.086495	0.0025
D(PRSUP(-2))	0.310700	0.089386	3.475944	0.0007
C	0.768818	0.176424	4.357790	0.0000

R-squared	0.236367	Mean dependent var	0.003162
Adjusted R-squared	0.216094	S.D. dependent var	0.701192
S.E. of regression	0.620825	Akaike info criterion	1.918054
Sum squared resid	43.55284	Schwarz criterion	2.012487
Log likelihood	-108.2062	F-statistic	11.65895
Durbin-Watson stat	1.900313	Prob(F-statistic)	0.000001

Appendix Table A3. Dickey-Fuller Test for Unit Root on Monthly New York Milk Prices from 1993 through 2002, Random Walk

ADF Test Statistic	-0.909062	1% Critical Value*	-2.5836
		5% Critical Value	-1.9428
		10% Critical Value	-1.6172

*MacKinnon critical values for rejection of hypothesis of a unit root.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(PRSUP)
Method: Least Squares
Date: 09/02/04 Time: 14:19
Sample(adjusted): 1993:06 2002:12
Included observations: 115 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PRSUP(-1)	-0.012917	0.014209	-0.909062	0.3653
D(PRSUP(-1))	0.206144	0.093482	2.205173	0.0295
D(PRSUP(-2))	0.292752	0.092744	3.156552	0.0021
D(PRSUP(-3))	-0.223463	0.093253	-2.396305	0.0182
D(PRSUP(-4))	-0.180562	0.093746	-1.926071	0.0567

R-squared	0.200997	Mean dependent var	-0.002870
Adjusted R-squared	0.171942	S.D. dependent var	0.705765
S.E. of regression	0.642230	Akaike info criterion	1.994765
Sum squared resid	45.37054	Schwarz criterion	2.114109
Log likelihood	-109.6990	Durbin-Watson stat	2.026884