



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Irreversible Investment Decisions in Perennial Crops with Yield and Price Uncertainty

T. Jeffrey Price and Michael E. Wetzstein

Optimal entry and exit thresholds for Georgia commercial peach production are calculated when both price and yield follow a Brownian motion process. The thresholds are based on an irreversible sunk-cost investment model, where revenue from peach production is affected by the timing of when to enter production. Results indicate stability in Georgia peach production, with growers who are currently producing peaches remaining in production and potential peach growers delaying investment unless they have the ability of earning enhanced returns.

Key words: Brownian motion, hysteresis, Ito control, peach production

Introduction

Production of perennial crops including peaches is characterized by a relatively large sunk cost of orchard establishment and uncertainty in future crop yields and prices. Accounting for this uncertainty in yield and price requires modeling their stochastic processes. As outlined in Hertzler, Ito control offers a procedure for modeling stochastic processes with little sacrifice in realism for a large gain in analytical power. Ito control simplifies the stochastic structure of a model and allows for the derivation of optimality conditions. Since publication of Hertzler's article, a number of agricultural economics studies based on Ito control have emerged. For example, Fousekis and Shortle employed Ito control when considering investment demand with stochastic depreciation, and Purvis et al. applied the Dixit-Pindyck theoretical model to uncertainty about investment cost and environmental compliance. The Dixit-Pindyck model considers investment behavior under irreversibility and uncertainty and it employs the Ito control approach (Dixit and Pindyck).

Dixit and Pindyck generally examine entry and exit conditions for a firm when only output price is uncertain and follows a geometric Brownian motion. Output is assumed nonstochastic; however, in many instances a deterministic future level of output is not realistic. This is especially true in agriculture, where the inability to completely control environmental conditions contributes to the stochastic nature of yield. For example, entry and exit decisions facing commercial peach growers are characterized not only by price uncertainty and relatively high investment sunk costs, but also by yield uncertainty. The price per bushel a grower receives for peaches varies, depending on wholesale demand at the time a grower's peaches are at harvest maturity. For peach

production, the sunk cost of investment includes the cost of fixed inputs necessary for peach production along with three years of operating costs incurred for establishing an orchard with marketable yield. Frequent crop losses attributed to frost, hail, and other weather conditions contribute to the stochastic nature of yield.

A natural extension of Ito control, as suggested by Hertzler, is considering correlated prices and yields, where both price and yield follow a Brownian motion. Prior to Hertzler's article, Stefanou considered the interaction of two stochastic variables—real wage and stock of technical knowledge—when investigating technical change, and Dixit and Pindyck developed the optimality conditions for the product of two stochastic variables following Brownian motion. However, a review of current literature indicated that no research based on the Ito control approach has examined the concept of investment behavior under irreversibility and uncertainty when both price and yield interactions are considered.

This study determines the optimal entry and exit thresholds for commercial peach production when price and yield follow a stochastic process. The optimal entry and exit thresholds are compared with thresholds generated by standard nonstochastic present value analysis, and the sensitivity of these optimal results to changes in parameter values is discussed.

The Model

Given a sunk cost for entering peach production of I , standard present value analysis would compare the discounted present value of expected profits, V , with this sunk cost. If operating costs are assumed fixed, then the revenue threshold triggering adoption would occur where $V = I$. As noted by Dixit and Pindyck, however, McDonald and Siegel demonstrate how this analysis is flawed. The stochastic nature of price and yield creates an opportunity cost associated with entry. Given this opportunity cost, the threshold level of revenue triggering entry will not be where $V = I$, but instead at some level where V is larger than I .

This opportunity cost exists because the timing of when to enter peach production will affect the revenue threshold. Postponing entry may increase revenue, R . This is an optimal stopping problem where, for deterministic problems, the optimal time to exercise the option to enter peach production is determined. But because price and yield are stochastic processes, it is not possible to determine the optimal time of entry. Instead, the entry rule is a threshold value of revenue, R_H . If $R \geq R_H$, then the grower should exercise the option and enter. Similarly, a threshold value of revenue for exiting peach production, R_L , can be determined. As long as revenue is maintained above R_L , production should continue.

The uncertainty associated with entry and exit decisions in peach production arises from fluctuations over time in both the market price for peaches, p , and the yield of peaches, q . This uncertainty may be represented by geometric Brownian motion processes:

$$(1) \quad dp = \alpha_p p dt + \sigma_p p dz_p$$

and

$$(2) \quad dq = \alpha_q q dt + \sigma_q q dz_q,$$

where dp and dq represent the change in the per bushel price and yield of peaches, respectively, α is the rate of change or drift rate, σ is the standard deviation, and the subscripts p and q denote parameters associated with price and yield, respectively. The increment of a Wiener process is dz , with $E(dz_p^2) = E(dz_q^2) = dt$, and $E(dz_p, dz_q) = \rho dt$, where ρ denotes the correlation coefficient between p and q .

Following Dixit and Pindyck, it is assumed growers are risk neutral and maximize their expected net present value of investment. A further assumption is the log-normal distribution of $R = pq$, the product of price and quantity. The log-normal distribution has the theoretically desirable property of expected percentage revenue and associated variance being independent of the level of revenue (Hull). The stochastic process of revenue, R , is determined by the differential of the change in logarithm of R , $dr = d\ln(R)$, following Ito's lemma:

$$(3) \quad dr = \frac{\partial r}{\partial p} dp + \frac{\partial r}{\partial q} dq + \frac{1}{2} \frac{\partial^2 r}{\partial p^2} dp^2 + \frac{1}{2} \frac{\partial^2 r}{\partial q^2} dq^2 + \frac{\partial^2 r}{\partial p \partial q} dp dq$$

Noting $\partial r / \partial p = 1/p$, $\partial r / \partial q = 1/q$, $\partial^2 r / \partial p^2 = -1/p^2$, $\partial^2 r / \partial q^2 = -1/q^2$, and $\partial^2 r / \partial p \partial q = 0$, equation (3) reduces to

$$(4) \quad dr = \frac{1}{p} dp + \frac{1}{q} dq - \frac{1}{2p^2} dp^2 - \frac{1}{2q^2} dq^2.$$

Equations (1) and (2) can be substituted for dp and dq , respectively, noting $(dt)(dz)$ is of order $(dt)^{3/2}$ and, in the limit, every term with dt raised to a power greater than one will go to zero faster than dt . This substitution yields

$$(5) \quad dr = (\alpha_p + \alpha_q - \frac{1}{2}\sigma_p^2 - \frac{1}{2}\sigma_q^2)dt + \sigma_p dz_p + \sigma_q dz_q.$$

Thus, $r = \ln(R)$ follows a simple Brownian motion of general form $dr = \alpha_r dt + \sigma_r dz_r$, implying dr over a time interval T is normally distributed with mean

$$(6) \quad (\alpha_p + \alpha_q - \frac{1}{2}\sigma_p^2 - \frac{1}{2}\sigma_q^2)T,$$

and variance

$$(7) \quad (\sigma_p^2 + \sigma_q^2 + 2\rho\sigma_p\sigma_q)T.$$

An increase in the negative correlation between price and yield reduces the variation in returns, σ_r^2 , by $2\sigma_p\sigma_q$ per unit. Applying Ito's lemma to $R = e^r$, the geometric Brownian motion for dR is specified as

$$(8) \quad dR = \alpha_R R dt + \sigma_R R dz_R,$$

where $\alpha_R = \alpha_r + \frac{1}{2}\sigma_r^2$.

Let $V_0(R)$ denote the expected present value of entering into peach production with revenue R based on the stochastic process (8), and let $V_1(R)$ denote the expected present value of exiting peach production. Dixit and Pindyck demonstrate that the optimal strategy for entry and exit will take the form of two per acre revenue thresholds, R_L and R_H , with $R_L < R_H$. A potential peach grower will not enter into peach production as long as revenue remains below R_H , and will enter production only if R reaches R_H . Growers currently producing peaches will continue growing peaches until revenue falls to R_L . The optimal strategy for growers falling within the range between R_L and R_H is to continue their status quo—either producing peaches or waiting.

These revenue thresholds are determined by the following:

$$(9) \quad -A_0 R_H^{\beta_{01}} + B_1 R_H^{\beta_{12}} + \frac{R_H}{\delta} - \frac{C}{r} = I,$$

$$(10) \quad -A_0 R_L^{\beta_{01}} + B_1 R_L^{\beta_{12}} + \frac{R_L}{\delta} - \frac{C}{r} = 0,$$

$$(11) \quad -\beta_{01} A_0 R_H^{\beta_{01}-1} + \beta_{12} B_1 R_H^{\beta_{12}-1} + \frac{1}{\delta} = 0,$$

$$(12) \quad -\beta_{01} A_0 R_L^{\beta_{01}-1} + \beta_{12} B_1 R_L^{\beta_{12}-1} + \frac{1}{\delta} = 0,$$

where A_0 and B_1 are coefficients, along with R_L and R_H , to be determined. Parameters β_{01} and β_{12} are roots of the fundamental quadratic equation (see Dixit and Pindyck), and C and I represent variable operating costs and sunk cost, respectively. Parameter r denotes the risk-free rate of return, and δ is the return shortfall or dividend measured by the difference in the total risk-adjusted rate of return (γ) and the capital gain (α_R), i.e., $\delta = \gamma - \alpha_R$. These four equations are nonlinear in R_L and R_H , requiring a numerical solution which solves the equations simultaneously.

Application

Dixit and Pindyck's model assumes a nonstochastic output of one unit per period. Thus revenue per period is equal to output price, and the stochastic properties of price then may be used to model uncertainty in the value of the option to invest. In contrast, for this application, both price and output are stochastic; thus revenue becomes a more complicated stochastic function of price, output, and the correlation between them.

As an application, parameter values calculated from Georgia statewide data are listed in table 1 as a baseline from which to consider the decision to enter into or exit from peach production. Annual per acre yield and nominal average seasonal price for Georgia [U.S. Department of Agriculture (USDA)] were modeled to fit the following AR(2) processes:

$$(13) \quad \Delta Z_{it} = \lambda_{0i} + \lambda_{1i} Z_{it-1} + \lambda_{2i} Z_{it-2} + \epsilon_{it}, \quad Z_i = p \text{ and } q,$$

where the λ 's are parameters, the subscript t represents time, and ϵ_{it} denotes the error term. This is the discrete time version of Brownian motion with drift. The variable Z_{it-2}

Table 1. Baseline Parameter Values Employed for Georgia Peach Growers' Investment Decisions

Parameter	Description	Parameter Value
α_p	Price Drift Rate	0.0155
α_q	Yield Drift Rate	0.0045
σ_p^2	Price Variance	0.0813
σ_q^2	Yield Variance	0.0488
ρ_{pq}	Price and Yield Correlation	-0.5206
α_R	Revenue Drift Rate	-0.0451
σ_r^2	Revenue Variance	0.0645
r	Risk-Free Rate of Return	0.06
γ	Risk-Adjusted Rate of Return	0.08
C	Variable Operating Cost	\$864.48
I	Investment Cost	\$2,352.07

is included to allow for the possibility of higher order autoregressive processes in the data series. Under the null hypothesis of Brownian motion without drift, $\lambda_{0i} = \lambda_{1i} = \lambda_{2i} = 0$. The coefficient λ_{2i} can be tested using standard t -test critical values. However, λ_{0i} and λ_{1i} do not have standard asymptotic distributions and should be tested using tables developed for Dickey-Fuller unit root tests. In contrast with yield, which did not indicate the presence of a trend, the upward trend of nominal seasonal price was removed prior to unit-root testing. Accepting the null that $\lambda_{0i} = \lambda_{1i} = 0$ implies the presence of a unit root (Hamilton). The results for both yield and price fail to reject the null hypotheses at a 5% significance level. For both yield and price, an autocorrelation function, a partial autocorrelation function, and the Akaike Information Criterion were also employed in determining the most parsimonious representation of the data. Results indicate both yield and price time series are represented by an AR(1) process.

Yield and price processes are characterized by values for the drift and volatility of price and yield. In calculating drift and volatility for price, the law of one price results in one time series, whereas different drift and volatility values for yield will exist for each grower's orchards, making the values of α_q and σ_q used in the calculation of entry and exit thresholds a matter of choice. Specifically, Davis reports yields for 200 orchards for four of the larger peach producers in Georgia during the period 1990-94. With such a short data series, variances in the annual change in yield from individual orchards during this period range from 6.0 to 0.001, and are highly skewed with a median of 0.40. Given this range in σ_q , statewide data are employed as a baseline for calculating yield drift and volatility. Sensitivity of the associated baseline results to changes in price and yield drift and volatility (α_p , α_q , σ_p , and σ_q) are then investigated.

Values for drift and variance of price and yield (reported in table 1) were computed, as outlined by Hull, from USDA annual yields and average seasonal price data for the

period 1978–97. In 1996, a late-season frost resulted in extremely low yields. This led to a large increase in yield volatility due to the relatively short time series employed for calculating volatility. Consequently, this 1996 catastrophic event is not considered in the table 1 baseline case. However, entry and exit thresholds incorporating this catastrophic event are calculated and discussed.

In table 1, the risk-free rate of 6% reflects recent rates on U.S. Treasury bonds, and the risk-adjusted rate of 8% was calculated from per acre revenue, adjusted for inflation, based on USDA data. For peach production, the sunk cost of investment includes the cost of fixed inputs such as land, trees, and machinery, along with three years of operating costs incurred for establishing an orchard with marketable yields. These sunk operating costs are establishment inputs including chemicals, fuel, repair and maintenance, management, labor, and overhead. The present value of investment discounted at 6% to the third year is \$2,352, and the annual variable operating costs after the third year are \$781.11 per acre (Davis; Harrison, Smajstrla, and Zazueta).

Peach trees have a life of approximately 20 years, with 17 of these years being commercially productive. The analysis can be modified to account for various types of depreciation including sudden death or exponential decay. One would expect that an opportunity to invest in a depreciating project would be less valuable, and therefore allowing for depreciation would reduce the importance of the value of waiting and irreversibility. However, as Dixit and Pindyck demonstrate, the value of the option to invest depends on the degree of irreversibility, which in turn depends not only on the life expectancy of the project, but on the opportunities that may be available when the first project comes to the end of its life. Therefore, an infinite horizon model is employed with an infinite stream of revenue. This continuous stream of revenue is generated from the initial entry into peach production with an annuity of \$83.37 per acre paid annually for 17 years. At the end of a productive orchard's life (17 years), the sum of the annuity covers the three years of orchard establishment costs (\$2,352). Thus, for example, a second orchard will become commercially productive just as the first orchard is being retired. Due to nematode problems, peaches are not normally replanted on a retiring peach orchard. Instead, the orchard is replaced with an orchard on a new land parcel. By adding this annuity to the annual operating costs (for a total annual operating cost of \$864.48), peach production can be continued indefinitely.

Parameter values for drift and variance associated with price and yield are first used to calculate the revenue parameter values. The resulting revenue values are used to calculate the characteristic roots, which in turn are used for simultaneously solving the optimal entry and exit thresholds (R_L and R_H) in (9)–(12).

Results

Table 2 presents entry and exit thresholds for revenue and yield, along with the hurdle rates calculated from the baseline parameter values listed in table 1. As a basis for comparison, consider first the conventional Marshallian revenue thresholds R_L and R_H . These thresholds represent the criteria for entry and exit decisions under the static or myopic approach. Under this conventional approach, growers should consider entry into peach production if the present value of returns is greater than the annualized full cost of investment (R_H), and should consider exiting if returns fall below operating costs (R_L).

Table 2. Entry and Exit Thresholds for Revenue and Yield with Hurdle Rates for Conventional Production

Production Scenario	Revenue Threshold ^a (\$)		Price Per Bushel ^b (\$)	Yield Threshold ^c (bu./acre)	
	R_L	R_H		Y_L	Y_H
Conventional (213 bushels) ^d	864.48	1,006.10	6.50	133.00	154.79
			10.50	82.33	95.82
Optimal (213 bushels) ^d	852.10	2,216.00	6.50	131.09 (0.03)	340.92 (2.20)
			10.50	81.05 (0.03)	211.05 (2.20)
Optimal (catastrophe) ^e	741.40	4,791.00	6.50	114.06 (0.16)	737.08 (4.76)
			10.50	70.61 (0.16)	456.29 (4.76)

^a R_L and R_H denote the revenue per acre which triggers exit and entry, respectively.

^b Net price per bushel after deducting a \$4.50 per bushel harvesting and marketing cost.

^c Y_L and Y_H denote the yield in bushels per acre required to reach R_L and R_H , respectively, for the given price. Numbers in parentheses are the hurdle rate, which is the percentage the optimal Y_L is below or Y_H is above the conventional threshold.

^d Expected bushels per acre.

^e Considers the once-every-35-years 1996 catastrophe.

The zone of inaction between the entry and exit thresholds is caused by what is known as "hysteresis," defined by Dixit to be "the failure of an effect to reverse itself as its underlying cause is reversed" (p. 622). Thus standard theory states that the entry trigger (R_H) is equal to $C + rI$, and the exit trigger (R_L) is equal to C , where C is the variable operating cost, r is the interest rate, and I is the sunk cost of investment. No action takes place when revenue lies between the two. A firm entering when $R = R_H$ will continue to operate until $R = R_L$, while a firm that is idle will not enter until R climbs back to R_H .

Price and yield uncertainty widen the gap between these thresholds, representing the zone of inaction. Many firms will continue to operate even during periods of negative profits if they expect conditions to improve within a specified period of time. Also, firms often will not expand production or make additional investments even during periods of extra-normal profits if expected future uncertainty is sufficiently high. In contrast, if there were no sunk costs, there would be no hysteresis. But with sunk costs, uncertainty quickly becomes an important factor in the decision to invest.

Incorporating price and yield uncertainty, the irreversibility of the investment decision, and the value of the option to delay production enters into the decision, results in a 120% increase in the entry threshold and a 3% decrease in the exit threshold from the conventional thresholds (table 2). These thresholds are robust in terms of the discount rate. Entry thresholds vary by less than 2% from a 2% increase or decrease in

the discount rate. Conversely, exit thresholds vary approximately 0.6% for the same change in the discount rate.

From (6), α_R is a function of α_p , α_q , σ_p , and σ_q . As indicated in table 1, the positive drift in both price and yield is offset by the volatility in price and yield, resulting in a negative revenue drift. This negative revenue drift explains the relatively high hurdle rate for the entry threshold and the relatively low hurdle rate for exiting. With a negative revenue drift, growers would delay entry until the expected revenue threshold is sufficiently high to compensate for the expected downward drift in revenue. In contrast, growers will not delay exiting given the prospect of future declines in revenue.

The negative correlation between price and yield prevents the hurdle rate from being even higher, as a result of revenue volatility shown in (7). This negative correlation dampens the effect of considering the additional yield variability. If there were no correlation between price and yield, R_H would equal \$2,481, and R_L would equal \$761.60.

Figures 1–5 illustrate the variation in entry and exit thresholds as one of the parameters α_p , α_q , σ_p , σ_q , or ρ is varied, holding all other parameters at their table 1 base levels. Recall that changes in these parameters will alter the values for revenue drift and variance according to (6) and (7). Measured on each of the vertical axes is the ratio of optimal to conventional revenue, so as this ratio approaches one, the optimal threshold converges to the conventional revenue level.

Figures 1 and 2 illustrate the effect of variation in α_p and α_q , the trend of the price and the yield processes, respectively. The qualitative effects are the same for each, although quantitative results differ due to the other baseline parameter values. An increase in α reduces both R_H and R_L . If a favorable price trend or yield trend is expected, producers will enter production at a lower threshold of current profitability and, once in production, are willing to continue longer despite a temporary dip below price or yield breakeven levels. As the drift rate increases, for a given variation in revenue the optimal entry threshold converges toward the conventional threshold. The drift rate dominates the tendency of revenue variation to increase R_H , whereas the optimal exit threshold diverges from the conventional threshold as the drift rate increases. Given a relatively strong positive drift rate, producers would be less likely to exit facing low returns.

Figures 3 and 4 show the effect of changes in σ_p^2 and σ_q^2 , the variance in the price and yield processes. Notice that the gap between entry and exit thresholds, representing the zone of inaction or hysteresis, narrows slightly initially and then widens with increasing volatility in either price or yield. This initial narrowing of the zone of inaction is due to the effect of the negative correlation coefficient. At these relatively low volatility levels, the correlation coefficient dominates the volatility in both yield and price resulting in a declining revenue variance.

Assuming a competitive, price-taking industry, commercial peach producers are likely to face the same price and therefore the same level of uncertainty in the price process (σ_p^2 and α_p). However, individual producers may experience different levels of yield drift and/or volatility. As discussed in the applications section, yield variance (σ_q^2), calculated from Davis' data, ranges from approximately 6.0 to 0.001. With σ_q^2 equal to 0.4, which is the median value from Davis' data, the entry and exit revenue thresholds are \$3,495 and \$770.96, respectively. Increased volatility is also associated with the 1996 catastrophe. The baseline variance of 0.0488 increases to 0.8625 with the consideration of the catastrophe. However, this increase in volatility is biased upward, given the

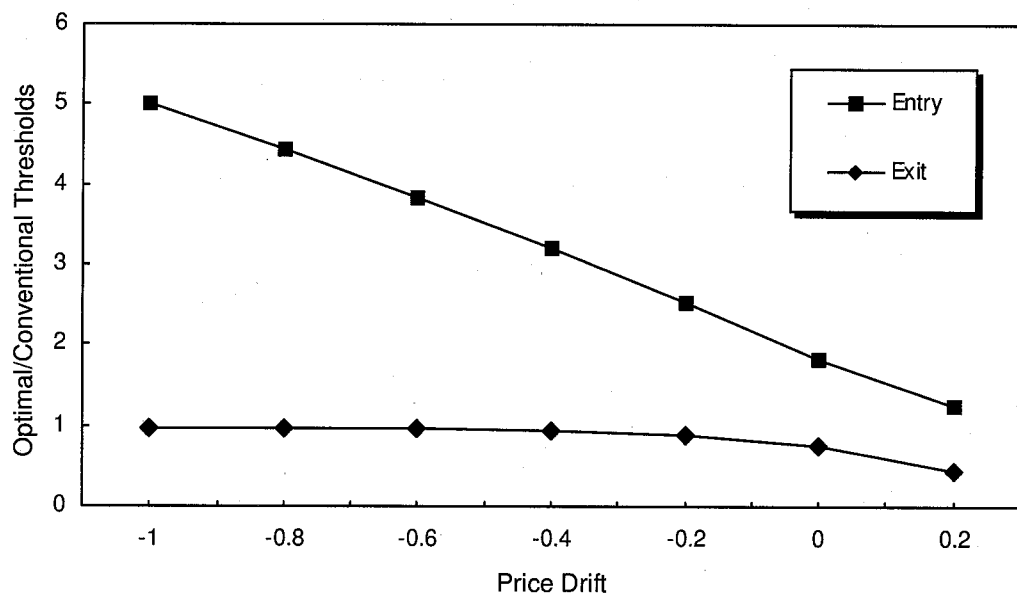


Figure 1. The effect of changes in price drift on optimal/conventional threshold ratios

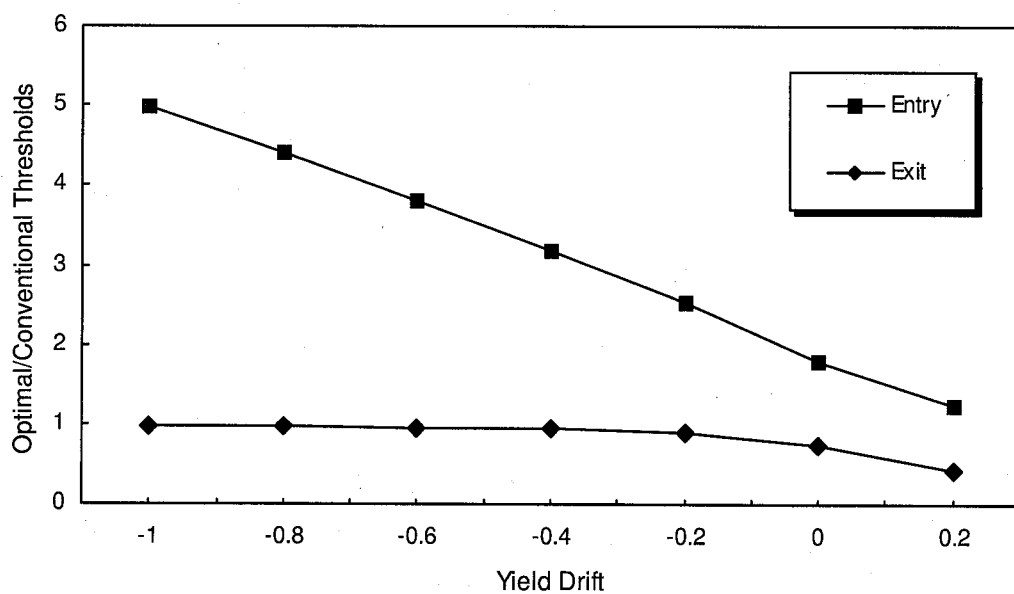


Figure 2. The effect of changes in yield drift on optimal/conventional threshold ratios

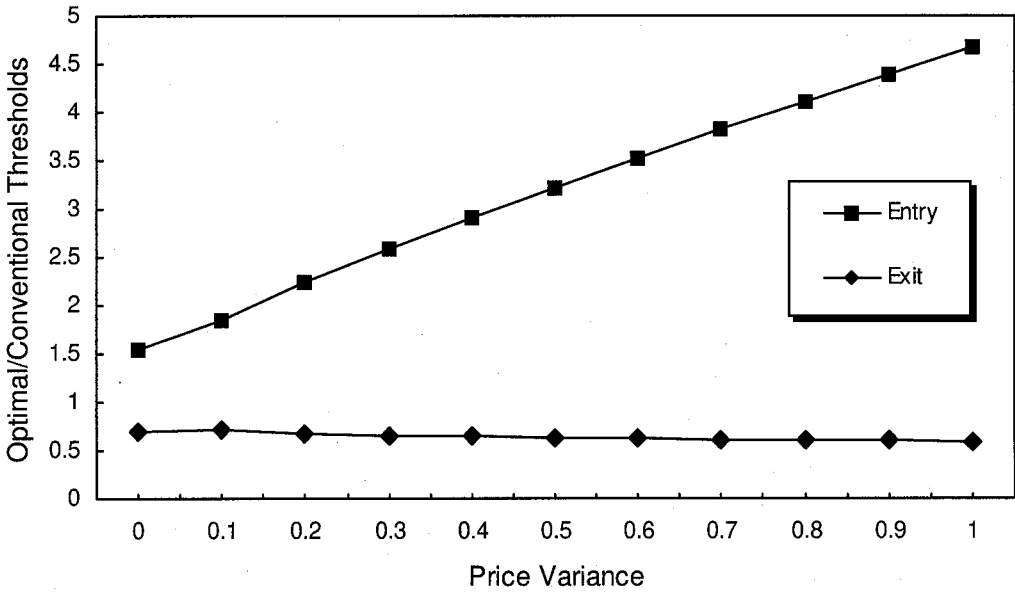


Figure 3. The effect of changes in price variance on optimal/conventional threshold ratios

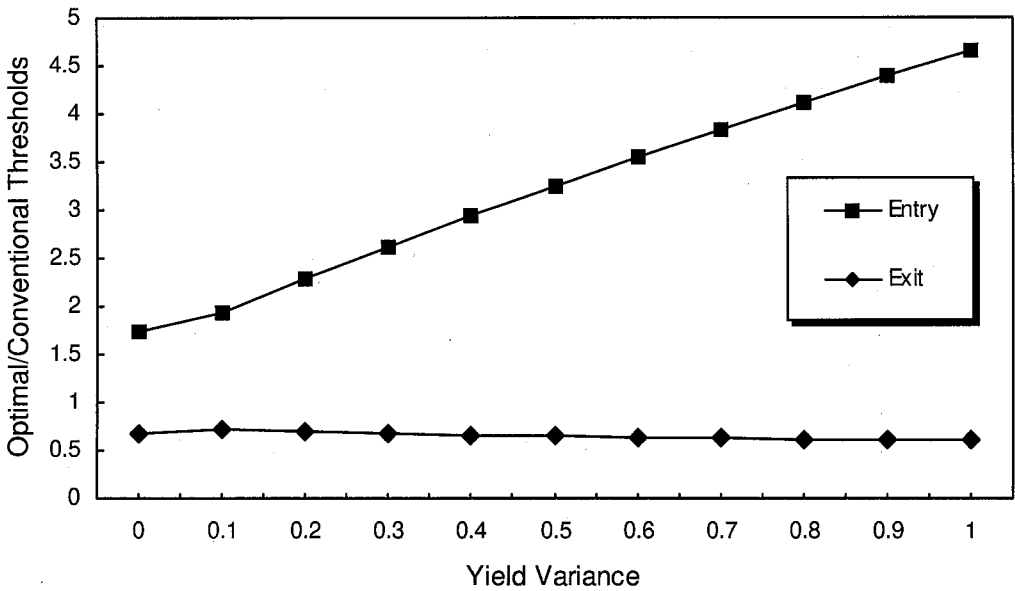


Figure 4. The effect of changes in yield variance on optimal/conventional threshold ratios

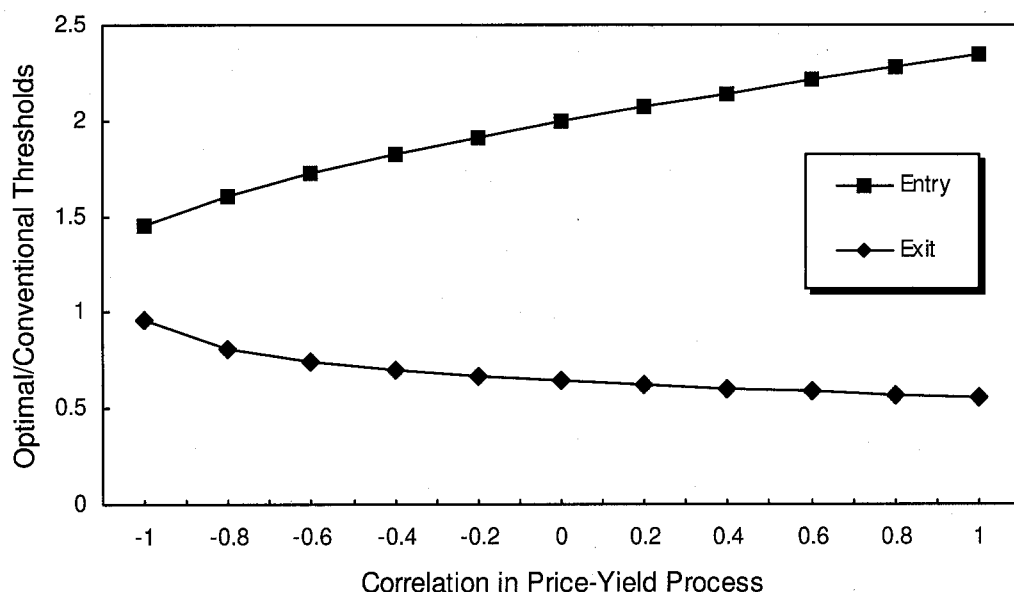


Figure 5. The effect of changes in price-yield correlation on optimal/conventional threshold ratios

catastrophe occurs approximately once every 35 years, a period longer than the time series employed. As indicated in table 2, entry and exit thresholds with a yield variance of 0.8625 are \$4,791 and \$741.40, respectively.

Figure 5 illustrates the effect of changes in the correlation coefficient between price and yield. The stronger the negative correlation between price and yield, the more this tends to reduce the variance in revenue, which in turn narrows the gap between entry and exit thresholds.

Dividing the revenue thresholds in table 2 by a price per bushel for peaches allows thresholds to be represented in terms of yield. The effect of a change in any of the parameter values, illustrated in figures 1-5, will be qualitatively the same for both yield and revenue thresholds. Table 2 lists the yield thresholds Y_L and Y_H given per bushel peach prices of \$11 and \$15 and considering a \$4.50 per bushel harvesting and marketing cost (Davis). The higher price reflects a premium for larger peaches. This translates into net prices of \$6.50 and \$10.50 per bushel. Davis et al. report a mean per acre yield for all orchards, over five years, of 213 bushels per acre. This is above the conventional Y_H threshold of 155 bushels associated with a net price of \$6.50. The optimal Y_H threshold of 340.92 bushels at \$6.50 per bushel is well above the mean yield of 213 bushels per acre, indicating any new investment in peaches is infeasible. Thus, for the given expectation in yield at a net price of \$6.50, generating the necessary revenue is unlikely, and therefore entry is infeasible. In contrast, potential growers anticipating producing above-average yields or receiving a price premium for their peaches have an optimal Y_H of 211.05 bushels per acre, and may consider entry. Growers currently producing peaches should continue production even with low expected yields

and prices, given the Y_L thresholds are well below the mean yield of 213 bushels per acre. Yield thresholds calculated with high yield volatility (for example, considering the 1996 catastrophe) indicate investment is infeasible.

Based on the above findings, the optimal scenario indicates relative stability in Georgia peach production, with growers who are currently producing peaches remaining in production and potential peach growers delaying investment in peach production unless (as indicated above) they anticipate above-average returns. This scenario generally reflects the current situation in Georgia.

Conclusion

Dixit and Pindyck's model of a firm's entry and exit decisions under price uncertainty is extended to include both price and output uncertainty. Revenue is modeled as the product of price and output which are each assumed to follow an Ito process, specifically a geometric Brownian motion. While additional uncertainty usually has the effect of further widening the gap between optimal entry and exit thresholds, the analytical results are inconclusive when uncertainty takes the form of a product of two correlated stochastic variables. The empirical results depend on the magnitude of the drift and variance of price and output processes, and the correlation between them.

This methodology has potential application ranging from foreign trade analysis to the response of supply-induced policy shifts. While the concept of hysteresis and the effects of uncertainty and irreversibility on decision making is rather intuitive, models of this kind make the idea precise by quantifying the significance of these elements, enabling more accurate analysis of the decision process. The technique also has relevance in policy evaluation, as failure to consider irreversibility, flexible timing, and uncertainty can result in flawed recommendations and considerable financial or environmental losses.

[Received March 1998; final revision received December 1998.]

References

- Davis, S. B. "Risk, Scattering, and Efficiency in Orchard Farm Production." Unpub. Ph.D. diss., Dept. of Agr. and Appl. Econ., University of Georgia, Athens, 1996.
- Davis, S. B., T. J. Price, M. E. Wetzstein, and M. W. Riger. "Reducing Yield Variation in Peach Orchards by Geographic Scattering." *Amer. J. Agr. Econ.* 79(1997):1119-26.
- Dixit, A. K. "Entry and Exit Decisions Under Uncertainty." *J. Polit. Econ.* 97(1989):620-39.
- Dixit, A. K., and R. S. Pindyck. *Investment Under Uncertainty*. Princeton NJ: Princeton University Press, 1994.
- Fousekis, P., and J. S. Shortle. "Investment Demand When Economic Depreciation Is Stochastic." *Amer. J. Agr. Econ.* 77(1995):990-1000.
- Hamilton, J. D. *Time Series Analysis*. Princeton NJ: Princeton University Press, 1994.
- Harrison, D. S., A. G. Smajstrla, and F. S. Zazueta. "An Economic Analysis of Irrigation Systems for Production of Citrus in Florida." *Proceedings of the Florida State Horticultural Society* 96(1983):7-11.
- Hertzer, G. "Dynamic Decisions Under Risk: Application of Ito Stochastic Control in Agricultural Economics." *Amer. J. Agr. Econ.* 73(1991):1126-37.

- Hull, J. C. *Options, Futures, and Other Derivatives*. Englewood Cliffs NJ: Prentice-Hall, 1997.
- McDonald, R., and D. Siegel. "The Value of Waiting to Invest." *Quart. J. Econ.* 101(1986):707-28.
- Purvis, A., W. G. Boggess, C. B. Moss, and J. Holt. "Technology Adoption Decisions Under Irreversibility and Uncertainty: An Ex Ante Approach." *Amer. J. Agr. Econ.* 77(1995):531-51.
- Stefanou, S. "Technical Change, Uncertainty, and Investment." *Amer. J. Agr. Econ.* 69(1987):158-65.
- U.S. Department of Agriculture, National Agricultural Statistics Service, Crops Branch. "Statistics of Fruits, Tree Nuts, and Horticultural Specialties." In *Agricultural Statistics*, pp. 168-215. Washington DC: U.S. Government Printing Office, 1993.