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An Equilibrium Analysis of the Impact of Antibiotics Bans on Investment in Apple Orchards

by

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Abstract: The decision to replant a fire blight-susceptible apple orchard is analyzed. Embedding the problem into an equilibrium framework facilitates the welfare analysis of changes in orchard survival probabilities arising from a ban on antibiotics use. We estimate the structural impacts and welfare changes of the ban.

Introduction

Antibiotics are used in fruit production to control fire blight, an economically important bacterial disease of apples and pears that is caused by the bacterium *Erwinia amylovora*. Fire blight differs from other common plant diseases in that it not only affects yield and quality of the current crop, but also leads to significantly lower productivity of plants for several years. Severe infections can lead to tree death (van der Zwet and Beer). Currently, 36% of U.S. apple acreage is planted to fire blight susceptible varieties (Rosenberger). This percentage is increasing because many of the new varieties such as Fuji and Pink Lady are much more susceptible than the common older varieties such as Red or Golden Delicious. This development is reinforced by a similar trend towards planting rootstocks with high susceptibility to fire blight (van der Zwet and Beer). Plant pathologists have consistently reported fire blight as a disease of high importance in apple and pear orchards (van der Zwet and Beer). If antibiotics are lost for fire blight control, experts conjecture that apple acreage would decrease by 13% in the next five years and annual yield would decrease by 8% (Rosenberger). The principal antibiotics in a fire blight control program are streptomycin and oxytetracycline. Copper compounds are available as an alternative means of control; however, they are much less effective and more phytotoxic than antibiotics.

The possibility of losing access to antibiotics as a means of control arises because their use in agriculture is currently a controversial issue due to public health concerns over the risk of resistance development (Witte; Grady). Bacteria can store their resistance genes in plasmoids, a cell structure that can be transferred between bacteria. Especially if bacteria are of common families, it is likely that resistance features can be transferred. *Erwinia* for instance belongs to the family of Enterobacteriaceae, the family that includes *Escherichia coli*, *Salmonella*, and *Shigella*, all of which are well known causes of foodborne diseases. It has been shown that people who are frequently exposed to antibiotics are at a higher risk to contract antibiotic resistant bacteria (Levy 1998) and this is also true for human exposure to antibiotic resistant bacteria in food (Corpet, Levy 1992). These public health concerns put in question the future use of antibiotics for disease control in fruit production. A study of the implications of losing control over fire blight is furthermore of interest because of developments in apple production systems themselves. Specifically, the fire blight bacterium has developed resistance to streptomycin in the Pacific

Northwest (Smith). Growers have to rely on access to oxytetracycline for which an exceptional permission has to be obtained from the Environmental Protection Agency, and the industry is continuously at risk of not having sufficient means for blight control. This problem is aggravated by the fact that in recent years unusually warm spring weather conditions in the Northwest have led to an increase in the fire blight prevalence.

The objective of this paper is to estimate the importance of antibiotics in apple production systems. To this end, a model of orchard replanting that can incorporate the changes in orchard survival probabilities is developed. Existing models developed to estimate marginal-cost changes resulting from a regulation of pesticide use are not suitable for our case because marginal-cost changes in these models result only from changes in costs of production or from changes in yield (Lichtenberg, Parker, and Zilberman; Sunding). They do not incorporate risk, and so do not offer a way to accommodate survival probability changes. Furthermore, there does not exist any model that analyzes the contribution of survival probability to the orchard replanting decision.

The Model

Building on the existing literature in forestry economics (Hartman; Reed), we analyze the replanting decision of the individual orchard depending on survival probability.

Site Value

In this section, we develop a Faustmann-type model (Clark, ch. 9) to analyze the decision to replant an orchard, where we explicitly model the probability that an orchard is destroyed at any given time. An orchard is planted at cost I, and can remain in production for several decades. At planting time, the basic orchard technology is chosen, including aspects such as variety, rootstock, irrigation, and planting density, and subsequently the production function has a very low elasticity of substitution with respect to variable input choices. To focus on the long-term planting decision, we model production as a Leontief technology that changes with orchard age t. The instantaneous revenue function can be described by

$$r(t) = p(t)y(t) - c(t) \tag{1}$$

where $p(t)$ is the price paid for the crop at time t, $y(t)$ is yield at time t, and $c(t)$ presents the cost of running the existing orchard.

Times between successive orchard destructions are denoted as $X_1, X_2, \ldots$, and can occur either because the orchard has been destroyed by disease or other adverse events or because management has made the removal decision. Each period from planting to cutting of the orchard is described as an orchard cycle, and the duration of the n-th orchard cycle is X_n. Discounting forward the net returns of the orchard over its life cycle, the cumulative return of one orchard cycle is

(2) $$R_n = \int_0^{X_n} r(t)\, e^{\delta(X_n - t)} dt = e^{\delta X_n} \int_0^{X_n} r(t)\, e^{-\delta t}\, dt .$$

The occurrence of destruction by fire blight or any other adverse event is modeled as a Poisson process with the intensity rate λ, so that the probability distribution of the random variables $\{X_n\}$ is

(3) $$F_X(t) = \begin{cases} 1 - e^{-\lambda t}, & t < T \\ 1, & t \geq T \end{cases}$$

where $F_X(t)$ is the cumulative density function, i.e., for n = 1, 2, ..., $F_X(t) = \text{Prob}(X_n \leq t)$. In (3), T is the time of planned replanting so that the planned replanting time T is the upper bound on orchard age. The destruction times are independent of each other and form a renewal process (Taylor and Karlin).[1]

To calculate the complete site value, we compute the discounted infinite return to the land, applying the discount rate δ, so that the expected discounted return is

(4) $$J(T) = E\left[\sum_{n=1}^{\infty} e^{-\delta(X_1 + X_2 + \cdots + X_n)}(R_n - I)\right].$$

From Reed's observation, we employ the independence of the identically drawn X_i to write $J(T)$ as

(5) $$J(T) = \frac{E\left[e^{-\delta X}(R - I)\right]}{\left[1 - E\left(e^{-\delta X}\right)\right]}$$

and we can calculate $E\left[e^{-\delta X}\right] = \left(\lambda + \delta\, e^{-(\lambda+\delta)T}\right)/(\lambda + \delta)$.[2] Carrying out the expectations in (5), the total site value can be calculated as

[1] The independence assumption is not very restrictive for our problem. Disease outbreaks are often related spatially for a given year because the bacteria spreads epidemically through a region, but little dependence would be expected between replantings across time.

[2] Employing (3), this follows from

$$E\left[e^{-\delta X}\right] = \int_0^T \lambda e^{-\lambda t}\, e^{-\delta t} dt + e^{-\lambda T}\, e^{-\delta T} = \lambda\left(1 - e^{-(\lambda+\delta)T}\right)/(\lambda + \delta) + e^{-(\lambda+\delta)T} = \left(\lambda + \delta e^{-(\lambda+\delta)T}\right)/(\lambda + \delta)$$

$$(6)\quad J(T) = \frac{(\lambda+\delta)\lambda\int_0^T\int_0^\tau r(t)e^{-\delta t}dt\, e^{-\lambda\tau}d\tau}{\phi} + \frac{(\lambda+\delta)e^{-\lambda T}\int_0^T r(t)e^{-\delta t}dt}{\phi} - \frac{I\left[\lambda+\delta e^{-(\lambda+\delta)T}\right]}{\phi}$$

where $\phi = \delta\left[1-e^{-(\lambda+\delta)T}\right]$. As expressed in equation (6), the total return to the site is equal to the appropriately weighted expected revenue in the event of involuntary destruction plus the survival probability times the appropriately discounted expected revenue conditional on survival until planned replanting less the appropriately discounted cost of replanting in either event.

Impact of λ on Site Value

We can observe that the size of λ has two opposing effects on the total site value. This is easiest to ascertain from equation (5). One the one hand, the expected lifetime decreases with an increase in λ which lowers the denominator and increases the annualized cost of investment. Therefore, the term involving investment increases. On the other hand, expected revenue is likely to decrease. This, however, depends on the particular form of $r(t)$ and the size of δ and T^* and cannot be signed unambiguously.

Replanting Decision

Differentiating $J(T)$ with respect to T and setting the derivative equal to zero gives implicitly the optimal lifetime of an orchard. Note that $d\phi/dT = \delta(\lambda+\delta)e^{-(\lambda+\delta)T}$, and so

$$\begin{aligned}\frac{dJ}{dT} &= \frac{1}{\phi}\Big[(\lambda+\delta)\lambda\int_0^T r(t)e^{-\delta t}dt\, e^{-\lambda t} - \lambda(\lambda+\delta)e^{-\lambda T}\int_0^T r(t)\, e^{-\delta t}dt \\ (7)\qquad &\quad + (\lambda+\delta)e^{-\lambda T}r(T)\, e^{-\delta T} + I\delta(\lambda+\delta)e^{-(\lambda+\delta)T} - \delta(\lambda+\delta)e^{-(\lambda+\delta)T}J(T)\Big] \\ &= \kappa\,[r(T) + \delta I - \delta J(T)]\end{aligned}$$

where $\kappa = (\lambda+\delta)e^{-(\lambda+\delta)T}/\phi \neq 0$. Letting T^* denote the optimizing value, the first-order condition can be written as

$$(8)\qquad r(T^*) = \delta J(T^*) - \delta I\,.$$

The optimal orchard replanting time T^* depends on the discount rate δ, on the risk parameter for orchard destruction by disease λ, and on the shapes of the price function $p(t)$, yield function $y(t)$, and cost function $c(t)$. The first-order condition states that the incremental return of keeping the orchard, $r(T^*)$, has to

equal the rent from starting over, $\delta\left[J(T^*)-I\right]$, so that the instantaneous return at T^*, $r(T^*)$, must be smaller than the average return $\delta J(T^*)$. Revenue at the replanting date must be exactly equal to the average return corrected for the cost of replanting.

The second-order condition requires $r_T(T^*) \le 0 \Rightarrow \; p_T(T^*)y(T^*) + p(T^*)y_T(T^*) \; - c_T(T^*) \le 0$ where we use the first-order condition to assert that $J_T(T^*) = 0$. If $r(t)$ increases, peaks and then falls substantially then a global maximum is likely. Henceforth we assume such a maximum.

Equilibrium

Equation (8) defines the optimal cycle length for one orchard. For the equilibrium analysis, we assume that there exists a sufficiently large acreage that is equally fit for apple production and that in the long run acres switch to or from apple production according to the opportunity cost of production. Each acre remains in apple production as long as the average return $\delta J(T^*)$ meets or exceeds the opportunity cost, which is denoted by π_0. All orchards are equal and the supply for apples is assumed to be perfectly elastic, an assumption based on the notion of a long-run equilibrium as in Silberberg.

A supply shift due to changes in average returns or opportunity costs affects market prices, and an equilibrium analysis requires us to study the effect on prices and T^* simultaneously. To do so, we have to further characterize the dynamic structure of the industry. It is assumed that in a steady-state equilibrium an equal number of acres is planted each year. The price $p(t)$ is a function of orchard age and it is necessary to precisely define a shift in the price functions. We develop the price function as $p(t) = a + s(t)$ and let $s(t)$ evolve according to orchard age. Explicitly, we set $s(0) = 0$ so that $p(0) = a$. Changes in $s(t)$ reflect the decreases in quality that occur with orchard age (Funt et al.) and changes in the marketability of a variety. A change in the price schedule is then defined as a shift in the parameter $a > 0$. The equilibrium price schedule is thus determined to satisfy

(9) $$\pi_0 = \delta J(T^*),$$

and equations (8) and (9) determine jointly the endogenous variables of the market equilibrium.

To focus in on the risk aspect of the problem, we also restrict the cost function to be a step

function such that $c(t) = c_N$ if $t \le t_0$ and $c(t) = c_B$ if $t > t_0$, where t_0 is the time at which the orchard comes into full bearing. The cost of production are smaller in early years when orchards are in the nonbearing stage while they are larger when orchards are in full production. Our results carry over to more general cost functions; however, the model would become more cumbersome without leading to further insights into the problem.

Simulation Analysis of the Economic Impact of Antibiotics Use Removal

In order to assess the welfare impacts of a ban on antibiotics, we conduct a simulation analysis using the discrete analog of the analytical model since apple trees yield fruit once a year. We describe the data entering the simulation analysis.

Yield Function

Yield patterns over time vary depending on the production system. In traditional systems, a relatively low number of trees is planted per acre, but newer high-density systems increase yields per acre by planting a high number of trees. Funt reports yield data for plantings of four different densities; 66 trees/acre, 181 trees/acre, 605 trees/acre, and 792 trees/acre. His data concerns three varieties (York Imperial, Golden Delicious, and Red Delicious) over 36 years from planting to orchards of age 36 for each system. Apple yields can fluctuate considerably between years depending on weather and pest conditions, and we smooth the data by using a centered five-year moving average. Zeros are implemented for year 0 and –1 in the first two moving averages, and so 34 years of yield data remain.[3] A preliminary study of the data revealed that the shape of the yield trajectories over an orchard's lifetime is quite different depending on the planting density, but is rather homogeneous across varieties for systems of the same tree density. This impression was confirmed through discussions with experts on apple production systems. For this reason, four different yield functions for the four different tree densities were estimated using the data for all three varieties in each of them. The yield function was specified as

(10) $$\ln y_t = a_0 + a_1 t + a_2 \ln t + a_3 t^{-1} + a_4 t^{-2}$$

[3] Using zeros in the moving average for the first two years seemed to be the best way to proceed because in most cases yield is zero in the first three years in any event.

where $\ln y_t$ is the natural logarithm of yield at orchard age t, and $a_0, \ldots, a_4$ are parameters to be estimated. The function was estimated using a fixed-effect model to account for differences in the slope of $\ln y_t$ between varieties which result in multiplicative differences in y_t. The parameter estimates are given in table 1 together with goodness of fit measures, where yield 1 reports the estimates for 66 trees/acre, yield 2 the estimates for 181 trees/acre etc. The F-test examines the hypothesis of equal intercepts for the different varieties and including fixed effects is therefore appropriate.[4]

In addition to these yield data for different orchard designs by Funt, we use data by O'Rourke who estimates the yield for an average orchard in the state of Washington.[5] This yield function (yield 5) gives data for 41 years of orchard age. For the welfare analysis we normalize all yield functions so that the average yield will equal the U.S. average yield of 23,500 lb./acre (1994-96 average) under the assumption that an equal number of acres of each maturity are in production.

Price Function

Little data is available to estimate the price function. Discussions with many industry specialists indicated to us that price decreases for the orchard crop are a major reason for replanting an orchard. For a particular variety, prices may decrease because of supply increases and changes in the demand. In addition to price changes by variety, the value of crop from a particular genetic material may change according to details such as coloring or storage quality of the apples. The data to estimate these effects is sparse and ignores many quality and demand effects.

We obtain price data by variety from the Washington Growers Clearing House Bulletin to estimate a price function by variety. For the newer varieties Gala, Fuji, Braeburn, and Jonagold we have data for the production years 1992/93 through 1997/98 and use it to estimate price as a function of time using an exponential function with a positive intercept as a lower limit for price. This lower limit is

[4] The yield data were collected from growers in Pennsylvania in the early 1970s. It would have been preferable to cover a wider geographical range and a higher number of varieties. However, to our knowledge there do not exist other data covering orchards over so many years. Part of the problem is that we need to estimate the yield trajectory beyond the typical replanting date. We compare our results with European data in Goedebure (1980, 1986) and discuss the issue with members of the apple industry. It appears that the shape of the yield trajectories depends mostly on the orchard system planted so that for the four given systems our estimates appropriately describe the orchard productivity over time.

chosen to be the average price received for apples in the processed sector (7.54 ¢/lb.) and the restriction on the intercept is imposed in the estimation procedure. The function is estimated as

$$(12) \qquad p_t = 0.0754 + (0.737 + 0.221D_1 - 0.183D_2 - 0.102D_3)\ \exp(-0.134\,t)$$
$$\qquad\qquad (9.223)\quad (2.535)\quad (-2.112)\quad (-1.189)\qquad (-5.230)$$

where D_1, D_2, and D_3 represent dummy variables to distinguish the multiplicative term for the different varieties. The numbers in parenthesis report t-values and the R^2 of regression equals 0.72.[6] For the estimation of welfare impacts, the price function is calibrated to yield the U.S. average price of 15.31 ¢/lb. by adjusting the multiplicative term to the exponential function

Cost Function

Two specification for the cost function were chosen using evidence from enterprise budgets for apple orchards [Bechtel et al.; Carkner, Havens, and MacConnell; Dickrell, Hinman, and Tvergyak; Funt et al.; Hinman et al. (1993a, 1993b); Hinman, Williams, and Faubion; Marshall et al.; Parker et al.; Seavert and Burkhart]. They are specified as a discrete step function with low cost (c_1 = \$1,700/acre; \$1,200/acre) in early years for $t \leq 5$ and higher cost (c_2 = \$2,500; \$2,000) in later years for $t \geq 6$. The set (c_1; c_2) = (\$1,700; \$2,500) will henceforth be referred to as cost 1, and the set (c_1; c_2) = (\$1,200; \$2,000) as cost 2. Evidence from these sources also motivated our choice for *I* to lie between \$6,000/acre and \$8,000/acre.

Replanting Time and Price Adjustments

We analyze the impacts of changes in the production environment on the long-run equilibrium of the apple industry. For the simulation analysis, the base level of λ is set at 0.01 based on tree survival probabilities in O'Rourke, and the discount rate δ is set approximately at the real rate of return on long-term securities at 0.04. Based on expert surveys that were conducted as part of a USDA-NAPIAP project, Rosenberger estimates that a loss of antibiotics for fire blight management will lead to a decrease in yield by 8% and an acreage reduction by 13% in the subsequent five years. Under the assumption of a Poisson process, the acreage loss is equivalent to a value of λ=0.027. Experts assert that the cost of production increases are almost negligible at \$2.6/acre.

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[5] O'Rourke (1997) estimates the yield curve by employing available data from fruit censi in the state of Washington and also additional evidence from the industry.

[6] The F-test statistic on the restriction is F(1,18)=11.6 and is rejected at the 1% significance level.

We employ these data to estimate the impact of an antibiotics ban using the different yield, cost, and investment function specifications. For this estimation, $J(T)$ is calculated in discrete form using the annual return data for each of the functional specifications. We calculate the optimal replanting time under our baseline assumptions (T_0) together with the base return (π_0). Increasing λ to 0.027 and simultaneously decreasing yield by 8%, we vary a and calculate the new $T^* = T_1$ such that $\delta\, J(T_1, a_1) = \delta\, J(T_0, a_0)$. Estimates are given in table 2. The change in price after losing antibiotics varies by 2.1 to 3.2 ¢/lb. (14-21%) at the farm level and the increase in replanting age adjusts by between 2-8 years.

We carry our simulation analysis further and obtain estimates of welfare impacts resulting from a ban on antibiotics. Implementing a partial-equilibrium model, we estimate changes in apple supply and demand and use the resulting changes to calculate changes in consumer and producer surplus. The partial-equilibrium model for the U.S apple market including net imports is described by

$$Q^D(P) = Q^D, \tag{13.1}$$

$$M(P, Q^P) = M, \tag{13.2}$$

$$Q^P + M = Q^D. \tag{13.3}$$

Equation (13.1) describes the demand function (Q^D) as a function of price (P), equation (13.2) depicts the net import equation (M) as a function of price (P) and home production (Q^P), and lastly equation (13.3) poses the market clearing condition. Q^P is modeled as being invariant to prices because we assume for our equilibrium analysis that locally the supply function is perfectly elastic.

Given the change in price (Δa) as calculated from equations (8) and (9), we can derive the changes in quantities demanded and supplied by totally differentiating (13) and so obtain

$$\left(\frac{\partial Q^D}{\partial P}\frac{P}{Q^D}\right)\frac{Q^D}{P}\Delta a = \Delta Q^D, \tag{14.1}$$

$$\left(\frac{\partial M}{\partial P}\frac{P}{M}\right)\frac{M}{P}\Delta a + \left(\frac{\partial M}{\partial Q^P}\frac{Q^P}{M}\right)\frac{M}{Q^P}\Delta Q^P = \Delta M, \tag{14.2}$$

$$\Delta Q^P + \Delta M = \Delta Q^D, \tag{14.3}$$

System (14) is linear in the changes ΔQ^D, ΔM, and ΔQ^P, and thus can easily be solved for these quantities given the appropriate elasticity estimates and data on current quantities and prices.

Elasticity estimates have been obtained from Roosen who estimates the demand elasticity as –0.55, the elasticity of imports with respect to prices as –0.76, and the elasticity of imports with respect to home production as –3.3. Given production and yield changes, we can now calculate the change in acreage, ΔAcre, and the change in producer surplus, $\Delta PS = \Delta\text{Acre} \times \pi_0$. Consumer surplus changes are calculated as $dCS = -(Q + \Delta Q/2)\Delta a$.

Tables 2 shows the estimated changes in quantity demanded, ΔQ^D, and produced domestically, ΔQ^S, together with the estimated welfare changes, ΔPS and ΔCS, in the lower part of each cell. The results vary across the different revenue functions that enter our analysis and depend in particular on the size of price increase needed to compensate growers for profit losses caused by changes in the risk environment. Consumption decreases by about 940 mill. lb., production decreases by 1.6 bill. lb. and U.S. apple acreage decreases by between 45,700 and 69,700 acres or by between 10% and 15%. Welfare losses are in the vicinity of $320 mill. Because the experts' estimates appear rather high, we repeat the simulation exercise for a yield decrease of 4% and $\lambda_1 = 0.0185$, and the welfare impact is reduced to $155 mill.

Conclusion

We have developed an equilibrium model of the decision to replant fruit orchards that incorporates the risk that an orchard could be destroyed by disease or other adverse events. The model facilitates thinking about long-term issues in pest control for perennial crops and about the decision to replant. We employ the model to simulate losses resulting from a ban on antibiotics in U.S. apple production, and we estimate upper-bound welfare losses of about $320 mill.

About 50% of all antibiotics used in the United States are used as agricultural inputs, the vast majority as growth enhancers in animal production. Still, 30% of U.S. apple acreage are treated with antibiotics (U.S. Department of Agriculture) and the most common application of the broad-spectrum antibiotic streptomycin is for treatment of fire blight in apple and pear production. With this paper we

attempt to initiate a discussion of the importance of antibiotics in fruit production. A complete analysis of the economic impacts would in addition require a precise analysis of the risk of antibiotics use on human exposure to resistant pathogens. Experts agree that antibiotics use in food production encourages the development of antibiotic-resistant human pathogens. But the importance of this link is an open scientific issue. If the link between resistance development in plant and human pathogens is strong, then the impact of increasing the prevalence of antibiotic resistant bacteria on human welfare is likely to have a large effect. The cost of increased antibiotic resistance is not negligible. Sawert estimates that treatment cost alone would increase from $20,000 to $180,000 for tuberculosis patients with resistant *Mycobacterium tuberculosis.*

A good place to begin an economic analysis of the human health benefits could be Harper and Zilberman, who incorporate worker health risk into the analysis of pesticide regulation. A line of research by Foreman, by Sawert, and by Wallace and Wallace that was stimulated by the resurgence of tuberculosis in some subpopulations in the 1980s and 90s would also be of interest given the epidemic character of diseases that are affected by antibiotic resistance. Furthermore, Philipson shows how the cost of disease avoidance effort can be acknowledged in health economic studies, and it is likely that these costs would increase if the probability of effective treatment declines.

Table 1. Parameter Values for Yield and Price Function[a, b]

	Yield 1	Yield 2	Yield 3	Yield 4
a_1	6.857	1.114	-0.763	1.266
	(10.607)	(5.751)	(-1.666)	(5.528)
a_2	-0.259	-0.048	-0.002	-0.066
	(-12.396)	(-5.447)	(-0.094)	(-7.355)
a_3	28.481	-3.447	-15.813	-2.391
	(5.651)	(-4.785)	(-6.257)	(-1.893)
a_4	-26.8455	[c]	8.887	2.067
	(-5.510)		(6.204)	(2.886)
F-test[d]	159.3	134.9	19.1	58.7
R^2	98.6	97.5	95.4	97.9

[a] The estimate for the intercept a_0 is not listed as the fixed effect model estimates a different intercept for each time series.
[b] The values in parentheses report t-values.
[c] This term was excluded to improve the fit of the estimation according to the adjusted R^2.
[d] The degrees of freedom for the F-tests are (2,93), (2,93), (2,95), and (2,95) for yield 1-4, respectively.

Table 2. Ban on Antibiotic Use employing Expert Assessments[a, b]

				Yield 1	Yield 2	Yield 3	Yield 4	Yield 5
Cost 1	I=6000	π_0	$	694.2	918.8	915.1	964.0	871.8
		T_0	yrs.	28.0	26.0	21.0	22.0	28.0
		T_1	yrs.	31.0	33.0	25.0	26.0	33.0
		Δa	¢/lb.	3.0	2.3	2.2	2.1	2.6
		ΔQ^D	mill. lb.	-1,129.3	-871.3	-804.0	-785.3	-961.0
		ΔQ^P	mill. lb.	-1,900.0	-1,465.9	-1,352.6	-1,321.2	-1,616.8
		ΔAcre	thsnd. acre	-57.8	-66.6	-45.9	-46.3	-60.3
		ΔCS	mill. $	-310.3	-242.4	-224.4	-219.4	-266.2
		ΔPS	mill. $	-40.1	-61.2	-42.0	-44.7	-52.6
	I=8000	π_0	$	671.1	888.1	870.9	922.3	846.6
		T_0	yrs.	29.0	27.0	22.0	23.0	29.0
		T_1	yrs.	31.0	35.0	26.0	27.0	34.0
		Δa	¢/lb.	3.2	2.5	2.3	2.2	2.7
		ΔQ^D	mill. lb.	-1,200.4	-927.4	-848.9	-833.9	-1,024.6
		ΔQ^P	mill. lb.	-2,019.5	-1,560.2	-1,428.1	-1,402.9	-1,723.8
		ΔAcre	thsnd. acre	-58.1	-69.7	-46.3	-46.5	-61.1
		ΔCS	mill. $	-328.7	-257.3	-236.4	-232.4	-283.0
		ΔPS	mill. $	-39.0	-61.9	-40.3	-42.9	-51.8
Cost 2	I=6000	π_0	$	1,186.3	1,410.9	1,407.3	1,456.1	1,363.9
		T_0	yrs.	28.0	26.0	21.0	22.0	28.0
		T_1	yrs.	31.0	33.0	25.0	25.0	33.0
		Δa	¢/lb.	3.0	2.3	2.1	2.1	2.6
		ΔQ^D	mill. lb.	-1,121.8	-867.5	-800.2	-781.5	-957.3
		ΔQ^P	mill. lb.	-1,887.4	-1,459.6	-1,346.3	-1,314.9	-1,610.6
		ΔAcre	thsnd. acre	-57.2	-66.4	-45.7	-40.8	-60.0
		ΔCS	mill. $	-308.4	-241.4	-223.4	-218.4	-265.2
		ΔPS	mill. $	-67.9	-93.7	-64.3	-59.4	-81.9
	I=8000	π_0	$	1,163.2	1,380.3	1,363.1	1,414.4	1,338.7
		T_0	yrs.	29.0	27.0	22.0	23.0	29.0
		T_1	yrs.	31.0	35.0	26.0	27.0	34.0
		Δa	¢/lb.	3.2	2.5	2.3	2.2	2.7
		ΔQ^D	mill. lb.	-1,196.6	-923.6	-845.1	-830.2	-1,020.9
		ΔQ^P	mill. lb.	-2,013.2	-1,553.9	-1,421.8	-1,396.7	-1,717.5
		ΔAcre	thsnd. acre	-57.8	-69.4	-46.0	-46.2	-60.9
		ΔCS	mill. $	-327.7	-256.3	-235.4	-231.4	-282.0
		ΔPS	mill. $	-67.2	-95.8	-62.7	-65.3	-81.5

[a] T_0, T_1, and Δa are calculated according to equations (8) and (9). ΔQ^D and ΔQ^P follow from the partial equilibrium model (13).

[b] Yield decreases by 8%, cost increases by $2.6/acre, and λ increases to 0.027.

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