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Optimizing yield distribution under biological and economic constraints: Florida strawberries as a model for perishable commodities

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ABSTRACT

In this interdisciplinary study we propose a modeling framework for deriving the optimal yield curve for strawberry production in Florida that maximizes the profit of growers given competition from California and Mexico and sensitive price responses to market supply. The model integrates both biological and economic constraints. The biological constraints for Florida production are formulated assuming that potential improvement of yield has genetic and horticultural limits, while economic constraints account for price changes in response to supply. The optimal yield curves derived show clear differences from the historical yield patterns observed in Florida, indicating that yields during the first 6 to 8 weeks of the season should be maximized to realistic limits and that total season yields should be limited to 27,465 and 32,415 kg/ha under two different yield distribution scenarios assuming current acreage and market demand. Obtaining optimal yield distributions under the two scenarios could generate $7685 and $14,293 per ha more profit, whereas the historical yield pattern will result in significant losses under assumed acreage, raising concerns about the sustainability of the industry. The results of this study will be used to guide efforts in breeding and improvement of cultural practices and will assist growers in making informed decisions on cultivars and technologies/practices to adopt to maximize profit. The methodology proposed can be adapted to other regions or countries and used for other perishable crops with extended production seasons.

1. Introduction

Fresh strawberries are an important crop in the U.S. fruit and vegetable industry, with a national farm gate value of $2.2 billion in 2012, more than two times that of fresh tomatoes (USDA, 2013). Florida and California produce about 99% of strawberries in the country. Florida is the largest producer of winter strawberries, with a production area of approximately 4500 ha and a production value of $366 million in 2011 (USDA, 2013). In the past few years, however, the Florida industry has been faced with various challenges including increasing supplies from Mexico and California and volatile market prices. Mexico has become the major competitor for the Florida strawberry industry, and imports of fresh strawberries from Mexico reached 159,000 tonnes in 2012. This volume is twice as much as the total Florida production (USDC, 2013). Meanwhile, California, the largest, year-round producer of strawberries in the U.S.A., is increasing its winter production. Along with market integration, the rapidly rising imports and domestic production have depressed market prices and in some seasons have caused significant losses for Florida growers. The effects of rising supplies are further aggravated by the uneven distribution of strawberry yield over the production season in Florida, which, in conjunction with the perishable nature of the product, makes the market even more volatile. Fig. 1 shows the dynamics of market average prices corresponding to the average supplies from California, Florida, and Mexico.

Given the North American Free Trade Agreement (NAFTA) and the trend of market integration between the U.S.A. and Mexico, American growers must focus on technological advances and the breeding of new, improved cultivars to compete effectively. An important goal of strawberry breeding is to maximize growers profit through new cultivars. To achieve this, breeders simultaneously target several traits that are of economic importance, among which early yield has been a major goal, particularly in Florida. Early season yields have typically received the highest prices, thus producing the highest returns. Breeders at the University of Florida have developed such early cultivars, e.g. 'Sweet Charlie', 'Winter Dawn', and 'Florida Radiance' in 1992, 2003 and 2008, respectively (Chandler et al., 1997, 2009).

Although growers and breeders have striven for early season productivity, very little has been known about the overall economic contribution of a strawberry cultivar's yield and the distribution of yield over the course of the season. This is mainly due to the complexity of the interactions between production and market prices and yield dynamics

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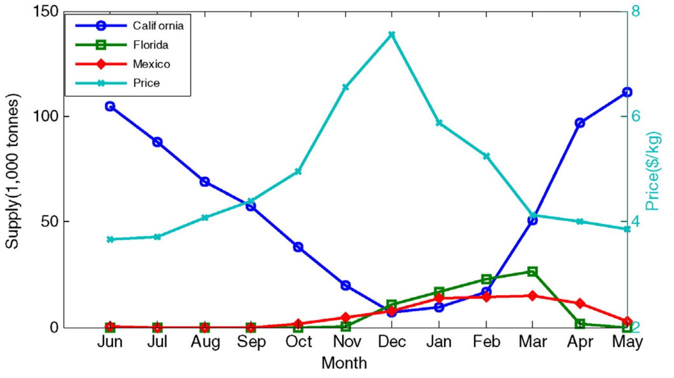

Fig. 1. Four-year average (2009 to 2012) supplies of strawberries from California, Florida and Mexico to the US market and the average market price.

over the extended production season. Increased supply will lead to lower market prices and could reduce the total profit of the industry at some point. Therefore, the total effect of a yield increase, including that of early yield, matters. Strawberry production in annual plasticulture systems, such as the one in Florida, utilizes cultivars and cultural practices that result in extended fruiting seasons lasting several months. Although early fruit can take advantage of price premiums to generate significantly higher revenue, the distribution of yields should be optimized to maximize the whole-season profit. Herrington et al. (2012) conducted an economic sensitivity analysis for the Queensland, Australia strawberry industry and estimated that a 10% redistribution of yields from late season to early season would lead to a gross margin increase of 23%. Explicitly quantifying the relationship between yield patterns and prices/revenues will allow us to identify the optimal yield distribution across the entire season.

Determining a target yield distribution for breeders based on the changing market and price dynamics is an interesting research question for both geneticists and economists. Strawberry yield follows a peculiar pattern of yield waves over the season. In Florida, for example, the first wave peaks around the 10th week (late December) and the second wave around 19th week (mid-March). Both the yield distribution pattern within the season and total yield over the season are subject to certain constraints in breeding (Whitaker et al., 2012). Optimal yield distribution derived under appropriate biological constraints as well as economic constraints would generate important insights to inform breeding decisions.

The objective of this study is to derive optimal yield curves over the season under biological and economic constraints that maximize the profits of Florida strawberry growers. To achieve the objective, we developed an empirical model to quantify how Florida price responds to supply over the harvest season, while simultaneously addressing the impacts of Mexico and California production of fresh strawberries in the same market window. Based on the estimated price response, we maximized growers' profit under appropriate constraints formulated on the ground that potential yield improvement and dynamics are subject to genetically realistic limits. The information generated from this analysis will illustrate the gap between actual and target yield patterns and will be useful to breeders, horticulturalists and growers. The modeling framework that integrates both biological and economic constraints can be used for other perishable crops for specific regions/countries facing competitions from other areas.

2. Materials and methods

2.1. Econometric model specification

To derive the optimal yield curve that would maximize growers' profit, we first estimated the price yield response parameters. We specified a systems model of the U.S. winter strawberry market. A systems approach is appropriate because of a national strawberry market that includes supplies from three regions (Marsh, 2003). The supply season covers the beginning of November through the beginning of the next April, totaling 23 weeks, fully accounting for the Florida harvesting season. The model is represented by Eqs. (1) to (4) as follows, with variables defined in Table 1:

$$\ln P_{ft} = \alpha_0 + \alpha_1 D_{ct} + \alpha_2 D_{ft} + \alpha_3 D_{mt} + \alpha_4 I_t + \varepsilon_{1t}; \tag{1}$$

$$\begin{aligned} S_{mt} = {} & \beta_0 + \beta_1 Tm_{mt} + \beta_2 t \cdot Tm_{mt} + \beta_3 R_{mt} + \beta_4 t \cdot R_{mt} + \beta_5 t + \beta_6 t^2 \\ & + \beta_7 A_{mt} + \varepsilon_{2t}; \end{aligned} \tag{2}$$

$$\begin{aligned} S_{ct} = {} & \gamma_0 + \gamma_1 Tm_{ct} + \gamma_2 t \cdot Tm_{ct} + \gamma_3 R_{ct} + \gamma_4 t \cdot R_{ct} + \gamma_5 t + \gamma_6 t^2 \\ & + \gamma_7 A_{ct} + \gamma_8 \ln P_{ft} + \varepsilon_{3t}; \end{aligned} \tag{3}$$

$$D_{ft} = S_{ft}; \quad D_{mt} = S_{mt}; \quad D_{ct} = S_{ct}. \tag{4}$$

Eq. (1) is an inverse demand function; Eqs. (2) and (3) are functions of supplies from Mexico and California; and Eq. (4) is a market clearing equilibrium function. Note that the Florida supply model is not presented explicitly as it is the variable we are to solve in the optimization model in the next step given supplies from Mexico and California, to be forecast with Eqs. (2) and (3).

Eq. (1) models the Florida farm gate price responses to demand for Florida, Mexico and California strawberries (D_{ft}, D_{mt} and D_{ct}), which is equal to supply (S_{ft},S_{mt} and S_{ct}) at market clearing, equilibrium prices (see Eq. (4)). In this study we distinguished strawberries of different origins and allowed them to have different effects on the price Florida growers receive due to potential product or market differentiation. Florida has traditionally been the primary producer for the U.S. winter strawberry market due to its unique subtropical climate. Mexico has emerged as a major competitor and alternative supplier over the past few years. Southern California also produces strawberries during the wintertime. Therefore, demands for Florida (D_{ft}), Mexico (D_{mt}) and California strawberries (D_{ct}) and accordingly their supplies (S_{ft}, S_{mt}, S_{ct}) are all included in the model. As there are zero-value observations, we used level values instead of logarithms of these variables in the model. The Florida price is used in the model to facilitate direct forecasting of the price and computation of profit of Florida production in the next step (discussed in the next section). The Florida price has a direct link with the national price, and the two are convertible to each other. The U.S. real consumer spending, representing per capita disposable income (I_t), is also included in Eq. (1) as it may affect strawberry consumption and therefore market prices (Torok and Huffman, 1986).

Eq. (2) describes Mexican exports (S_{mt}) to the U.S. while Eq. (3) is the California strawberry supply (S_{ct}) equation. The equations link supply with strawberry production determinants, including strawberry acreage (A_{mt},A_{ct}) and weather conditions. Variation in strawberry yield can be explained quite well by climatic conditions (Lobell et al., 2007; Palencia et al., 2013) as weather influences the rate of physiological processes in all parts of the plant (Fernandez et al., 2001). In light of these results linking climate variables with yields, we used average daily maximum temperature for Mexico (Tm_{mt}) and California (Tm_{ct}) during each week and the total weekly precipitation for each region (R_{mt},R_{ct}) to predict total strawberry production (rather than per ha yields) of strawberries in the two regions. In view of differential effects of climatic variables at different growing stages (Døving and Måge, 2001; Lobell et al., 2007; Palencia et al., 2013) (i.e. increased temperatures improve early yields and reduce late season yields), we also included a cross term of climatic variables with time (t) in the regression to predict total regional production. Climate data for the major winter production areas of California (Oxnard) and Mexico (central Mexico) were used. Apart from climatic variations, genetically determined developmental patterns also influence yield over time. The pattern is non-monotonic, thus time (t) and time squared (t^2) are included to model the nonlinear yield trend.