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An Ex Ante Assessment of Investments in Texas Grapefruit under Uncertainty

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ABSTRACT

The Dixit-Pindyck model was applied to examine the hypothesis that uncertainty associated with grapefruit production costs and returns is an important determinant of Texas grapefruit growers' investment behavior. Freezes, price variability, and the effects of expanded trade were analyzed as risk factors. An investment decision rule based on a net-present value calculation would approve a 25-year commitment to a 20-acre grapefruit grove, given a 6-percent discount rate. The modified hurdle rate, calculated using an ex ante version of the Dixit-Pindyck model, is 24 percent. The major source of the risk borne by Texas grapefruit investors is from freezes, rather than from expanded trade.

Key Words: *citrus, ex ante analysis, Dixit-Pindyck model, freezes, investment, simulation, Texas, trade.*

According to orthodox economic theory, if the expected net present value of a proposed investment is positive, then the proposal is worth pursuing. Dixit and Pindyck (1994, 1995) modified this orthodox analytical framework by conceptualizing investment opportunities as options in order to account for how investment decision processes are altered by irreversibility, uncertainty, and the leeway to choose the timing of investment.

In this paper the Dixit-Pindyck model is applied to assess future investment prospects for Texas grapefruit growers. The grapefruit industry is located next to the Mexican border in the three southern-most counties of Texas (Cameron, Hidalgo, and Willacy). Grapefruit production contributes $47 million per year to the Texas economy, and the sector is a mainstay of an historically vital agricultural economy in the Lower Rio Grande Valley. Investments in grapefruit groves are irreversible: the costs of tree-planting and irrigation systems, for example, cannot be completely recouped if an investor elects to disinvest during the early years of the 25-year productive life of a grove.

Texas grapefruit investors face three sources of uncertainty. First, in the 75-year history of the Texas grapefruit industry (1923–1998), its production region has experienced six severe freezes (i.e. most groves were completely destroyed) and five milder freezes (i.e. most groves suffered some damage and some loss of production). Second, grapefruit prices fluctuate from year to year. Finally, in the 1990s expanded trade associated with the North American Free Trade Agreement (Nafta) has

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triggered increasing competition for scarce natural resources in south Texas, especially water, land, and open space. Accordingly, the future opportunity costs of resources invested in grapefruit groves are expected to trend up, but their trajectory is uncertain.

This empirical study examines the general hypothesis that uncertainty associated with grapefruit production costs and returns is an important determinant of Texas grapefruit growers' investment behavior. A corollary hypothesis is that an estimate of the relative magnitude of the effects of three sets of risk factors (uncertain climate, prices, and the effects of expanded trade) on investment behavior can be useful in the design and implementation both of agricultural policies and of policies to address the effects of expanded trade. The baseline model accounted for unavoidable risks inherent to citrus production anywhere (climate and price variability), and then the analysis was augmented to consider site-specific risk factors due to the competition for natural resources which is accompanying expanded trade in the Texas-Mexico region.

Literature Review

This empirical research builds on previous work in three ways. First, this study adds to the growing number of empirical applications of the Dixit-Pindyck model. Second, it focuses on investment behavior factors which condition supply response in perennial crops. Finally, testing an expanded-trade research hypothesis contributes to an on-going policy discussion concerning interactions between trade and natural resource management.

Investment under Uncertainty

Dixit and Pindyck (1994) reviewed results from a dozen studies which applied their real-options model to analyze investment behavior under uncertainty. Since then, many additional empirical studies applying the Dixit-Pindyck model have been published, including several in the agricultural and resource economics literature, notably Albers, Batabyal, Conrad, Purvis et al., Salin, and Stiegert and Hertel. Most published empirical studies have applied the Dixit-Pindyck model to analyze time series data; thus their results describe historical investment behavior. Simulation-based data may also be used to predict the likely responsiveness of investors to future opportunities using the Dixit-Pindyck model, as demonstrated by Purvis et al. This empirical study is another application of an ex ante version of the Dixit-Pindyck model, using simulation techniques to analyze likely prospective investment behavior in response to opportunities in the Texas grapefruit sector in the future.

The key result from the Dixit-Pindyck model is a modified hurdle rate. The basis of orthodox investment analysis is a net present value (NPV) calculation, and the hurdle rate is defined as the discount rate or the internal rate of return which gives a zero NPV. Summers and others (see Dixit and Pindyck, 1995, p. 109) interviewed experienced investors in the private sector about how they assess prospective investments. Routinely, they applied hurdle rates three to four times higher than their cost of capital. Decision rules about how much the hurdle rate should exceed the actual cost of capital were described more often as ad hoc than as systematic.

Using a real-options approach, the Dixit-Pindyck model augments the hurdle rate derived from a NPV analysis by also accounting for the value of the option to wait to invest, given descriptive data concerning the uncertain factors affecting the likely returns from investing. The Dixit-Pindyck hurdle rate can be estimated using historical data to identify the effective internal rate of return which actually triggered a past decision about whether or not to invest.

The hurdle rate derived from an ex ante application of the Dixit-Pindyck model answers a question which is posed routinely in real-world problem-solving: "Given that this prospective investment is risky, what discount rate should I use to evaluate it?" An orthodox NPV analysis uses point estimates for expected costs and returns; in contrast, an ex ante Dixit-Pindyck hurdle rate requires data on the confidence intervals associated with any cost and returns estimates considered risky. Prospective investors and their advisors can usually provide such data. Rather than making arbitrary choices and adjustments in the discount rates applied in their NPV analyses, ex ante application of the Dixit-Pindyck model offers investors a systematic, data-rich conceptual framework to use in evaluating prospective investments.

Modeling Supply Response for Perennial Crops

Progress in modeling perennial crop supply response has been most significant where researchers have had high quality time-series data, in particular data profiling the age structure of groves and matching yields with tree age. Those with complete data sets have improved the precision of their forecasts by fine-tuning the functional forms appropriate to modeling price expectations for different crops (Nerlove), in particular by using non-normal distributional assumptions to estimate crop yields (Zanzig, Moss, and Schmitz).

For Texas grapefruit, the first bi-annual grapefruit tree inventory was conducted in 1975. No inventory was conducted following a severe 1989 freeze until 1993. No inventory was conducted in 1997. Historical output data are available on an aggregate regional level rather than by grove or by county; thus it is impossible to correlate historical yield data with the sketchy available data on the age structure of Texas groves. Due to these data limitations, the one-equation supply response model used to estimate the mean and variance on the price of Texas grapefruit for use in an ex ante application of the Dixit-Pindyck model was rudimentary.

The modeling of perennial supply response was refined in this empirical study by accurately depicting investment behavior following a freeze resulting in a loss of trees, as suggested by Moss, Pagano, and Boggess. In previous empirical research on citrus, McClain and Kalaitzandonakes and Shonkwiler accounted for whether or not investors decide to replant their groves following a freeze. This study augments this past citrus supply-response research by modeling the proportion and age structure of the replanted acreage. For Texas grapefruit, it is probable that freezes will occur more than once during the 25-year productive life of a grove; accordingly, the likely investment behavior in the event of multiple freezes was modeled.

The Effects of Expanded Trade

The fundamental economic argument in favor of expanded trade is that open exchange among a diverse set of trading partners allows each to produce according to their comparative advantage; thus, under free trade more goods can be produced using the same endowment of natural resources than if nations operate as autonomous entities (Seale and Fairchild). A correlary notion is positive correlation between economic growth and demand for environmental quality as economies become developed (Arrow et al.).

This empirical analysis tests the hypothesis that expanded trade in general and Nafta in particular will have adverse effects on ecologically fragile and resource-constrained corridors, in this case the lower Rio Grande valley of Texas. This issue was raised by the US Office of Technology Assessment (1995) and again by Ervin and Keller: existing trade policies are inadequate to prevent "excessive environmental stress from trade surges and shifts, for example along border zones" (p. 281).

Setting and Data

Three of the ten most poverty-stricken counties in the U.S. are located along the border with Mexico, and 21 U.S. border communities have been designated economically distressed (US EPA). Projections for the coming decades suggest that the lower Rio Grande valley region is likely to have the lowest growth in per-capita income in Texas. The region is experiencing rapid population growth, with a 55-percent increase from 1980 to 1995 and an anticipated 232-percent gain from 1995 to 2030 (Conner et al.). Hidalgo County, which produces 85 percent of Texas grapefruit, is the second fastest growing county in the state

(Murdock and Hogue). Of the 305,400 Texans who lack adequate potable water, 66 percent reside in the lower Rio Grande valley (Conner et al.).

Economic development associated with expanded trade in south Texas is occurring in locations with unusual biodiversity. There are eleven distinct ecosystems in the lower Rio Grande valley (Jahrsdoerfer and Leslie). These ecological niches are crucial to the survival of six endangered species and 115 species which are threatened and/or occurring at the periphery of their range. South Texas is an important flyway for migratory birds as well as native semi-tropical birds. The Laguna Atacosta National Wildlife Refuge, next to grapefruit groves in Cameron County, holds the record for the largest number of bird sightings in the United States. In town meetings, South Texans ranked water quality, water availability, and protection of wildlife habitat the most pressing problems associated with expanded trade (US EPA).

Investment in grapefruit was chosen as the focal point for this research because of its inherent irreversible and uncertain character. Furthermore, grapefruit is a land-extensive and water-intensive crop; thus it is sensitive to increased competition for ecologically unique and locally valued natural resources. The unit of analysis for the modeling is a prototypical 20-acre grove, as profiled by Taylor (1994a, 1994b, 1994c), the size of a Texas operation which can usefully exploit economies of size in grapefruit production technologies.

The Baseline Model

Historical data were used to set the basic parameters of a baseline model, to take account of the risk of freezes and the variability of market prices for Texas grapefruit during a 25-year production cycle. A grapefruit grove has its first break-even harvest six years after planting, and its yields level off after 25 years of production. The fixed cost of establishing a 20-acre grapefruit grove is $61,025, which covers land, planting costs, and an irrigation system (Elmer).

Freeze Risk

Based on climate data for 1936–1996, the risk of a freeze was modeled as a discrete[1] variable (freezes occur one year in ten). Half the freezes are severe (modeled as zero production in the year of the freeze, and the entire grove is replanted the next year) and half are mild (modeled as reducing yields by half in the year of the freeze, with production returning to normal the next year). Most Texas grapefruit growers buy grove insurance; thus payment of insurance premiums are included as annual fixed costs in this analysis as well as the receipt of a $2000-per-acre payment for replanting in the event of a severe freeze. Premiums increase as the grove matures. Insured growers receive no compensation for lost fruit in the aftermath of a freeze.

Two severe freezes occurred in the 1980s. When the 1983 freeze hit, there were 44,436 acres in grapefruit production. In the aftermath of the 1983 freeze, 13,304 acres (30 percent of the total) were withdrawn from grapefruit production and converted to commercial or residential land uses. Another severe freeze occurred in 1989. It was 1995 before Texas grapefruit acreage returned to its pre-1989 level. In the baseline scenario, the model depicts the prototypical grower always replanting in the year following a severe freeze, unless three severe freezes are drawn in 25 years. In a three-freeze scenario, the model assumes that the grower disinvests after the third freeze rather than replanting because most Texas growers would be unable or unwilling to recoup the investment capital required to start over a third time in 25 years. Current tax guidelines on insurance receipts for orchard freeze damage allow producers no more than two years to replant before being required to claim insurance receipts as taxable income. If

[1] The model was also fitted using a Poisson random variate ($p = 0.1$) for freeze risk. As expected, there were no statistically important differences in the model results, i.e. modified hurdle rates, since for small p and large n the Poisson and the binomial distributions converge. The discrete specification was chosen for ease in describing the model to a policy audience.

Table 1. Estimated Supply Equation Coefficients for Texas Grapefruit, 1960-1996

Explanatory variable	Estimated coefficient	Standard error	t-ratio
YIELD	874.46	56.8	15.4*
LGACRE	235.28	28.15	8.36*
NPRICE	466.97	127.4	3.66*
FREEZE	−1571.4	774.4	−2.03*
CONSTANT	−9452.5	1544	−6.123

Adjusted R^2 = .9298, F statistic = 116.85*, Durbin-Watson statistic = 1.2512.

* indicates statistical significance at the 95-percent confidence interval.

growers indeed replant, then insurance receipts are not taxed as income.

Price Variability

A supply response model was fitted using an ordinary least squares regression equation using data for 1960–1996 to estimate the price of grapefruit, its mean and standard deviation (Table 1). The dependent variable was annual Texas grapefruit production (in acres) and the explanatory variables were nominal marketing year average price (NPRICE); yield (YIELD); a dummy variable for severe freeze years 1962, 1983, 1989 (FREEZE); and a one-period lagged variable quantifying bearing acreage (LGACRE). The marketing year average price variable was a close proxy for net returns to growers, because this price measure is calculated at the packinghouse door by deducting picking, hauling, sorting, grading, packing, cooling, and marketing from the average fresh and processed base prices. Based on these econometric results, in the baseline model the price of grapefruit was simulated using a truncated normal distribution with a mean of $87.76 per ton and a standard deviation of $23.87 per ton,[2] with the lowest possible price at $26.11 per ton and the highest possible price at $188.00 (the lower and upper bounds, respectively, of the prices observed in 1960–1996).

Model Scenario Depicting the Effects of Expanded Trade

Here the baseline model was augmented to take account of how intensifying population pressure and the associated increase in competition for scarce resources (i.e. water, land) are likely to affect future investment in Texas grapefruit production facilities. Post-Nafta grapefruit growers voiced concerns about three sets of likely changes due to expanded trade and the associated growth in south Texas: (1) as residential water demand grows, competition for irrigation water will increase; (2) as more people move to south Texas, there will be increased opportunities for speculative gains in the land market, especially as agricultural land is sold for residential sub-divisions; and (3) expected losses of fruit from theft are likely to increase as the numbers of non-farming neighbors increase.

Since the demographic profile of south Texas has changed dramatically in the past two decades, and change continues apace, data describing past trends in demand for water, land, and open-space amenities are likely to be a poor predictor of future trends. Accordingly, in addition to historical data, grapefruit growers and industry experts were interviewed to develop a profile of likely future scenarios for water costs and availability, speculation in the land market, and the need to fence out thieves.

Water Cost Risk

Irrigation on grapefruit grown in south Texas is essential because rainfall is variable and evapo-transpiration is high, especially during the summer months. Average rainfall in the lower Rio Grande is 20 inches per year, and the perennial evergreen grapefruit tree requires a minimum of 50 inches of water per year (Sauls). A water market in the lower Rio Grande valley was established in 1989 (Chang and Griffin). Available data on irrigation costs

[2] The mean price of a box of grapefruit is $3.73/box. A box of grapefruit weighs 85 pounds, so the per-ton price is $87.76. Calculated using the coefficients from the fitted supply response equation, the standard deviation is 127.4 divided by 466.97 or 27.2 percent. Accordingly, the standard deviation on the price of a ton of grapefruit is $23.87.

show an increasing trend, from $7.76 per acre in 1989 to $9.60 per acre in 1997. Typically, an irrigation application is six to eight acre-inches, and approximately seven irrigation applications per year are applied. Because the water market is young, however, there are inadequate data to estimate the correlation between water prices and precipitation. Furthermore, in 1996 interviews industry experts expressed confidence that water for irrigation would continue to be available at an affordable price for the foreseeable future.[3] In the expanded trade model scenario, therefore, the cost of irrigation was simulated as a random variate using a triangular distribution parameterized by the median, highest, and lowest prices (respectively, $8.00, $30.00, and $4.25) observed from 1989–1997 in five irrigation districts where there are grapefruit groves.

Opportunity Cost of Land

Average rural land values in the lower Rio Grande valley are among the highest in the state, $1242 per acre in 1995 (Gilliland). The value of agricultural land sold for commercial and residential development in the urban-rural fringe regions in the lower Rio Grande valley is from $3000 to $5000 per acre.

To describe how growers are likely to respond to speculative opportunities in the land market, interviews were conducted with growers, representatives of the grapefruit industry's commodity group (Texas Citrus Mutual), and a local real estate broker. To account for the opportunity cost of holding land in grapefruit in the expanded trade model scenario, the sale price for land in grapefruit was simulated using a random variate, modeled using a triangular distribution with median, high and low prices of $1500, $5000, $1000, respectively. In each year that the model predicted a severe freeze, an independent draw for the opportunity cost of land was simulated. A grower's decision about whether to disinvest after a severe freeze was modeled as contingent on the observed opportunity cost of land. If the opportunity cost of land was $3500 or above, then there was a 60-percent probability of replanting and a 40-percent probability of the land being sold. If the grove was sold, the value of the land sale was added to farm income for the year of the freeze and the present value of the investment was calculated upon liquidation.

Congestion

In the lower Rio Grande valley there is increasing residential development in traditionally rural areas. Many of these neighborhoods, called *colonias*,[4] are homes to residential areas largely inhabited by recent emigrants. An estimated 71,500 people lived in colonias in the lower Rio Grande valley in 1986, and the Texas Water Development Board estimates that colonia populations will more than double from 1986 to 2010 (Piper). Colonias are often located next to agricultural land holdings. As a consequence of having more non-agricultural neighbors, the only additional expense grapefruit growers reported was the cost of fencing their groves to deter fruit theft.[5] The estimated cost of a fence ($20,000) was added

[3] The lower Rio Grande valley suffered water shortages in 1996 and 1998. However, the simulation model was constructed based on data from interviews with industry experts conducted in 1997, a wet year, when water was plentiful. Accordingly, the estimate of downside risk associated with irrigation costs used in this modeling is optimistic. In June, 1998, there was more skepticism about the future. In reviewing the 1997–98 grapefruit season, a Texas Citrus Mutual official reflected that "the success of next year's Valley citrus crop will depend to a great extent on the availability of water, either in rainfall or irrigation" (Aggie Hotline). The year 2000 was another dry year.

[4] Piper described colonias as unincorporated residential developments, generally with substandard housing and inadequate water supplies and wastewater services. Colonias developed in the border area as land developers sold small plots of land to low-income families, often recent emigrants. Until recently, county governments and other local zoning authorities did not have the legal authority to require water and sewer systems in these developments.

[5] In the early 1990s many cotton producers in south Texas were asked to make major changes in which pesticide to apply and in application techniques to accommodate the preferences of their new neighbors in colonias. To date, south Texas grapefruit growers have not encountered such requests from neighbors.

to the expanded trade model scenario, a fixed annual payment of \$2014.08 amortized at 9 percent over 25 years.

Methods

The *ex ante* methods employed in this study involved estimating the expected returns from an investment in a Texas grapefruit grove in multiple time periods using a series of draws from the same distribution, in order to forecast the anticipated performance of this investment over time. Purvis et al. described the procedures followed in detail (their Equations 5–14): investment returns were simulated over 5000 iterations, and a trend and variance on the value of the incentive to invest were estimated from the simulation data. The model was built using @Risk software; convergence was monitored at the 1.5-percent confidence interval (Palisade, p. 98) averaging results from using 100 different seeds for the random number generator.

Simulated annual returns from investing (R) were assumed to follow a geometric Brownian motion process.[5] In the limit, a discrete approximation to a geometric Brownian motion process converges to the expected value of a geometric Brownian motion variate (Cox, Ross and Rubinstein). To describe the time path of this random process, the parameters of the random variable were estimated by measuring the movements which occur in an infinitesimally small, discrete interval over N iterations of a simulation model. Conceptually, this procedure is similar to estimating a difference equation. Purvis et al. (pages 545–546) explained the rationale underpinning this procedure and the intuition driving it.

This statistic which best summarizes the outcome from applying an ex ante version of the Dixit-Pindyck model is the modified hurdle rate,

$$(1) \quad \rho' = \frac{\beta}{\beta - 1}\rho,$$

where ρ is the discount rate which would have been chosen for an orthodox investment analysis and

$$(2) \quad \beta = \frac{1}{2}\left[1 + \sqrt{1 + \frac{8\rho}{\sigma^2}}\right],$$

with σ^2 being the variance on V, the expected incentive to invest, (i.e. following the notation from Purvis et al., it is the variance on V).

An alternate (and equivalent) way of looking at the decision whether and when to invest is the level of expected annual returns which would trigger investment. In orthodox NPV analysis, an investment merits consideration if expected returns from investing exceed the Marshallian trigger (M), where $M = \rho K$ and K is the sunk cost of investing. If the investor opts instead to apply a real-options framework in deciding whether and when to invest, the investor uses an optimal investment trigger, H, (Dixit), defined as

$$(3a) \quad H = \frac{\beta}{\beta - 1}\rho K.$$

Equivalently,

$$(3b) \quad H = \rho' K.$$

The difference between the Marshallian trigger from orthodox economic analysis and the modified trigger, H, is the value of the option to invest (the value of investing plus the value

[6] In applying the real-options framework, choice of stochastic process is fundamental. Though a Poisson random variate was considered for modeling the probability of freezes (see Footnote 1), as the number of consecutive Poisson trials approaches infinity the Poisson stochastic process converges to the geometric Brownian motion specification used in this analysis. Furthermore, though this model depicts growers experiencing major fruit losses in freeze years, their costs of replanting are offset by insurance receipts which dampens the overall effect of freeze shocks on the distribution of expected annual returns. (The model assumes replanting unless there are three freezes in a 25-year production cycle.)

A characteristic of the geometric Brownian motion process is the maintained assumption that the range of possible outcomes increases with time. This is appropriate to the south Texas setting being modeled. Due to the dynamic nature of the Nafta-driven trading regime, forecasts far into the future about the pace and direction of growth and change are increasingly uncertain.

Table 2. Effects of Varying Sensitivity Analysis on the Baseline Model Results

Investment Indicator	$\rho = 0.03$	$\rho = 0.06$	$\rho = 0.09$
Modified hurdle rate (ρ')	19%	24%	29%
Optimal investment trigger (H)	\$22,347	\$19,180	\$19,871
Break-even expected returns	\$3,505	\$4,774	\$6,213

Note: for all three scenarios, $\sigma^2 = .272$ and sunk costs were constant at \$61,025.

of the choice to delay investing). The modified hurdle rate is denoted as ρ'.

Results

In analyzing an investment in a Texas grapefruit grove, a discount rate of 6 percent was used. This was the internal rate of return on south Texas grapefruit production estimated by Taylor in the most recent published costs and returns profiles for the industry. Sensitivity analysis is reported to show the effects of choosing a lower (3-percent) or higher (9-percent) discount rate.

Baseline Model

Accounting for freeze risk and price risk associated with a 25-year investment in a 20-acre grapefruit grove, the expected net present value (NPV) of returns was \$5068.62. A NPV-based decision rule would rate this investment as being favorable. Nonetheless, the prototypical grapefruit investor has a greater than 50-percent probability of earnings below the break-even threshold.

A modified hurdle rate, ρ', was calculated using Equation (1), having confirmed the stationarity of the trend in V (see Elmer, p. 84). The modified hurdle rate, $\rho' = 24.08$ percent, indicates the internal rate of return which would be required for an investor to proceed with an investment in grapefruit if the investor were considering irreversibility and uncertainty. The modified hurdle rate for this project is four times ($\beta/\beta - 1 = 3.99$) higher than the hurdle rate ($\rho = 6$ percent) required to approve an investment under an orthodox decision rule.

To assess this result, a formal hypothesis test was conducted:

$$(4) \qquad H_0\text{:} \quad \rho = \rho' \qquad H_A\text{:} \quad \rho < \rho'.$$

The standard deviation of ρ', calculated from the 100 simulation-based estimates of ρ', was 0.0146. Using a one-tailed test the null hypothesis was rejected. Accordingly, in a portfolio setting, an investment in grapefruit would be rejected, given options to pursue other investments with an estimated internal rate of returns closer to the 6-percent cost of capital. Accordingly, for this case, "the simple NPV rule is not just wrong, it is very wrong" (Dixit and Pindyck, 1994, p. 136).

Sensitivity Analysis: Changing the Discount Rate

To assess the sensitivity of model results to the initial choice of a 6-percent discount rate, a modified hurdle rate and an optimal investment trigger were estimated using lower (3-percent) and higher (9-percent) discount rates (Table 2). The direction and the magnitude of the effects of varying the discount rate on the modified hurdle rate and the optimal investment hurdle were as expected. Over this range of discount rates, option value plays an important role in investment behavior.

Expanded Trade Model

The stationarity of the trend on V was confirmed and equation (1) was used to calculate a modified hurdle rate from a simulation model augmented to account for the environmental effects of expanded trade. Similar to the results from the baseline model run, the modified hurdle rate from the expanded-trade version of the model, $\rho' = 25.25$ percent, indicates that an internal rate of return more than four times ($\beta/\beta - 1 = 4.17$) the hurdle rate (ρ = 6 percent) would be required to approve this investment using an orthodox decision rule. A formal hypothesis test was conducted, following equation (4). The standard deviation of ρ' was $\sigma = 0.0215$ and the t-test statistic was 8.94. Using a one-tailed test the null hypothesis was rejected, indicating that there is a statistically significant difference between this modified hurdle rate and the discount rate used as the orthodox decision rule, as with the baseline model.

A second hypothesis test was conducted to compare the modified hurdle rates from the baseline model (labeled V) and the expanded-trade model (labeled Z). Formally stated,

$$(5) \qquad H_0\text{:}\ \ \rho_z' = \rho_v' \qquad H_A\text{:}\ \ \rho_z' < \rho_v'$$

The t-test statistic was 0.5401; applying a one-tailed test, the result was to fail to reject the null hypothesis. The modified hurdle rate from the expanded-trade model scenario is not significantly different from the baseline result, even though both the modified hurdle rates from the baseline model (ρ_v') and the expanded-trade model (ρ_z') were substantially higher than a hurdle rate from a NPV-based decision rule.

It is noteworthy that the expected net present value of an investment under the expanded trade scenario is negative, a loss of \$25,093.57. When the combined effects of higher irrigation costs, speculative opportunities in the land market, and the cost of fencing the grove are taken into account, then an investment in a 20-acre grapefruit grove is no longer considered a favorable investment, based on an orthodox analysis using a NPV-based decision rule.

Discussion

It makes a difference to account for uncertainty and irreversibility in analyzing an investment in a 20-acre Texas grapefruit grove, in both a baseline scenario and in an expanded-trade scenario. The most significant deterrent to investment in grapefruit is the climate-related risk of losses in the aftermath of a freeze. In the baseline scenario, risk associated with freezes accounts for 83 percent of the increase from the NPV-based decision rule to the modified hurdle rate, and the remaining 17 percent of the increase is due to price variability.

Technological innovations in irrigation systems have a role to play in helping growers protect their groves from freeze damages. Micro-sprinkler systems cost \$1200 to \$1500 per acre to install (Sauls) and would mitigate the loss of trees and fruit, particularly in the event of a mild freeze. In addition, micro-sprinklers conserve water and would buffer the effect of future increases in the cost of irrigation. One obstacle to widespread adoption of micro-sprinkler systems, however, is that producers must retrofit their pumps in order to install micro-sprinklers. To date, only 12 percent of the current south Texas citrus acreage is equipped with drip irrigation or micro-sprayers, presumably because growers have judged that the additional capital outlay cannot be justified by its water cost savings or freeze protection benefits.

Those growers who replanted after the 1983 and 1989 freezes have demonstrated a high risk tolerance, plus faith in a sustained or improved competitive position for Texas grapefruit over time. However, there have been virtually no new investors entering the grapefruit industry in south Texas during the 1980s and 1990s.

In summary, with or without expanded trade the risk of freezes is the major factor dampening investment in Texas grapefruit. As modeled, however, the effects of expanded trade make future investments in grapefruit look unfavorable, according to a NPV-based decision rule, because of non-stochastic cost increases (i.e. irrigation water and fencing).

Consistent with expert opinion in 1996, conservative assumptions were employed in modeling likely future water scenarios and speculative opportunities in the land market. To run more pessimistic scenarios would have misrepresented the viewpoints of industry experts. If drought conditions in Texas persist through the next decade (2000–2010), if world prices for grapefruit change, or if south Texas land prices increase dramatically, then it will be necessary to update this investment analysis.

Conclusions

Both the baseline and the expanded-trade model scenarios indicate that investors taking account of uncertainty and irreversibility are less likely to invest in Texas grapefruit than those applying orthodox investment-decision rules. Applying the ex ante procedures generated potentially useful information for investors considering Texas grapefruit as a future investment option. Additionally, from a policy planning perspective, these results suggest that Texas grapefruit is likely to be a declining industry, particularly in the wake of expanded trade. The major cause of this expected decline, however, is climate risk rather than the interactions between expanded trade and natural resource management, per se.

Results from an augmented model which described an expanded trade scenario do not show these being important factors in growers' and prospective investors' future decision making. In this ecologically sensitive corridor where Nafta is fueling increased growth and economic activity, at this particular juncture, these research results suggest the appropriateness of an investment-decision rule which is not responsive to the effects of expanded trade.

Analysts choosing to use an ex ante application of the Dixit-Pindyck model rely on those with a stake in the investments being studied for data about future expectations of costs and returns. Unfolding events shape those expectations over time. In this case, south Texas is changing rapidly. Those involved in policy planning associated with the region's agricultural economy and those interested in the effects of Nafta-driven trade may wish to revisit this case in a decade to assess how well ex ante forecasts matched real-world events.

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