Pricing Powdery-mildew-resistant Dogwoods: Simulated Impacts on the Nursery-industry Supply Chain

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SUMMARY. The University of Tennessee developed a flowering dogwood tree (*Cornus florida*) that is resistant to powdery mildew (*Microspora pulchra*). A simulated cooperative game was created to estimate a university fee and predict the behavior of nursery growers and nursery product retailers. The simulation suggests a university fee of \$3.51, leading to an average retail price premium for the resistant tree of \$10.41. At this price level the simulation predicts that 62 percent of all retail dogwood trees sold would be powdery mildew resistant. Based on 1998 sales of 1.475 million dogwood trees nationwide, 914,500 were predicted to be the powdery mildew resistant varieties, resulting in \$3.2 million in revenue for the university. Given this level of sales and markup pricing, the cost of the trees will rise in subsequent stages of the distribution channel, and revenues will increase as well. The simulation suggests nursery revenue will increase by nearly \$4 million and costs by \$3.2 million, resulting in a net nursery gain of \$0.8 million. Similar computations for the retail level are \$9.5 million in revenue and a net increase of \$5.5 million.

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Powdery mildew (*Microspora pulchra*) is a disease affecting flowering dogwoods (*Cornus florida*) that limits growth, detracts from plant aesthetics, and may cause plant decline and death (Windham and Witte, 1998). The University of Tennessee has developed a series of dogwood trees that are resistant to powdery mildew and is considering their commercial introduction. The dogwood is an important source of revenue for Tennessee's nursery and landscape industry. In 1998, Tennessee's nursery industry income from retail and wholesale dogwood sales was \$6.1 million, and dogwoods comprised 14.9% of the Tennessee wholesale and retail nursery sales (Tennessee Agricultural Statistics Service, 2002). Additionally, Tennessee ranked first in dogwood sales in the country, accounting for 23.2% of the nation's wholesale and retail dogwood sales (U.S. Department of Agriculture, 1998). The Tennessee nursery industry also produces seedlings that are sold to out-of-state nursery growers. Six counties in Tennessee supply about 80% of the country's dogwoods (Simmons, 2002).

Powdery mildew increases growing and marketing costs for dogwood nursery stock producers and distributors. Costs are primarily due to the increased number of fungicide applications and the loss of trees. In 1984, the estimated cost of pest and disease control for 1 acre (0.4 ha) of flowering dogwoods was \$290 over a 3-year period (Badenhop et al., 1985). For 2000, this estimate was about \$1,075/acre (\$2,656/ha), with the increased cost largely due to powdery mildew (Klingeman et al., 2001). After adjusting fungicide costs with the producer price index for fungicidal preparations in order to account for inflation between 1984 and 2000 (U.S. Dept. of Labor, 2002), a nursery grower can save \$593/acre (\$1,465/ha) by using resistant trees. The typical nursery grower produces 4,000 trees/acre (9,884/ha) (Badenhop et al., 1985) and, assuming a constant cost per tree, a typical nursery can expect to save \$0.148/tree.

The feasibility of introducing a series of resistant trees depends largely on consumer acceptance. Gardner et al. (2002) estimated the mean willingness to pay (WTP) for resistant trees and concluded that the characteristics of a respondent's yard, landscape ex-

penditures, criteria for selecting plants and trees, type of retail outlet where respondents shop for landscape materials, and the city where the outlet is located had significant effects on the mean willingness to pay.

An important consideration for the introduction of the new trees is the reaction of the nursery industry from the producer to the retail levels. Researchers who developed the trees have speculated that the resistant tree could sell at the retail level for a \$2.00 to \$3.00 premium, an amount that is considerably less than the mean WTP of \$13.35 estimated by Gardner et al. (2002). The objective of this study was to estimate an optimal university fee (e.g., royalty) for a patented flowering dogwood tree by simulating the effects of alternative fees on the supply and demand of dogwoods by nurserymen, retailers, and consumers.

Materials and methods

A willingness to pay (WTP) survey was used to ask respondents' for their opinions regarding the risks and costs associated with powdery mildew. Respondents could be thought of as having been given a choice between two uncertain alternatives, or gambles. The decision tree is shown in Fig. 1. Each dogwood tree has an unknown probability of not contracting powdery mildew. Winning is defined as a dogwood not contracting the disease. Let

p = the probability of winning and π = the utility a person receives from a healthy dogwood. Losing occurs when a dogwood becomes infected with powdery mildew. The probability of losing is $(1 - p)$, and π^* represents the utility associated with having a diseased tree in a homeowner's yard. Subscripts r and n refer to the resistant and nonresistant varieties.

The information provided during the survey had four components. First, the resistant tree had a higher probability of winning (p_r) than a non-resistant tree (p_n), or $p_r > p_n$. Second, for an additional maintenance cost, nonresistant trees can be sprayed with fungicide to prevent powdery mildew. Third, although the resistant tree is not immune to powdery mildew, respondents may have been led to believe that it is immune, or $p_r = 1$, so the resistant tree would be thought of as a certainty equivalent. Fourth, fungicides may provide the same degree of prevention as the resistant tree, or $p_r = p_n$. However, having to spray the nonresistant tree more would result in a lower level of utility derived from a nonresistant tree.

The probabilities and payoffs are unknown, and beliefs about these values are not fixed across respondents. For the i^{th} respondent, the probability, p_{ij} (where $j = r$ or n), for example, can change depending on the growing conditions that any given respondent expects. The satisfaction a respondent believes he or she will receive from owning a healthy flowering dogwood is π_{ij} . Satisfaction from owning a diseased tree, π_{ij}^* , ranges from the utility received from the total loss of a tree to the utility received from stunted growth. The utility an individual receives from π_{ij}^* is less than the utility of π_{ij} , holding everything else constant.

A consumer's purchase decision entails valuation of the risks associated with the two types of dogwoods contracting powdery mildew and the alternatives' payoffs. The assessment process can be broken down into four conceptual parts. First, the respondent as-

sesses the probabilities based on prior experience and information available to the respondent at the survey location. Second, expected utility values (EU_{ij}) are calculated for the types of dogwood. This is done by adding together the results of multiplying the probability of each outcome within a gamble by its respective utility. For gamble 1, the resistant tree:

$$EU_{i1} = \pi_{ir} p_{ir} + \pi_{ir}^* (1 - p_{ir}).$$

For gamble 2, the nonresistant tree:

$$EU_{i2} = \pi_{in} p_{in} + \pi_{in}^* (1 - p_{in}).$$

Third, the respondent develops a risk premium (RP_i). RP_i is the difference between EU_{i1} and EU_{i2} . This method for assessing an RP_i includes the time and disutility of spraying a nonresistant tree, as well as the possible loss in utility due to powdery mildew. Fourth, the RP_i is converted from utility to dollars, and the respondent estimates WTP_{*i*}.

PROBABILITY ASSESSMENT. After the distribution of WTP has been estimated for a sample of landscape plant consumers, it is possible to estimate the probability, θ , that a consumer selected at random would purchase a resistant tree, given a specific price premium or fee at the retail level, F_{Retail} . To assess this probability, a cumulative distribution function (CDF) can be generated based on the sample distribution. If $F_{\text{Retail}} = 0$, the probability of purchasing a resistant tree is 1, because consumers would be able to receive RP without having to pay. There also is an F_{Retail} that is so high that no consumer would buy the resistant tree.

GAME SIMULATION. Decision theorists use influence diagrams and decision trees to visualize problems that contain uncertainty. Figure 2 presents the influence diagram for a powdery mildew resistant dogwood. Circles represent unknown values, which can be approximated by probability distributions. The rectangle is an assumed fee charged by the university, F_{Univ} , which is varied to assess the impact of different fees. The rectangle with rounded corners represents a calculation. In this case the calculation is based on the market interaction of supply and demand needed to determine retail fees and the alternative probabilities of a purchase.

A Monte Carlo simulation was used to model a known probability

Fig. 1. A respondents' decision-tree for resistant (r) and nonresistant (n) dogwoods as impacted by probabilities of contracting or not contracting powdery mildew and the resulting payoffs. The "P" denotes the probability of winning, $(1 - p)$ is the probability of losing, " π " represents the utility a person receives from a healthy dogwood, and " π^* " the utility associated with having a diseased tree.

Fig. 2. Flow chart presenting the sequential influence of fee selection, nursery and retail pricing decisions, and consumer purchase decisions. Circles represent unknown values that are approximated by probability distributions. The rectangle represents the fee selected by the university. The rectangle with rounded corners represents a calculation of the interaction between supply and demand.

Fig. 3. Simulation game-tree illustrating the generation of variations in distributions resulting from high (H) to low (L) fee selection decisions by the university, and subsequently by nurserymen. The maximum and minimum bounds of the distribution are represented by H and L.

distribution. Here, the objective was to mimic a cooperative game among members of the dogwood supply chain. Figure 3 portrays the interaction between the university and a nursery in the first stage of the game. The upper and lower branches, labeled H and L, respectively, represent upper and lower bounds of the distributions. In actuality, there is no bound on the distribution; however, extremely large or small values are neither realistic nor likely. Arcs in the diagram represent ranges of alternative fees. The university (as the owner of the patent) sells the trees to a nursery. The distribution of the subsequent players' actions is based on an expert opinion. The game

tree for the remaining stages of the simulation would be similar to the one shown in Fig. 3. The simulation implicitly assumes that whatever the mix of resistant (r) plus nonresistant (n) dogwoods supplied to the retail market, all are sold. That is, the analysis considers 1,000 hypothetical consumers who are assumed to purchase 1,000 dogwoods, and interest centers on the fee and the mix of trees.

The university is assumed to maximize revenue from a fee ($F_{Univ.}$) by cooperating with the supply chain, allowing the other players to make their normal profits on the resistant tree. In the first stage, nurseries purchase resistant seedlings and are charged by the university. Producers are assumed to realize a per unit reduction in production cost [cost savings (CS)] because of reduced fungicide applications and decreased tree loss. Consequently, the net additional cost per tree to the nursery is ($F_{Univ.} - CS$). It is assumed that the savings are passed on due to competition in the nursery industry. Nursery growers are assumed to use a percentage markup ($M_{Nursery}$) that can vary by nursery. Therefore, the percentage markup is modeled as a normally distributed random variable. The percentage markup is applied to the net additional cost of the resistant tree to arrive at a fee ($F_{Nursery}$) that is passed on to the next stage of the distribution system, therefore, $F_{Nursery} = (F_{Univ.} - CS) \times (1 + M_{Nursery})$.

In the second stage, a retail store sets fees (F_{Retail}) in a similar manner. The retail markup is a percentage that can vary by outlet. Its distribution is based on an expert opinion. Retail markups are multiplied by $F_{Nursery}$ to simulate the retail fee, i.e., $F_{Retail} = (F_{Nursery}) \times (1 + M_{Retail})$.

In the final stage of the simulation, the retailer faces the consumers' market demand. A dogwood consumer enters a retail store at random and compares prices for regular dogwood trees and resistant trees. At this point it is useful to realize that a real consumer could purchase a resistant dogwood, a nonresistant dogwood, a substitute landscape product, or make no purchase. The simulation assumes the consumer purchases a dogwood tree of some type.

WILLINGNESS TO PAY. WTP data were collected at lawn and garden shows in four different cities: Knoxville, Tenn.; Nashville, Tenn.; Detroit, Mich.; and Jackson, Miss. Cities were chosen based on access to home and garden shows and the availability of personnel to conduct the survey. A display was designed in order to create a WTP setting. Materials consisted of pictures of diseased dogwood leaves, healthy dogwood leaves, a flowering dogwood in full bloom, and a brief description of powdery mildew. Respondents were then asked to complete a survey questionnaire.

The first question asked how much more the respondent would pay for a typical dogwood tree that is resistant to powdery mildew, compared to a nonresistant tree. The typical size tree is ≈ 5 ft (1.5 m) tall, has a 1-inch (2.5-cm) diameter trunk, and is sold in a 5-gal (18.9-L) plastic container. The questionnaire had a number line that ranged from \$0.00 to \$30.00. One dollar increments were hatch-marked, and \$5.00 increments were numbered. Respondents had a tendency to indicate

Fig. 4. Relative frequencies of respondents' willingness-to-pay (WTP) for powdery mildew resistant dogwoods as price increments increase.

Fig. 5. Cumulative relative frequency distribution for the probability of purchasing a powdery mildew resistant dogwood as the willingness-to-pay (WTP) varies from an additional \$30 per tree to zero.

WTP in multiples of \$5.00 (Fig. 4). This may reflect the way the number line was labeled, as well as a possible tendency for respondents to evaluate in terms of \$5.00 increments. The mean and standard deviation were \$13.35 and \$8.43 respectively, while the most frequent response was \$10.00. Figure 5 shows the cumulative distribution of WTP.

SUPPLY CHAIN MARKUP. No data are available on retail and nursery price markup rates. As an alternative, subjective probability assessments about the distribution of these variables were used (Clemen, 1995). Typically, nursery growers attempt to mark up products between 25% and 30% (Hall, 2002). Given this information, M_{Nursery} is assumed to be normally distributed with a mean 27.5% and a standard deviation of 5%. Based on expert opinions, M_{Retail} tends to range between 200% and 300%, with two-thirds of the retailers marking up products between 200% and 250%, and the probability of any given markup within its respective range is the same (Hall, 2002).

Results and discussion

SIMULATED RANDOM VARIABLES. The accuracy of the simulation depends on how well the theoretical distributions used to create random variables replicate the real world. Therefore, comparison between the distributions of simulated random variables with actual distributions of the variables that are being modeled is useful.

In the first stage of the game, the nursery grower is assumed to

add a markup, M_{Nursery} . The simulated distribution was nearly identical to the assumed distribution. It had the same mean, 27.5%, and a slightly larger standard deviation of 5.2%. Figure 6 shows the relative frequency histogram for M_{Nursery} . Because of the markup process, as F_{Univ} increases, F_{Nursery} increases as does its variability (standard deviation).

Simulating the retail price markup presented a modeling challenge. Two uniform distributions, one between 200% and 250% and the other between 251% and 300%, were generated. Then

a Bernoulli trial was used to pick a distribution, resulting in the representation of the simulated distribution (Fig. 7). Sixty-seven percent of the simulated markup distribution was contained in cells centered on 210% through 250%, with the remaining 33% in cells centered on 260% through 300%. The simulated average retail markup was 242% with a standard deviation of 1,030%. The large standard deviation relative to the mean reflects the distribution of markups at the nursery and retail levels. A nursery with a large (small) markup could supply a retailer with a large (small) markup. These markups were then subjected to the distribution of consumers' WTP.

Winningness-to-pay was modeled using a discrete distribution. Dollar amounts were assigned a cumulative probability based on the actual WTP data. The simulated distribution had a mean of \$13.69 and a standard deviation of \$8.63, compared to the actual sample mean, \$13.35, and standard deviation, \$7.78. Figure 8, the simulated WTP distribution, is comparable to the actual distribution shown in Fig. 5.

SIMULATION RESULTS. Using the distributions described above, three

Fig. 6. Nursery markup percentages with relative frequencies for dogwood trees resistant to powdery mildew.

Fig. 7. Retail markup percentages with relative frequencies for dogwood trees resistant to powdery mildew.

Fig. 8. Cumulative relative frequency distribution for the probability of purchasing a powdery mildew resistant dogwood as the willingness-to-pay fee varies from an additional \$30 per tree to zero.

scenarios were developed, and 1,000 simulation trials were run for each scenario. Results for all three scenarios are found in Table 1. It is important to keep the scenario context in mind when interpreting these results. The simulations attempt to predict if a random consumer would purchase a tree given a fee (starting with $F_{Univ.}$ and passed through to $F_{Retail.}$) that is determined by random supply chain markups. It is incorrect to think of each scenario in terms of a nursery that grows 1,000 resistant trees, or multiples thereof, because the analysis is based on simulated demand as opposed to actual sales. Rather, the simulation is directed toward analyzing a hypothetical level of demand for dogwoods in terms of mildew resistant trees and traditional dogwoods.

Scenario 1 simulates the effects of $F_{Univ.} = \$1.00$. In this scenario 1,000 random consumers of dogwood trees each visited a random retailer; 908 of them purchased resistant dogwood trees. The remainder is assumed to have purchased nonresistant dogwoods. The retailer sells about nine resistant trees for every nonresistant tree, and the industry should, therefore, produce the trees in such a ratio. The university's

simulated return is \$908.00. Assuming the wholesale nursery fee is a normally distributed random variable with mean \$1.09 and standard deviation \$0.04, the average nursery would experience an increase in revenue of $\$986.60 = (908 \times \$1.09)$. Given a normally distributed $F_{Retail.}$ with mean \$2.64 and standard deviation \$0.34, the simulated retailers' expected increase in revenue is $\$2,396.46 = (908 \times \$2.64)$.

In Scenario 2, $F_{Univ.} = \$3.51$, and there are 620 simulated purchases of resistant dogwoods. About six out of every ten dogwood trees sold are resistant. Expected return to the university is \$2,177.37. The mean $F_{Nursery.}$ is \$4.29, with a standard deviation of \$0.17. Nurseries' simulated sales increase is \$2,659.73. Given a mean $F_{Retail.}$ of \$10.41 and standard deviation \$1.33, the simulated retail sales increase is \$6,460.52 per 1,000 trees.

A \$6 fee is used in Scenario 3, resulting in the purchase of 282 resistant dogwood trees out of 1,000 total trees. The university would expect a return of \$1,690.00. $F_{Nursery.}$ has a mean of \$7.46, and standard deviation \$0.29. Nurseries' simulated return is \$2,201.10. In this scenario, $F_{Retail.}$ has a mean of

\$18.13 and standard deviation \$2.32, with an expected return to retailers of \$5,106.04.

The effects of other fees were simulated. Figure 9 shows how $F_{Univ.}$ affected $R_{Univ.}$, $R_{Nursery.}$ and $R_{Retail.}$. In each stage of the simulated game, revenue behaves the same way. That is, a fee that maximizes $R_{Univ.}$ also maximizes $R_{Nursery.}$ and $R_{Retail.}$. The diagram can be interpreted two ways. First, if the objective is a target rate of return per 1,000 trees (e.g., \$2,000 for the university), then there is a range of $F_{Univ.}$ values consistent with this objective (e.g., \$2.59 to \$5.10). If the objective is to maximize the revenue then a specific $F_{Univ.}$ is used.

Figure 9 displays revenue, not cost or profit. The nursery (retailer) curve lies above the university (nursery) curve due to the fee being marked-up as the trees move through the distribution channel. Since retailers have the highest mark-up, the vertical distance between the retail and nursery curves is the largest. Given $F_{Univ.}$ and markup pricing, the costs of the trees rise in subsequent stages of the distribution channel, and revenues increase as well.

Given the 1998 level of dogwood sales of 1.475 million trees (U. S. Department of Agriculture, 1998), 914,500 (1.475 million trees times 0.62) resistant trees would be sold with a $F_{Univ.}$ of \$3.51. Consequently, nurseries would incur increased costs of \$3.2 million. The markup process would increase nursery revenue by \$3.9 million, so the net change due to the fee would be \$0.7 million. Not having to spray these trees as often would increase the gain to over \$0.8 million. The retail markup leads to \$10.41 per tree, or \$9.5 million in additional revenue, based on 1998 sales. Subtracting the increased cost of the trees leads to an estimated retail revenue increase of $\approx \$5.5$ million.

Table 1. Simulation results for hypothetical sales of 1,000 dogwoods.

Financial parameter	Scenario 1	Scenario 2	Scenario 3
University fee ($F_{Univ.}$)	\$1.00	\$3.51	\$6.00
University revenue ($R_{Univ.}$) ^z	\$908.00	\$2,177.37	\$1,690.00
Nursery fee ($F_{Nursery.}$)	\$1.09	\$4.29	\$7.46
Nursery revenue ($R_{Nursery.}$) ^y	\$986.60	\$986.60	\$2,102.10
Retailer fee ($F_{Retail.}$)	\$2.64	\$2.64	\$18.13
Retailer revenue ($R_{Retail.}$) ^x	\$2,396.46	\$6,460.52	\$5,106.04
Resistant dogwood sales ^w	908	620	282
Percent of total dogwood sales	91%	62%	28%

^z $R_{Univ.} = (F_{Univ.})(\text{resistant dogwood sales})$.

^y $R_{Nursery.} = (F_{Nursery.})(\text{resistant dogwood sales})$.

^x $R_{Retail.} = (F_{Retail.})(\text{resistant dogwood sales})$.

^wPer 1,000 total dogwood trees sold.

Fig. 9. Revenue effects on the university, nurserymen, and retailers from various university fee levels.

Conclusions and implications

Simulation results such as this can be quite useful in predicting cost savings and price markups. These simulations allow for different reactions by nurserymen, retailers, and consumers. The distributions of reactions are based on expert opinions or survey data. A below-optimal fee would not necessarily result in a lower retail price, as other players in the supply chain could increase their respective markups.

For the revenue maximizing producer and retailer, an important result is the ratio of resistant to nonresistant trees, because producing nonoptimal quantities will reduce revenue. In the optimal scenario, this ratio is about six resistant trees out of every ten total dogwoods. If the nursery industry as a whole were to produce too many resistant trees then the excess supply would drive prices down, resulting in a loss of revenue. Given the simulation assumptions and holding retail sales held constant at the 1998 level, the university could expect a return of \$3.2 million from the sale of 914,500 resistant dogwood trees.

Literature cited

- Badenhop, M.B., W.T. Witte, and T.E. Glasgow. 1985. Production systems and costs for producing balled and burlaped trees of dogwood cultivars, Tennessee, 1984. Tenn. Agr. Expt. Sta. Bul. 637.
- Clemen, R.T. 1995. Making hard decisions: An introduction to decision analysis, 2nd ed. Duxbury Press, Pacific Grove, Calif.
- Gardner, J.G., D.B. Eastwood, J.R. Brooker, J.B. Riley, and W.F. Klingeman. 2002. Consumers willingness-to-pay for powdery mildew resistant flowering dogwoods. Univ. Tenn. Dept. Agr. Econ. Res. Ser. 02-02.
- Hall, C.R. 2002. An economic assessment of the importance of the green industry in Tennessee. Tenn. Green Times (Summer):3.
- Klingeman W.E., J.R. Brooker, D.B. Eastwood, B.K. Behe, J.B. Riley, and P. Knight. 2001. Consumer perceptions of landscape characteristics, disease and pest problems, and the value of powdery mildew resistant dogwood. Univ. Tenn. Dept. Agr. Econ. Res. Ser. 09-01.
- Simmons, M. 2002. Disease free dogwood on the way. Knoxville News Sentinel (Sect. A1, 7 Apr. ed.):section B, page 1.
- Tennessee Agricultural Statistics Service. 2002. Tennessee agriculture 2000. Tenn. Dept. Agr. Bul. 35.
- U.S. Department of Agriculture. 1998. Census of horticultural specialties, USDA, Natl. Agr. Stat. Serv., Wash., D.C.
- U.S. Department of Labor. 2002. Producer price index for fungicidal preparations primarily for agricultural, garden or health service. Series PCU2879#7, Bur. Labor Stat., Wash., D.C.
- Windham, M.T. and W.T. Witte. 1998. Naturally occurring resistance to powdery mildew in seedlings of *Cornus florida*. J. Environ. Hort. 16:173-175.