Journal of Agricultural and Resource Economics 45(2):199–218 ISSN: 1068-5502 (Print); 2327-8285 (Online)

doi: 10.22004/ag.econ.302450

Grower Willingness to Pay for Fruit Quality versus Plant Disease Resistance and Welfare Implications: The Case of Florida Strawberry

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We assess decision making when growers choose to invest in a new fruit cultivar, given the trade-offs between superior fruit quality and improved disease resistance. We also estimate the welfare effects of adopting a cultivar with improved disease resistance. Florida strawberry growers are more willing to pay for fruit quality relative to improved disease resistance. When adopting a cultivar with improved disease resistance, Florida strawberry growers save between $182.40 and $204.50 per 1,000 plants every annual harvest period. Our findings improve the understanding of how strategic decisions are made to meet increasing marketplace demands for superior fruit quality and reduced chemical applications.

Key words: adoption of new cultivars, improved cultivars, producer decision making, welfare estimation, WTP space

Introduction

For agricultural producers, improved plant cultivars are demand-driven innovations that directly address farming opportunities and growers' perceived risks (Pannell and Zilberman, 2001). Yield and product quality losses caused by disease and pest pressures are a constant threat. Growers typically manage these risks with pesticide treatments, but incorporating genetic resistance to pests offers an opportunity to address regulatory restrictions, control costs, and potentially meet increasing consumer demands to limit applications of agricultural chemicals, thereby reducing the human health and environmental impacts often associated with pesticide use. Previous literature suggests that consumers are willing to pay price premiums for pesticide-free fruits and vegetables (Boccaletti and Nardella, 2000; Florax, Travisi, and Nijkamp, 2005; Onozaka, Bunch, and Larson, 2006).

Strawberry (*Fragaria times ananassa*) is an increasingly popular specialty crop produced across the United States. Between 2007 and 2017, the volume of strawberries produced in the United States increased by 23.5%, from 24.45 million hundredweight (cwt) to 31.95 million cwt (U.S. Department of Agriculture, 2017, 2018b) and per capita domestic consumption increased by 28%, from 6.1 lb

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This research is funded by the USDA National Institute of Food and Agriculture Specialty Crop Research Initiative project: RosBREED: Combining Disease Resistance with Horticultural Quality in New Rosaceous Cultivars (2014-51181-22378). The authors appreciate comments from Seonghee Lee and Hayk Khachatryan.

Review coordinated by Darren Hudson.

in 2006 to 8 lb in 2016 (U.S. Department of Agriculture, 2018a). In 2017, the total value of the domestic strawberry crop was $3.49 billion, of which 94.6% was fresh and 5.4% processed (U.S. Department of Agriculture, 2018b).

The two largest strawberry-producing states are California and Florida, accounting for 91.3% and 7.5% of U.S. production, respectively (U.S. Department of Agriculture, 2018b). Primarily marketed nationwide as a fresh product in the winter, Florida-grown strawberries in 2017 had a farmgate value of $337 million (U.S. Department of Agriculture, 2018b). Florida strawberry growers annually face severe losses due to a complex of root and crown rot diseases caused by *Phytophthora cactorum*, *Colletotrichum* spp., and *Macrophomina phaseolina* (Ivors and DeVetter, 2015) and thus provide a useful, geographically specific case to analyze growers' decision whether to adopt a new cultivar.

Soil fumigants such as methyl bromide (MB) are a highly effective management tool for strawberry root and crown rot diseases (Schneider et al., 2003; Rosskopf et al., 2005; Ivors and DeVetter, 2015), but the 2005 federal Clean Air Act forbids MB production or import due to damage to the ozone layer (U.S. Environmental Protection Agency, 2018). While strawberry nursery fields qualify for a critical-use exemption, routine MB use in fruiting fields has gradually been eliminated (U.S. Environmental Protection Agency, 2018). By 2015, Florida had nearly completed phasing out MB for soil fumigation (Noling, 2016). Since alternative fumigants to control root and crown rot diseases are far less effective, producers might find growing more resistant cultivars to be a promising approach (Mangandi, Peres, and Whitaker, 2015). However, when adopting a new cultivar—even one that shows resistance to a critical stress like crown and root rot disease—growers must optimize their return on investment by balancing such production-desirable traits with market-demanded fruit quality traits.

This paper has two objectives. First, we investigate strawberry growers' willingness to pay (WTP) for selected fruit quality attributes and plant resistance to root and crown rot diseases. This information will help guide breeding programs in developing cultivars with trait combinations of value to their clientele. It will also help strawberry growers and the industry make informed decisions when adopting new cultivars. Second, we assess the welfare impact of the incidence of root and crown rot diseases relative to the MB phaseout. This information could help the industry and policy makers understand the economic impact of disease-induced losses and more efficiently develop disease resistant cultivars.

Literature Review

Several studies on consumer preferences for strawberry fruit quality attributes conclude that the quality attributes of sweetness, freshness, texture, fruit size, and color are determinants of preference (Bhat et al., 2015; Colquhoun et al., 2012). Colquhoun et al. surveyed U.S. strawberry consumers and concluded that the ideal strawberry was sweet and firm with a smooth internal texture. Conducting a latent class segmentation, Wang et al. (2017) identified three segments of U.S. strawberry consumers: search attribute sensitive consumers, experience attribute sensitive consumers, and balanced consumers. In general, consumers in all segments favored vibrant internal color, sweet flavor, and long shelf life. These attributes are also important for market intermediaries. Gallardo et al. (2015) surveyed U.S. strawberry packing and shipping operations and found these entities also prioritized quality attributes such as sweetness, freshness, texture, fruit size, and color.

A number of studies have investigated consumer preferences for fresh fruit credence attributes such as organic, fumigant/pesticide-free, environmentally sustainable, and locally grown (Yue and Tong, 2009; Moser, Raffaelli, and Thilmany-McFadden, 2011; Carroll, Bernard, and Pesek, 2013). Studies specifically exploring consumer preferences for pesticide-free attributes in fresh fruits suggest that consumers are willing to pay a premium for pesticide-free fruits because of the perceived personal benefits from avoiding such chemicals in their food (Boccaletti and Nardella, 2000; Onozaka, Bunch, and Larson, 2006). Loureiro, McCluskey, and Mittelhammer

(2001) found that consumers with stronger environmental attitudes were more likely to buy eco-labeled apples produced with reduced pesticide-application frequency. Ruth, Rumble, and Settle (2016) investigated Florida consumer preferences for Florida-grown strawberries and found that more than 80% of consumers purchased them because of perceived freshness and to support the Florida economy. These studies suggest that a new strawberry cultivar with improved disease resistance and improved fruit quality would help Florida strawberry growers remain competitive in the national and regional marketplaces.

Few studies have investigated grower preferences for fruit quality attributes compared to disease resistance. Yue et al. (2014) found that U.S. strawberry growers ranked quality attributes such as fruit firmness, flavor, and shelf life as more important than root rot resistance, but attribute ranking varied by state. Florida strawberry growers ranked fruit firmness as more important compared to California growers, and they ranked fruit flavor as less important compared to growers in Michigan and Oregon. In a different study, Yue et al. (2017) found that strawberry growers were willing to pay premiums for strawberry cultivars with improved external color, size, firmness, flavor, internal color, or shelf life. Additionally, Yue et al. (2017) found that larger-scale strawberry growers were more sensitive to potential cost increases for planting material of new strawberry cultivars than were small-scale growers.

A number of studies suggest that models for the decision to invest in a new cultivar need to control for growers' heterogeneous preferences (Birol, Villalba, and Smale, 2009; Zhao et al., 2017). Choi et al. (2017) identified strawberry growers' heterogeneous preferences for cultivars displaying color, firmness, flavor, and shelf life quality attributes but did not include disease resistance. Other studies (Yue et al., 2014, 2017) identify strawberry growers' preferences for fruit attributes when selecting a new cultivar, but most do not allow for heterogeneous preferences for both quality attributes and disease resistance.

The total effects of strawberry disease control include direct effects such as crop loss due to disease and indirect market effects such as reduced fruit quality and public welfare due to environmental concerns (Peres, Seijo, and Turechek, 2010). Empirical studies suggest that disease outbreaks generally imply a considerable social welfare loss for the fresh fruit industry (Kwon et al., 2015). As growers attempt to differentiate their produce with high fruit quality and reduced/modified pesticide application, cultivars with superior quality and disease resistance would address both goals.

Literature on plant breeding programs suggests that resource limitation and perceived lack of consensus between grower and consumer needs are challenges faced by many rosaceous crop-breeding programs (Gallardo et al., 2012; Yue et al., 2012). Specific to strawberry breeding programs, Gallardo et al. (2012) found that the five most important traits clusters selected by strawberry breeders were post-harvest quality, yield, texture, flavor, and appearance. The likelihood of selecting for resistance to disease traits was higher than selecting for abiotic stress resistance, yield, post-harvest quality, or phytonutrient content but lower than selecting for texture, flavor, or appearance. The most serious overall constraint reported by strawberry breeders (Yue et al., 2012) was available time versus other limitations such as the availability of genetic material, trait heritability, genetic variation, and inadequate facilities, suggesting that breeders must carefully plan their programs as efficiently as possible to mitigate their constraints.

This study adds to the existing literature on fresh produce growers' WTP and the trade-offs they make among various attributes associated with quality attributes and disease resistance. This study also examines the welfare effects of strawberry crop loss due to root and crown disease after the MB phaseout. Although focused on Florida strawberry growers, our methodology is also applicable to the more general population of specialty crop growers across the United States.

Methodology

Data Collection

We procured a random sample of 400 Florida strawberry farm representatives, including their names and mailing addresses, from Meister Media Worldwide (www.meistermedia.com). The questionnaire distribution strategy followed Dillman, Smyth, and Christian's (2009) Total Design Method (TDM). We implemented a mixed-mode survey, including online and paper versions of the questionnaire. During the third week of October 2016, researchers distributed a survey package including a printed paper questionnaire, a postage-paid return envelope, a \$1 pre-incentive, and a cover letter explaining the study and how to access the survey online if the respondent opted for the online version. Reminder postcards were sent 1 week later to nonrespondents. A second wave of surveys with replacement questionnaires was sent to growers who had not responded by the second week of November 2016. Because of the low response rate, reminder phone calls were made to nonrespondents during the last week of January 2017.

Of 400 questionnaires initially mailed, 189 of the contacts were identified as ineligible because the grower had not grown strawberries in 2015–2016. Of the 211 remaining contacts, 31 questionnaires were completed and returned, for a response rate of 14.7%. To increase the response rate, a second-round, open-access survey was made public on the Florida Strawberry Growers Association website in March 2017, in cooperation with the University of Florida strawberry breeding program. We received 6 more completed questionnaires from this last effort, bringing the total number of completed questionnaires to 37, with 22 paper and 15 online.

The questionnaire requested information related the 2015 production/marketing year and included questions about strawberry growers' choices of cultivars, experiences with root and crown rot diseases, perceptions of flavor and resistance to root and crown rot diseases, and the percentage of crop loss caused by root and crown rot diseases for cultivars such as the recently released Sweet Sensation® 'Florida127' (hereafter referred to as Sweet Sensation®) and 'Florida Radiance', among others. We included questions about sociodemographic information on principal operators, general farm characteristics, and preferences for improved cultivars.

Each respondent was presented with eight choice scenarios with different combinations of strawberry attributes, including flavor, size, transplant cost, and disease resistance attributes. In each scenario, strawberry growers were given two alternatives that differed by the levels of fruit size, flavor, a percentage of plant loss from root and crown rot diseases prior to first harvest, and transplant plus royalty cost (labeled as Options A and B). Figure 1 provides an example of a choice scenario. Growers were asked to select their preferred alternative; if neither Option B was of interest, respondents could choose Option C, a "neither" option. Cultivar attributes, value levels, and transplant plus royalty cost were obtained by consulting with strawberry breeders, extension educators, industry representatives, and growers.

Table 1 reports attribute levels for choice scenarios. We included three levels each for fruit size, flavor, percentage of plant loss from root and crown rot diseases, and transplant plus royalty cost, for a total of $3^4 = 81$ possible combinations. To limit the number of choices, we used a fractional factorial design and ended with 16 random combinations. To generate the experimental design, we used JMP® software, which consists of a two-step procedure using an algorithm based on Kessels, Jones, and Goos (2011). First, we determine the constant attributes and their levels (i.e., determine which attributes to hold identical for all alternatives; the set of constant attributes changes in each choice scenario). Second, we select levels for the remaining attributes, varying them to maximize D-efficiency.

More specifically, in the first step, we minimize the variance when each pair of attributes chosen to be held constant occurs at the same frequency. For example, suppose we allow two attributes to be set constant for each scenario, then $\gamma_{rs} = \gamma_{rs'}$ for any $r \neq r'$ and $s \neq s'$, where γ_{rs} is the number of times attributes r and s are both set to be the constant attribute. The second step is then to choose

For each of the following eight scenarios for growing strawberries, please indicate which option you would prefer to grow: A or B (only ONE), or if you would choose Neither (Option C).

Strawberry Features	*Option A*	*Option B*	*Option C:*
Percentage of plant loss from root and crown rot diseases prior to first harvest	5\%	0\%	Neither Option A nor B
Flavor on a scale of 1--7 (combination of sweet, tart/sweet balance, and aroma)	Weak/mild (score 1–2* see below)	Neutral (score 3–5* see below)	
Size (number of fruits in a 1 lb clamshell)	20	15	
Cost of transplant + royalty $/1000 plants)	$140	$150	
Which option would you choose?	☐	☐	☐

*Please use this 7-point scale when considering your preference for flavor (combination of sweetness, sweet/tart balance, and aroma).

Extremely weak/mild flavor			Neutral flavor		Extremely fully/intense flavor	
1	2	3	4	5	6	7

Figure 1. Example of a Choice Scenario Used in the 2016 Florida Strawberry Grower Survey

Table 1. Attribute Levels for the Discrete Choice Scenarios Used in the 2016 Florida Strawberry Grower Survey

Cultivar Attributes	**Unit**	**Level 1**	**Level 2**	**Level 3**
Plant loss due root and crown rot diseases prior to first harvest	%	0%	5%	10%
Flavor	Score	1–2 (weak/mild)	3–5 (neutral)	6–7 (full/intense)
Fruit size	Number of fruits in a 1-lb clamshell	15	20	25
Cost of transplant + royalty	$/1,000 plants	140	150	160

the other attribute levels to maximize D-efficiency, $D = \int \log |M(X_h,\ \tau)|\, \pi(\tau)\, d\tau$, where $M(X_h,\ \tau)$ is the determinant of the information matrix, determined by attribute levels X_h and parameter τ, and $\pi(\tau)$is the guessed distribution of parameter τ. The idea is to exchange one current element of X_h at a time with other possible values until the maximization converges.

The difficulty is in determining which value of X_h to change so that the convergence is fastest. The JMP® coordinate exchange algorithm (Meyer and Nachtsheim, 1995) generates fairly balanced designs (although the frequencies of different attribute levels are not exactly the same) while achieving optimal D-efficiency, which explains why JMP® is widely used by researchers to generate choice design. Further, the experimental design used in this study aims to minimize the number of scenarios to reduce participant survey fatigue (especially for producers, who have limited time to complete the survey) while maximizing D-efficiency. Based on the JMP® output, the current design (eight scenarios) has a D-efficiency of 80%. Trying a different number of scenarios (e.g., nine instead of eight) would slightly increases the D-efficiency (85%), at the cost of potentially increasing survey fatigue.

Empirical Estimation: Grower WTP for Strawberry Fruit Quality and Plant Disease Resistance Attributes

Based on Lancaster's (1966) model of consumer choice, consumers derive utility from the attributes of goods. We assume that a strawberry grower derives utility when she sees her profits augmented, where grower profits are a function of expected revenues derived from strawberry cultivars with improved fruit quality characteristics and expected costs resulting from planting a new cultivar. Assume a grower, n, has j strawberry varieties to choose from and is faced with t choice situations. Consistent with the random utility theory (McFadden, 1986), we define the grower's utility as

$$U_{njt} = V_{njt}(\beta_n) + \varepsilon_{njt}, \tag{1}$$

where $V_{njt}(\beta_n)$ is the deterministic portion of utility, defined as a function of strawberry cultivar attributes (including cost of transplant and royalty), and ε_{njt} is the random portion of the utility or the error term, which follows a Gumbel distribution.

In this study, we apply the concept of utility in the WTP space (Scarpa, Thiene, and Train, 2008). We specify utility V_{njt} as separable in strawberry cost of transplant and royalty, p, and a vector of strawberry cultivar attributes, described by $\boldsymbol{x}$, following

$$V_{njt} = -\alpha_n p_{njt} + \boldsymbol{\theta}_n \boldsymbol{x}_{njt}, \tag{2}$$

where the scalar α_n and vector $\boldsymbol{\theta}_n$ vary randomly over growers. Replacing equation (2) in equation (1), we obtain

$$U_{njt} = -\alpha_n p_{njt} + \theta_n \boldsymbol{x}_{njt} + \varepsilon_{njt}. \tag{3}$$

The variance of ε_{njt} is grower specific and follows $\mathrm{Var}(\varepsilon_{njt}) = \mu_n^2 \left(\frac{\pi^2}{6}\right)$, where μ_n is the scale parameter for grower n. Dividing equation (1) by the scale parameter μ_n, we obtain

$$U_{njy} = -\left(\frac{\alpha_n}{\mu_n}\right) p_{njt} + \left(\frac{\boldsymbol{\theta}_n}{\mu_n}\right) x_{njt} + \varepsilon_{njt}, \tag{4}$$

where ε_{njt} is an *i.i.d.* type I extreme value distribution with a constant variance $\frac{\pi^2}{6}$. Then, the utility in equation (1) could be expressed as

$$U_{njt} = -\lambda_n p_{njt} + c_n x_{njt} + \varepsilon_{njt}, \tag{5}$$

where $\lambda_n = \left(\frac{\alpha_n}{\mu_n}\right)$ and $c_n = \frac{\theta_n}{\mu_n}$. If one further assumes that the implied WTP for strawberry cultivar attribute is the ratio between the attribute's coefficient and the cost coefficient, then we have $w_n = \frac{c_n}{\lambda_n} = \frac{\theta_n}{\alpha_n}$. Equation (5) can then be expressed as

$$U_{njt} = -\lambda_n p_{njt} + (\lambda_n w_n) x_{njt} + \varepsilon_{njt}, \tag{6}$$

which depicts the utility in WTP space. Considering that the scale parameter varies by grower, this specification allows us to distinguish between WTP variation in terms of its distributional features and variation in scale. Additionally, the scale-free coefficients in equation (4) can be directly interpreted as WTP. Note that the cost-of-transplant coefficient is negative and expressed as $\lambda_n = -\exp(\nu_n)$, where ν_n is the latent random factor underlying the cost coefficient (Scarpa, Thiene, and Train, 2008).

A strawberry grower n chooses cultivar i at choice occasion t if $U_{nit} > U_{njt}\ \forall\ j \neq i$. Considering that the grower's chosen cultivar in occasion t is y_{nt}, then the grower's sequence of choices over the

T_n choice occasions is $y_n = \{y_{n1}, y_{n2}, y_{n3}, \ldots, y_{nT_n}\}$. The conditional probability of the grower n is given by

$$L(y_n|\beta_n) = \prod_{t=1}^{T_n} \frac{e^{-V_{ny_{nt}}(\beta_n)}}{\sum_j e^{-V_{njt}(\beta_n)}}. \quad (7)$$

The WTP in space is advantageous over specifications such as the mixed logit with price coefficients set as fixed, as it is possible that variation in the price scale might be confounded with variation in WTP, implying an inaccurate interpretation of the WTP coefficient. Also, specifying all coefficients as random, including price, can lead to a model that is unidentified empirically (Ruud, 1996).

In our study, both the actual percentage of plant loss and the number of strawberries per clamshell were used; the choice options represented in the survey considered 5% crop loss differences and 5 units of fruit change. Hence, we divided the WTP for percentage of plant loss by 20 to transform WTP per 100% change to WTP per 5% change for plant loss from disease to match the design in the choice experiment. Similarly, we multiplied WTP for number of fruits by 5 to transform WTP per 1 unit of fruit change to WTP per 5 units of fruit change per 1-lb clamshell to match the design in the choice experiment.

Economic Welfare Analyses

We use a partial equilibrium model to estimate the social welfare changes after the MB phaseout and the root and crown rot disease incidence shock (see Figures S1 and S2 in the Online Supplement (www.jareonline.org)). Two consequences are assumed to occur after the MB phaseout: Strawberry productivity will either increase (Figure S1) or decrease (Figure S2). We assume a change in productivity to justify the shift of the supply curve. In both figures, S_0 and D_0 are the initial supply and demand curves and p_0 and Q_0 are the equilibrium price and quantity, respectively. Consumer surplus is represented by I_0ap_0, producer surplus is J_0ap_0, and total welfare before the shock is the I_0aJ_0. For the purposes of this study, we assume that the Florida strawberry industry follows a closed competitive commodity economy market, implying that the price of Florida-grown strawberries is determined within the state and there is no trade outside state borders. It should be noted that this is a strong and limiting assumption to simplify the model and to illustrate the direct impact of disease costs on welfare. In reality, large strawberry farms in Florida market their strawberries throughout the United States, especially in the East.

Case 1: Welfare Changes after the Methyl Bromide Phaseout under a Productivity Increase

Assume that productivity increases after the MB fumigant ban, enabled by a technology change such as cultivar disease resistance improvement, new fumigant alternatives, or new disease control management. We would expect a parallel shift to the right of the strawberry supply curve, from S_0 to S_1, resulting in a supply increase equivalent to $k = P_0 - d$. After the phaseout, the change in producer surplus is $\Delta PS_1 = J_1bp_1 - J_0ap_0 = area\ p_1dcb$, the change in consumer surplus is $\Delta CS_1 = I_0bp_1 - I_0ap_0 = area\ p_0p_1ba$, and the resulting total welfare increase is $J_0J_1ab\ (= \Delta PS_1 + \Delta CS_1)$.

We then assume a percentage of strawberry crop loss from root and crown rot diseases, which causes a parallel leftward shift of the supply curve, from S_1 to S_2. Assume the crop loss percentage is $\lambda\ (0 \leq \lambda \leq 1)$, resulting in a change in equilibrium quantities, $\Delta Q = Q_1 - Q_2 = \lambda Q_1$. The producer surplus decrease after the incidence of root and crown rot diseases is $\Delta PS_2 = J_1bp_1 - J_2fp_2 = area\ p_1geb$, and the consumer surplus decrease is $\Delta CS_2 = I_0bp_1 - I_0fp_2 = area\ p_1p_2fb$, resulting in a total welfare decrease of $\Delta PS_2 + \Delta CS_2$.

Case 2: Welfare Changes after the Methyl Bromide Phaseout under a Productivity Decrease

Assume that productivity decreases after the MB phaseout, resulting in a parallel leftward supply curve shift, from S_0 to S_1, and the supply shifts down, $k = P_1 - d$. The resulting decrease in producer surplus is $\Delta PS_1 = J_0bp_0 - J_1ap_1 = area\ p_0dca$, the decrease in consumer surplus is $\Delta CS_2 = I_0ap_0 - I_0bp_1 = area\ p_0p_1ba$, and the resulting total welfare loss is $\Delta PS_1 + \Delta CS_2$. After the incidence of root and crown rot diseases, the strawberry supply curve shifts to the left, from S_1 to S_2. Next, the supply curve shifts further to the left, from S_1 to S_2. The crop loss is λ $(0 \leq \lambda \leq 1)$, and the change in the equilibrium quantity is $\Delta Q = Q_1 - Q_2 = \lambda Q_1$. The producer surplus decrease is $\Delta PS_2 = J_1bp_1 - J_2ep_2 = area\ p_1gfb$ and the consumer surplus decrease is $\Delta CS_2 = I_0bp_1 - I_0ep_2 = area\ p_2p_1be$.

Economic Welfare Analyses: Empirical Approach

Supply and demand for Florida-grown strawberries are specified as linear functions, with the phaseout shock as the intercept change:

(8) $$Q_D = \beta_0 - \beta_1 p,$$

(9) $$Q_s = \alpha_0 + \alpha_1 (p + k) = \alpha_0 + \alpha_1 k + \alpha_1 p,$$

where Q_D is the demand function for Florida-grown strawberries with intercept parameter β_0 and slope parameter β_1; p is the price received by the grower; Q_s is the supply function for Florida-grown strawberries, with intercept parameter α_0 and slope parameter α_1; k is the supply shift due to phaseout shock, and its value is positive when assuming a productivity increase, negative otherwise, and 0 when there is no phaseout.

At equilibrium, $Q_D = Q_s$, we solve for $p_1 = \frac{\beta_0 - \alpha_0 - \alpha_1 k}{\alpha_1 + \beta_1}$ and $p_0 = \frac{\beta_0 - \alpha_0}{\alpha_1 + \beta_1}$ when $k = 0$. Calculating the producer surplus and consumer surplus change, we obtain

(10) $$\Delta PS_1 = \frac{1}{2} \frac{\varepsilon_D}{\varepsilon_s + \varepsilon_D} |k| \, p_0 (Q_0 + Q_1),$$

(11) $$\Delta CS_1 = \frac{1}{2} \frac{\varepsilon_s}{\varepsilon_s + \varepsilon_D} |k| \, p_0 (Q_0 + Q_1),$$

(12) $$\Delta PS_2 = \frac{\lambda p_1 Q_1}{\varepsilon_s} (1 - 0.5\lambda),$$

(13) $$\Delta CS_2 = -\frac{\lambda p_1 Q_1}{\varepsilon_D} (1 - 0.5\lambda).$$

To calculate the values for producer and consumer surplus (equations 10–13), we define the values for ε_s and ε_D. The demand elasticity (ε_D) of -1.05 for Florida-grown strawberries was obtained from Suh, Guan, and Khachatryan (2017). We estimate the supply elasticity for Florida-grown strawberries (ε_s) using an ordinary least squares approach. To estimate supply elasticity, we used Florida strawberry production volume, price grower received, wage rate, Mexico fresh strawberry imports, and California fresh strawberry price for the period 1980–2017 (1980 was the earliest year of data available for Mexico strawberry imports). All data were obtained from the U.S. Department of Agriculture (2017) (see Table S1 in the Online Supplement). Other variables included were a binary variable to account for the North America Free Trade Agreement (NAFTA), equaling 1 for the year 1994 (when NAFTA was implemented) and later, and 0 otherwise. The other binary variable represented the MB phaseout, equaling 1 for the year 2009 (the year of the mandated MB phaseout) and later, and 0 otherwise.

Table 2. Summary Statistics for the Florida Strawberry Operations and Principal Operator Sociodemographics, Obtained from Responses to a 2016 Florida Strawberry Grower Survey

Item	Percentage of Respondents Indicating Category (%)
Total acres of strawberries owned or managed (%)	
<5 acres	46.7
5–14 acres	0.0
15–24 acres	0.0
25–49 acres	3.3
50–99 acres	16.7
100–249 acres	13.3
250–499 acres	6.7
500–1,000 acres	10.0
>1,000 acres	3.3
Weighted average	172.0 acres
Annual gross income from the strawberry farm	
<$25,000	53.6
$25,001–$49,999	0.0
$50,000–$74,999	3.6
$75,000–$99,999	3.6
$100,000–$249,999	0.0
$250,000–$499,999	0.0
$500,000–$999,999	3.6
$1,000,000–$2,499,998	7.0
>$2,500,000	28.6
Weighted average	$1,020,876
Percentage of gross income from the strawberry farm	
0%	6.7
1%–25%	33.3
26%–50%	16.7
51%–75%	6.7
76%–99%	6.6
100%	30.0
Weighted average	50.5
Use of one or more of the following marketing channels	
Broker	60.9
Supercenter	54.6
Grocery, retailer	59.1
Direct sale	69.6
Supported agriculture, roadside stand	35.3
Processor	23.5

Notes: To calculate weighted averages, we used upper cutoff points of 1,500 for farm size and $3,000,000 for income. Other categories used the midpoint as cutoffs.

The coefficient for the MB phaseout shock is the supply shift k. We used ‘Strawberry Festival’ to investigate welfare loss from both MB phaseout and crop loss.[1] We used ‘Florida Radiance’ only to investigate welfare loss from crop loss because it was commercialized after 2009. For ‘Strawberry

[1] ‘Florida Radiance’, which was commercialized in 2009, is the current leading strawberry cultivar in Florida Whitaker et al. (2017). ‘Strawberry Festival’ was commercialized in 2000 Chandler et al. (2009).

Table 3. Florida Strawberry Growers' Experiences with the Cultivars Planted in Production Year 2015–2016

Item	Mean	Std. Dev.
Number of respondents indicating that the following cultivar corresponds to the largest acreage in the farm		
Sweet Sensation®	2	
'Florida Radiance'	16	
Other	9	
'Albion'	1	
'Camarosa'	2	
'Chandler'	2	
'Strawberry Festival'	2	
'Sweet Charlie'	2	
Growers' perceived level of resistance to root and crown rot disease for the largest strawberry cultivar planted, on a 0–10 scale, where 0 = 100% susceptible and 10 = 100% resistant		
Sweet Sensation®	6	2.6
'Florida Radiance'	5	3.1
Other	7	2.9
Growers' perceived flavor for the largest strawberry cultivar planted, on a 1–7 scale, where 1 = extremely weak/mild flavor and 7 = extremely full/intense flavor		
Sweet Sensation®	5.9	0.7
'Florida Radiance'	4.5	0.9
Other	5.6	1.4

Festival', the annual yield per plant 4 years before (2004–2005) and after 2009 (2013–2014) were used to account for Q_0 and Q_1, and the average annual Florida strawberry price before and after 2009 (U.S. Department of Agriculture, 2013) was used to account for p_0 and p_1, respectively.[2] We also identified the effects of surplus loss across different harvest months using 'Florida Radiance'. Monthly yield data from Whitaker et al. (2017) were used to account for Q_1, and the average monthly Florida strawberry price was obtained from specialty crops shipping point custom reports (U.S. Department of Agriculture, 2018c).

Results

Table 2 presents summary statistics for Florida strawberry farm characteristics and principal operator sociodemographics are presented. The weighted average farm size for our survey sample of respondents was 172 acres. Our sample of respondents represent about 6,375 acres, about 59% of the total Florida area planted with strawberries in 2016 (U.S. Department of Agriculture, 2017). The weighted average grower income for the strawberry operations in our survey was about $1 million. Respondents reported that 50% of their total gross farm income was from the strawberry operation. Also, 74% of the respondents reported the use of crop insurance. When asked about the marketing channel for the strawberries produced, 70% reported using direct sales to consumers, 61% reported selling to a broker, 60% reported selling to grocery retailers, and 55% to supercenters. Most survey respondents used a mixture of marketing channels for their strawberries (Table 2). The self-reported rate of the principal's attitude toward risk was 6.4, measured on a scale from 0 to 10 (where 0 = unwilling to take risk and 10 = very prepared to take risk). Operators averaged 18 years as principal operator of the strawberry business. About 52% of respondents had a 4-year college degree or higher-level education.

[2] See Table S1 in the Online Supplement for price information.

Table 4. Summary Statistics of Florida Strawberry Principal Operator Experiences with Root and Crown Rot and Viewpoints on Planting a New Cultivar, as of Production Year 2015–2016

Item	Value (%)
Respondents who experienced crop loss due to crown and root rot diseases when growing the cultivar with the largest acreage on the farm	
‘Albion’	100.0
‘Camarosa’	100.0
‘Strawberry Festival’	100.0
‘Florida Radiance’	81.3
Sweet Sensation®	0.0
Average crop loss due to root and crown rot disease when growing the cultivar with the largest acreage on the farm	
‘Camarosa’	4.0
‘Albion’	5.0
‘Strawberry Festival’	6.5
‘Florida Radiance’	9.8
Respondents who indicated their variable production costs (operating, harvesting, and packing) followed in the category	
$0–$17,500/acre	33.3
$17,501–$20,000/acre	16.7
$20,001–$22,500/acre	12.5
$22,501–$25,000/acre	0.0
$25,001–$27,500/acre	4.2
$27,501–$30,00/acre	16.6
$30,001–$32,500/acre	12.5
$32,501–$35,000/acre	0.0
$35,001–$37,500/acre	0.0
$37,501–$40,000/acre	0.0
>$40,000/acre	4.2
Weighted average	$19,998.6

Table 3 presents summary statistics for growers’ experiences with strawberry cultivars. Of the responses obtained, 16 growers reported ‘Florida Radiance’ as the cultivar with the largest acreage in the operation, 9 growers reported growing other cultivars (e.g., ‘Albion’, ‘Camarosa’, ‘Chandler’, ‘Strawberry Festival’, and ‘Sweet Charlie’), and 2 growers reported Sweet Sensation®. On a 0–10 scale, where 0 = 100% root and crown rot susceptibility and 10 = 0% susceptibility (i.e., 100% resistant), respondents’ average perceived disease resistance varied among cultivars. Disease resistance for other cultivars was rated 7, followed by Sweet Sensation® (rated 6), and ‘Florida Radiance’ (rated 5). In addition, we asked participants to rate the perceived flavor of the cultivar they grew, using a 1–7 scale, where 1 = extremely weak/mild flavor and 7 = extremely full/intense flavor. Respondents assigned a 5.9 rating to Sweet Sensation®, 5.6 to other cultivars, and 4.5 to ‘Florida Radiance’.

Table 4 presents summary statistics for the control of root and crown rot diseases and growing new strawberry cultivars. All respondents who grew ‘Albion’, ‘Camarosa’, and ‘Strawberry Festival’ indicated they experienced crop losses due to root and crown rot diseases prior to first harvest. Similarly, 81.3% of respondents who grew ‘Florida Radiance’ reported crop losses due to the disease. None of the respondents who grew Sweet Sensation® reported losses due to this disease.

On average, respondents reported losing 4% of their production due to crown and root rot diseases prior to first harvest when growing ‘Camarosa’, 5% when growing ‘Albion’, 6.5% when growing ‘Strawberry Festival’, and 9.8% when growing ‘Florida Radiance’. These results align with findings by Mangandi, Peres, and Whitaker (2015), who concluded that Florida strawberry growers

Table 5. Parameter Estimates of the Model Depicting Utility Derived from Florida Strawberry Growers in a WTP Space

	Parameter Estimates	
Variables	Mean[a]	Std. Dev.[b]
Cost of transplant and royalty	−2.07***	0.73*
	(0.49)	(0.43)
Flavor score: full/intense	64.23***	24.64**
	(20.61)	(10.87)
Flavor score: neutral	30.70***	23.37**
	(11.06)	(9.81)
Fruit size (number of fruits in a 1-lb clamshell)	−3.42***	1.04***
	(1.01)	(0.41)
Plant loss from root and crown rot disease prior to first harvest	−223.66***	91.95*
	(80.12)	(55.10)
Alternative specific constant, grow option	196.87***	
	(14.51)	
No. of obs.	711	
Log-likelihood	−159.59	

Notes: Single, double, and triple asterisks (*,**,***) indicate significance at the 10%, 5%, and 1% level, respectively. Numbers in parentheses are standard errors.
[a] Mean of ln(coefficient).
[b] Standard deviation of ln(coefficient).

lost on average 5% of their crop to root and crown rot diseases, usually at the beginning (November) and the end (March) of the strawberry season. On average, respondents reported expenses of $443.80/acre to manage crown and root rots, which was 2% of total variable costs ($19,998.55/acre in 2015–2016). These management costs were lower than the $740/acre fumigation costs and $24,466/acre total operation variable costs reported for 2012–2013 (Guan, Wu, and Whidden, 2017). These differences might be due to the periods considered or size differences in growers in the two surveys. When asked about plans to adopt a new strawberry cultivar in the next year (2016–2017 by the time the survey was conducted), 46.7% of respondents indicated an interest in doing so. Similarly, when asked whether they had grown a new cultivar in the previous year (2015–2016), 46.7% of respondents answered yes.

Grower WTP for Strawberry Fruit Quality and Plant Disease Resistance Attributes

Table 5 reports the parameter estimates for the WTP in space model depicting Florida strawberry growers' utility when deciding to invest in a strawberry variety. Recall that the coefficient for cost of transplant and royalty is log-normally distributed; therefore, the mean and the standard deviation are the mean of the latent normally distributed random factor underlying the cost of transplant coefficient. All other coefficients in Table 5 follow the normal distribution.

Mean WTP for flavor was positive and statistically significant. Specifically, Florida strawberry growers are willing to pay $64.23 per 1,000 plants to invest in strawberry cultivars exhibiting improvement from extremely weak/mild to full, intense flavor and $30.70 per 1,000 plants for improvement from extremely weak/mild to neutral flavor. This finding is consistent with Choi et al. (2017) and Yue et al. (2017)—who found that U.S. strawberry growers preferred a full/intense flavor

Table 6. Correlation of WTP Estimates for Each Strawberry Attribute as Included in the Survey

	Flavor Score			
	Full/Intense	Neutral	Fruit Size	Plant Loss[a]
Flavor score: full/intense	1	–	–	–
Flavor score: neutral	-0.06	1	–	–
Fruit size (no. of fruits in a 1-lb clamshell)	0.12	0.43	1	–
Plant loss from root and crown rot disease prior to first harvest	0.56	0.09	0.19	1

Notes: [a] As a result of root and crown rot disease prior to first harvest.

over a weak/mild flavor—and consistent with the preferences of market intermediaries (Gallardo et al., 2015) and consumers (Colquhoun et al., 2012; Wang et al., 2017).

Mean WTP for fruit size was negative and statistically significant (Table 5). Recall that we measure fruit size as the number of strawberry units that fit in a 1-lb clamshell; therefore, the larger the number for size, the smaller each individual fruit. Growers were willing to discount $17.1 per 1,000 plants for an increase in fruit size equivalent to lowering the number of strawberries that could fit in a 1-lb clamshell by 5 units. The number 17.1 comes from multiplying 3.42 (in Table 5) by 5, to transform the WTP per 1 unit to 5 units of fruit increase to match the design of the choice experiment. Prices received by growers are positively impacted by fruit size, as described by the U.S. Grades and Standards for fresh market (Gallardo et al., 2015). Moreover, growers' preference for larger sizes aligns with previous investigations (Gallardo et al., 2015; Choi et al., 2017; Yue et al., 2017).

Mean WTP for the percentage of plant loss from root and crown rot diseases prior to first harvest was negative and statistically significant, suggesting that Florida strawberry growers generally prefer new cultivars with improved disease resistance (Table 5). Growers were willing to pay a premium of $11.18 per 1,000 plants for a 5% reduction in plant loss due to the above-mentioned disease. Note that 11.18 comes from dividing 223.66 (reported in Table 5) by 20 to transform WTP per 100% plant loss to WTP per 5% plant loss damage to match the design of the choice experiment.

The standard deviation parameters for fruit quality (e.g., fruit flavor and size) and disease resistance estimates were all statistically significant, suggesting heterogeneity in responses regarding fruit flavor and size.

The alternative specific constant (chose to grow Option A or B) was positive and statistically significant, indicating that Florida strawberry growers were more likely to invest in hypothetical cultivars encompassing the attributes included in the choice experiment scenarios.

To further evaluate the trade-offs between fruit quality and disease resistance, we conducted a correlation analysis. Results in Table 6 suggest that a full/intense flavor is negatively correlated with a neutral flavor score. Both full/intense and neutral flavor scores are positively correlated with fruit size and with plant loss from root and crown rot diseases prior to first harvest. Fruit size is positively correlated with plant loss from root and crown rot diseases prior to first harvest.

Economic Welfare Results

Economic welfare was calculated for two strawberry cultivars: 'Strawberry Festival' and 'Florida Radiance'. The choice is based mainly on data availability: 'Strawberry Festival' was the cultivar with the most acreage in Florida before 2012, and 'Florida Radiance' is now the leading Florida cultivar (Whitaker et al., 2017). Therefore, we estimated the effect of both the MB phaseout and crop loss due to crown and root rot diseases for 'Strawberry Festival' and only the effect of crop

Table 7. Parameters Used in the Economic Surplus Model for Analyzing the Welfare Effects of the Methyl Bromide Phaseout and Crop Loss Due to Crown and Root Rot Diseases in Florida-Grown Cultivar 'Strawberry Festival'

Parameter	Description	Unit	Value
Q_0[a]	Yield per strawberry plant in 2004–2005	g/plant	928
Q_1[b]	Yield per strawberry plant in 2013–2014	g/plant	642.8
P_0[c]	Price of strawberry plant in 2004–2005	\$/g	0.00241
P_1[c]	Price of strawberry plant in 2013–2014	\$/g	0.00316
K	Methyl bromide phaseout indicator	–	-0.22
λ	Crops loss percentage	%	5
Plants	Number of plants	units	1,000
ε_D	Demand elasticity	–	-1.05
ε_s	Supply elasticity	–	0.59

Source: [a] Chandler et al. (2009).
[b] Whitaker et al. (2015). 'Strawberry Festival' was the most popular in Florida for almost a decade, until 2012 (https://gcrec.ifas.ufl.edu/fruit-crops/strawberry-cultivars/).
[c] Table S1 in the Online Supplement, transformed to \$/g.

loss due to crown and root rot diseases for 'Florida Radiance'. Further, due to data availability, the welfare analysis is on an annual basis for 'Strawberry Festival' and on a monthly basis for 'Florida Radiance'. The monthly basis analysis enables us to capture the different welfare effects at different market prices paid to growers during the production season (Wu, Guan, and Whitaker, 2015).

Table 7 summarizes all parameters used in the economic surplus model for the MB phaseout and crop loss–induced supply shift for Florida-grown 'Strawberry Festival'. The parameters include annual yield per strawberry plant, annual price per strawberry plant, and demand and supply elasticities. The supply shift (k) after the MB phaseout was estimated at -0.22, suggesting that the phaseout had, in general, a negative impact on growers' welfare. Table 8 presents parameters used in the economic surplus model for 'Florida Radiance' crop loss. Here, the parameters include monthly yield per strawberry plant (November–March), monthly price per strawberry plant (November–March), and demand and supply elasticities. For both cultivars, the demand elasticity of -1.05 for Florida-grown strawberries was obtained from Suh, Guan, and Khachatryan (2017). We estimated a supply elasticity of 0.59 for Florida strawberry, explained in detail in Table S2 in the Online Supplement.

Total welfare loss after the MB phaseout was \$1,484.60 per 1,000 plants for 'Strawberry Festival' (see Table 9).[3] For this same cultivar, the welfare loss due to the incidence of root and crown rot diseases, assuming a 5% crop loss. was \$262.00 per 1,000 plants as of 2013–2014.[4] We note that a

[3] Producer surplus loss was calculated as $0.5 \times \frac{\varepsilon_D}{\varepsilon_D+\varepsilon_s} |k| \, p_0 \, (Q_0 + Q_1) \times 1{,}000 = 0.5 \times \frac{-1.05}{-1.05+0.59} \times 0.00241 \times (0.22) \times (928 + 642.8) \times 1{,}000 = \$950.5$ and consumer surplus was calculated as $0.5 \times \frac{\varepsilon_s}{\varepsilon_D+\varepsilon_S} k p_0 \, (Q_0 + Q_1) \times 1{,}000 = 0.5 \times \frac{0.59}{-1.05+0.59} \times 0.00241 \times (-0.22) \times (928 + 642.8) \times 1{,}000 = \$534.1$. Total welfare loss from the MB phaseout was $\$950.5 + \$534.1 = \$1{,}484.6$ for every 1,000 plants.

[4] The producer surplus loss from a 5% crop loss in 2013–2014 per 1,000 plants was calculated as $\frac{\lambda p_1 Q_1}{\varepsilon_s} (1 - 0.5 \times \lambda) \times 1{,}000 = \frac{0.05 \times 0.00316 \times 642.8}{1.05} (1 - 0.5 \times 0.05) \times 1{,}000 = \$94.3$, and the consumer surplus loss for 5% crop loss in 2013–2014 per 1,000 plants was calculated as $\frac{\lambda p_1 Q_1}{\varepsilon_D} (1 - 0.5 \times \lambda) \times 1{,}000 = \frac{0.05 \times 0.00316 \times 642.8}{0.59} (1 - 0.5 \times 0.05) 1{,}000 = \$167.8$, making the sum of welfare loss equal to \$262.

Table 8. Parameters Used in the Economic Surplus Model for Analyzing the Welfare Effects of the Methyl Bromide Phaseout and Crop Loss Due to Crown and Root Rot Diseases in Florida-Grown Cultivar 'Florida Radiance'

Parameter	Description	Unit	Value
Q_1[a]	Yield per strawberry plant	g/plant	
	November 2016		6.3
	December 2016		102.3
	January 2017		157.2
	February 2017		413.9
	March 2017		174.1
	Total		853.8
P_1[b]	Price of strawberry plant	$/g	
	November 2016		0.00744
	December 2016		0.00435
	January 2017		0.00383
	February 2017		0.00248
	March 2017		0.00279
λ	Crops loss percentage	%	5
Plants	Number of plants	units	1,000
ε_D	Demand elasticity	–	-1.05
ε_s	Supply elasticity	–	0.59

Notes: 'Florida Radiance' was commercialized after 2009 (Whitaker et al., 2017). We assume there was no methyl bromide phaseout change for this cultivar.
Sources: [b] Whitaker et al. (2017).
[b] U.S. Department of Agriculture (2018c).

Table 9. Welfare Effects after the Methyl Bromide Phaseout and Crop Loss from the Root and Crown Rot Disease Experienced by Florida Strawberry Growers and Consumers, Considering the Cultivar 'Strawberry Festival'

	Annual Welfare Effect Measured as Surplus Loss ($/1,000 plants)	
	Methyl Bromide Phaseout	Crop Loss Due to Root and Crown Rot Disease Assumed at 5%
Producer	950.5	167.8
Consumer	534.1	94.3
Total	1,485.60	262.1

larger percentage of the total welfare loss from both the MB phaseout and crop losses due to root and crown rot diseases was accounted to producers rather than consumers. Also, the estimated producer surplus loss from the MB phaseout was $950.50 per 1,000 plants, higher than the loss in producer surplus due to disease, at $167.80 per 1,000 plants. These results suggest that the MB phaseout generated a larger surplus loss to producers growing 'Strawberry Festival' relative to the loss due to the incidence (assumed at 5% crop loss) of root and crown rot diseases.

For 'Florida Radiance', the total economic welfare loss due to a 5% crop loss was $336.60 per 1,000 plants for 2016–2017 (see Table 10). We estimated the producer, consumer, and total welfare losses at 5% crop loss due to the crown and root rot diseases for 2016–2017 at different harvest months during the season. If the first harvest is in December, then the average producer surplus loss (November and December) from a 5% crop loss is $20.40 per 1,000 plants, which is higher than the

Table 10. Annual Welfare Effects Measured as Surplus Loss after Different Levels of Crop Loss Due to Root and Crown Rot Disease Experienced by Florida Strawberry Growers and Consumers, Considering the Cultivar 'Florida Radiance'

	Annual Welfare Effect	
	$/1,000 Plants	$/Year[a]
Producer		40,496,760
November	3.9	
December	36.8	
January	49.8	
February	84.8	
March	40.3	
Total	215.5	
Consumer		22,757,112
November	2.2	
December	20.7	
January	27.9	
February	47.7	
March	22.6	
Total	121.1	
Total		63,253,872
November	6.1	
December	57.5	
January	77.7	
February	132.5	
March	62.9	
Total	336.6	

Notes: Annual crop losses to due to root and crown rot disease are assumed to be 5%.
[a] Assuming transplant costs of $150 per 1,000 plants, transplant costs in 2012–2013 of $2,610/acre (Guan, Wu, and Whidden, 2017), and 10,800 Florida strawberry acres in 2016–2017 (U.S. Department of Agriculture, 2018b).

stated WTP for improving disease resistance via a 5% decrease in crop loss prior to first harvest at $11.40 per 1,000 plants. This reinforces our conclusion that an early crop loss would cost the grower more than a later crop loss. If plants are lost in November, then the yield of that plant is lost for the whole season. If plants are lost in February, then the yield of that plant is lost only for February and March, when prices are lower compared to earlier months. These results also point to the relative value of producing a cultivar with improved disease resistance at different months during the season. For example, an improvement in the crop loss due to root and crown rot diseases from a 5% crop loss represents $3.90 in November, $36.80 in December, $49.80 in January, $84.80 in February, and $40.30 in March, for a total of $215.50 per 1,000 plants over the whole harvest season. The surplus loss change in February is the highest because of the higher yield per plant generally obtained in this period. Similar findings are observed for both consumer and total surplus (Table 10).

We also estimated the welfare impacts for the Florida strawberry industry (Table 10). For this calculation we assumed (i) the cost of transplants for Florida strawberry growers to be $2,610/acre (Guan, Wu, and Whidden, 2017), (ii) the cost of 1,000 strawberry plants to be $150, and (iii) the total number of strawberry acres in Florida to be 10,800 (U.S. Department of Agriculture, 2018b). A 5% crop loss or 5% improvement in root and crown rot disease resistance represent savings of

$40 million to Florida strawberry producers, gains of $22 million to Florida strawberry consumers, and total gains of $63 million.[5]

Summary and Conclusions

We estimated Florida strawberry growers' WTP for strawberry fruit and plant disease resistance attributes. In addition, we investigated the welfare losses associated with MB phaseout policy regulation and crop loss due to the incidence of root and crown rot diseases. Our results suggest that Florida strawberry growers value fruit flavor improvement and fruit size more than improvements to genetic resistance to root and crown rot diseases. Further, our findings suggest that the MB phaseout represented a larger welfare loss than losses caused by root and crown rot diseases. Nonetheless, cultivars with improved resistance to disease could provide annual savings of $204.50–$182.40 per 1,000 plants for Florida strawberry growers, $114.90–$102.50 per 1,000 plants to Florida strawberry consumers, and $319.40–$284.90 per 1,000 plants in total annual savings. In addition, a cultivar with an improved disease resistance and reduced losses to disease could save about $40 million/year for Florida strawberry growers and $60 million/year to the Florida economy. Discrepancies in growers' stated WTP for a cultivar with improved disease resistance and the actual savings that could be experienced when adopting such cultivars are difficult to explain.

This study adds to the existing literature regarding growers' decision making regarding two attributes deemed important to guarantee the commercial success of a new cultivar: fruit quality and disease resistance. Growers face challenges given consumers' increasing concerns about pesticide use in fresh fruits and the phaseout of effective fumigants to control root and crown diseases. Breeders face technical challenges added to additional time and funding needed when combining production- and consumer-oriented traits in a single improved cultivar. Our findings provide information to strawberry breeders that can help develop effective and efficient strategies to identify priority attributes for new cultivars. Such improved cultivars will improve the competitiveness of Florida strawberry growers in an increasingly competitive marketplace.

Our study also analyzes the potential welfare impact of the MB phaseout and crop loss due to root and crown rot diseases using an *ex ante* partial equilibrium demand–supply framework. Based on the numerical results reported in the study, the total welfare loss from MB phaseout and crop loss comes disproportionately from a decrease in producer surplus. These results have important implications for the Florida strawberry industry and breeders in the development of improved cultivars with superior disease resistance and fruit quality.

[First submitted September 2019; accepted for publication September 2019.]

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[5] If a 5% crop loss would cause a $215.5 loss per 1,000 plants and $121.1 to producers and consumers, respectively, then for all Florida strawberry growers the loss would be $\frac{2{,}610}{150} \times 215.5 \times 10{,}800 = \$40{,}496{,}760$ for Florida strawberry consumers the loss would be $\frac{2{,}610}{150} \times 121.1 \times 10{,}800 = \$22{,}757{,}112$.

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Journal of Agricultural and Resource Economics 45(2):S1–S6
ISSN 1068-5502

doi: 10.22004/ag.econ.302450

Online Supplement: Grower Willingness to Pay for Fruit Quality versus Plant Disease Resistance and Welfare Implications: The Case of Florida Strawberry

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Online Supplement

This section includes the conceptual framework for welfare changes after the methyl bromide (MB) phaseout and algebraic calculations for changes in producer and consumer surplus. We discuss the two cases: productivity increase and decrease after the phaseout.

Case 1: Welfare Changes after the Methyl Bromide Phaseout, under a Productivity Increase

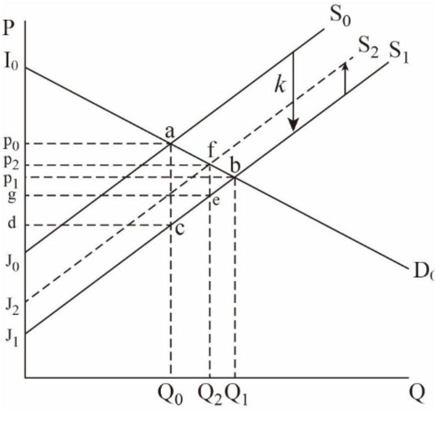

Figure S1. Schematic Analysis of the Welfare Change after a Production Increase due to the Phaseout

Quantities demanded of strawberries follows

(S1) $$Q_D = \beta_0 - \beta_1 p,$$

where Q_D is quantities of strawberry demanded, β_0 is the intercept parameter for the demand curve, β_1 is the slope of the demand curve, and p is the price. Quantities supplied of strawberries follows

(S2) $$Q_s = \alpha_0 + \alpha_1 (p + k),$$

where Q_s is quantities of strawberry supplied, α_0 is the intercept parameter for the supply curve, α_1 is the slope of the supply curve, p is price, and k is the production shift due to the MB phaseout. At equilibrium, $Q_D = Q_s$, prices at time 0 (p_0) and time 1 (p_1) follow

(S3)
$$p_0 = \frac{\beta_0 - \alpha_0}{\alpha_1 + \beta_1} \qquad (k = 0);$$

(S4)
$$p_1 = \frac{\beta_0 - \alpha_0 - \alpha_1 k}{\alpha_1 + \beta_1}.$$

Then,

(S5)
$$p_0 - p_1 = \frac{\alpha_1 k}{\alpha_1 + \beta_1}.$$

We assume a production increase implying a rightward supply shift from S0 to S1, then,

(S6)
$$p_0 - d = k.$$

Then, $p_1 - p_0$ (i.e., equation S6 minus equation S4) equals

(S7)
$$p_1 - d = \frac{\beta_1 k}{\alpha_1 + \beta_1}.$$

Multiplying the denominator and numerator of equation (S7) by $\frac{p_0}{Q_0}$ and the demand shift weighted by the innitial equalibrium price, we obtain

(S8)
$$p_1 - d = \frac{\varepsilon_D}{\varepsilon_D + \varepsilon_s} k p_0;$$

(S9)
$$p_0 - p_1 = \frac{\varepsilon_s}{\varepsilon_D + \varepsilon_s} k p_0.$$

The producer and consumer surplus follow

(S10)
$$\Delta PS_1 = area\ p_1 dcb = (p_1 - d)\, Q_0 + 0.5\,(p_1 - d)\,(Q_1 - Q_0) = 0.5 \frac{\varepsilon_D}{\varepsilon_D + \varepsilon_s} k p_0\,(Q_0 + Q_1);$$

(S11)
$$\Delta CS_1 = area\ p_0 p_1 ba = (p_0 - p_1)\, Q_0 + 0.5\,(p_0 - p_1)\,(Q_1 - Q_0) = 0.5 \frac{\varepsilon_s}{\varepsilon_D + \varepsilon_s} k p_0\,(Q_0 + Q_1).$$

Now, consider the appearance of the crown rot disease, resulting in a crop loss λ $(0 \leq \lambda \leq 1)$, leading to a leftward shift of the strawberry supply curve from S_1 to S_2, where $\Delta \mathrm{Q} = Q_1 - Q_2 = \lambda Q_1$. Supply elsticity follows

(S12)
$$\varepsilon_s = \frac{\Delta Q}{\Delta P}.$$

We further assume that

(S13)
$$\Delta P = p_1 - g = \frac{\Delta Q}{\varepsilon_s} \frac{p_1}{Q_1} = \frac{\lambda Q_1}{\varepsilon_s} \frac{p_1}{Q_1} = \frac{\lambda p_1}{\varepsilon_s}.$$

Then, producer surplus follows

(S14)
$$\Delta PS_2 = area\ p_1 geb = (p_1 - g)\, Q_2 + 0.5\,(p_1 - g)\,(Q_1 - Q_2) = \frac{\lambda p_1 Q_1}{\varepsilon_s}\,(1 - 0.5\lambda).$$

Similarly, elasticity of demand follows

(S15) $$\varepsilon_D = \frac{\Delta Q}{\Delta P}\frac{p_1}{Q_1};$$

(S16) $$\Delta P = p_2 - p_1 = \frac{\Delta Q}{\varepsilon_D}\frac{p_1}{Q_1} = \frac{\lambda p_1}{\varepsilon_D}.$$

Then, consumer surplus follows

(S17) $$\Delta CS_2 = area\ p_1 p_2 f b = (p_2 - p_1)Q_2 + 0.5(p_2 - p_1)(Q_1 - Q_2) = -\frac{\lambda p_1 Q_1}{\varepsilon_D}(1 - 0.5\lambda).$$

Case 2: Welfare Changes after the Methyl Bromide Phaseout, under a Productivity Decrease

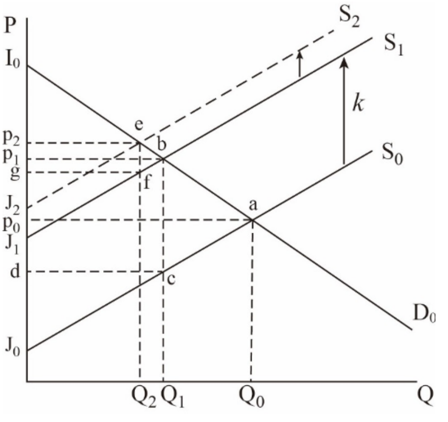

Figure S2. Schematic Analysis of the Welfare Change after a Productivity Decrease Due to the Phaseout

Because of the productivity decrease by the methybromide phaseout, a leftward supply shift and a price change occur, following

(S18) $$k = d - p_1,$$

(S19) $$p_1 - p_0 = -\frac{\alpha_1 k}{\alpha_1 + \beta_1},\ k < 0.$$

Adding equations (S18) and (S19), we obtain

(S20) $$\frac{\beta_1 k}{\alpha_1 + \beta_1} = d - p_0.$$

Including elasticities of supply and demand and weighting the demand shift by the innitial equalibrium price, we have

(S21) $$p_0 - d = -\frac{\varepsilon_D}{\varepsilon_D + \varepsilon_s} k p_0,$$

(S22) $$p_1 - p_0 = -\frac{\varepsilon_s}{\varepsilon_D + \varepsilon_s} k p_0.$$

Therefore, the producer and consumer surplus can be expressed as

(S23) $$\Delta PS_1 = area\ p_0dca = (p_0 - d)Q_1 + 0.5(p_0 - d)(Q_0 - Q_1) = -0.5\frac{\varepsilon_D}{\varepsilon_D + \varepsilon_S}kp_0(Q_0 + Q_1)$$

(S24) $$\begin{aligned}\Delta CS_1 &= area\ p_0p_1ba = (p_1 - p_0)\,Q_1 + 0.5\,(p_1 - p_0)\,(Q_0 - Q_1)\\ &= -0.5\frac{\varepsilon_s}{\varepsilon_D + \varepsilon_s}kp_0\,(Q_0 + Q_1)\,.\end{aligned}$$

The appearance of crown rot disease would result in similar producer and consumer surpluses as in equations (S23) and (S24), but the magnitudes of p_1 and Q_1 would be different.

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Table S1. Florida Strawberry Production, Prices Received by Growers, Wage Rate, and Strawberry Quantities Imported from Mexico: 1980–2017

Year	Production	Florida Grower Price	Mexico Imports	Farm Labor Wage Rate	Producer Price Index for Fruits	California Grower Price
Units	(million lb)	(cents/lb)	(million lb)	($/hour)	(%)	(cents/lb)
1980	47.5	58.8	34.4	4.7	85.7	46.3
1981	67.2	41.5	20.7	5	96.3	47.1
1982	97.5	53.7	17.7	5	100	55.7
1983	102.6	51.2	18.9	4.9	119.6	53.2
1984	86.7	44.8	23	4.7	112.3	49.1
1985	106	57.8	19.8	4	118.6	51.9
1986	90.7	55.3	27.4	5.1	132.8	58.2
1987	110.3	60.8	25.6	5.5	104.3	58
1988	125	59.1	30.1	5.6	99.9	52
1989	137.8	66.9	33.8	5.8	88.4	49.3
1990	116.6	64.6	35.5	6	104.9	50.5
1991	132	64.3	29.5	6.3	103	50.9
1992	162	67.2	21.9	6.4	113.5	59.2
1993	162.4	74.7	29.1	6.6	102.5	46.8
1994	168.2	60.3	46.5	7	93.1	59.1
1995	168	70.6	56.8	7.5	102.2	57.4
1996	156	72.2	64.7	7.3	100.1	52.5
1997	176.9	82.6	29.7	7.5	113.2	61.4
1998	161.2	100	57.3	7.9	109.3	68.7
1999	186	81	91.6	8.2	116.3	72.5
2000	220.5	76	74.6	8.5	114.4	61.4
2001	169	99	70.7	8.5	148	70.6
2002	176	87.2	89.9	8.7	119	67.4
2003	156.2	82.7	90.3	9.1	132.6	72.8
2004	163.3	109	94.4	9	138.8	62.2
2005	178.9	110	122.7	9.5	129.6	62.6
2006	204.4	117	153.4	9.4	135.7	65.1
2007	211.2	124	157.7	9.7	144.1	75.7
2008	179.4	139	143	10.1	160.3	77.3
2009	237.6	132	187.2	10.4	154.3	79
2010	193.6	187	198.3	10.7	159.8	80.3
2011	247.5	148	243.5	10.9	163.4	86.1
2012	249.3	110	351.3	11	157.4	88.8
2013	261.2	143	353.8	11.6	170.1	90.4
2014	232	148	355.3	11.2	170.1	100
2015	273.5	119	312.6	11.8	130	73.9
2016	245.7	166	362.2	12.2	133.3	123
2017	269.6	140	364.6	12.6	112.6	123

Notes: U.S. Department of Agriculture (2013, 2018).

Table S2. Parameter Estimates for the Florida Strawberry Supply Ordinary Least Squares Model

Variables	Parameter Estimates
Log own price[a]	0.59***
	(0.19)
Log own price lagged	−0.05
	(0.15)
Log wage rate	0.67**
	(0.29)
NAFTA	−0.72***
	(0.21)
Log Mexico imports × NAFTA	−0.05*
	(0.03)
Methyl bromide phaseout	−0.22**
	(0.09)
Log California strawberry price	0.06
	(0.14)
Constant	4.17***
	(0.03)
Adj. R^2	0.88
No. of obs.	37

Notes: Numbers in parentheses are standard errors.
[a] The real price, obtained by dividing nominal prices by the producer price index to account for the average change in prices received by the grower.