Alternative Strategies to Manage Weather Risk in Perennial Fruit Crop Production

Shuay-Tsyr Ho, Jennifer E. Ifft, Bradley J. Rickard, and Calum G. Turvey

Fruit producers in the Eastern United States face a wide range of weather-related risks that have the capacity to largely impact yields and profitability. This research examines the economic implications associated with responding to these risks for sweet cherry production in three different systems: high tunnels, revenue insurance, and weather insurance. The analysis considers a distribution of revenue flows and costs using detailed price, yield, and weather data between 1984 and 2013. Our results show that the high tunnel system generates the largest net return if significant price premiums exist for earlier and larger fruit.

Key Words: crop insurance, high tunnels, risk management, specialty crops, weather insurance

Producing high-value fruit crops in the Northeast and in the Great Lakes region presents both opportunities and challenges for growers. Many of the opportunities are related to the growing trend for local food that generated direct sales to consumers of more than $1.3 billion nationally in 2012. Of this total, approximately $330 million occurred in Michigan, New York, Massachusetts, Pennsylvania, and Wisconsin, which showcases the importance

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of local foods in these states (NASS 2014c). Many of the challenges facing fruit growers in these regions relate to weather risks such as extreme winter temperature events, late-spring frosts, hail, and excess precipitation occurring during the harvest season (Collier et al. 2008).

National participation levels by perennial fruit crop growers in federal crop insurance programs vary from 80 percent for blueberries to slightly over 50 percent for apricots, and were approximately 75 percent for cherries and plums in 2011 (RMA 2013). As shown in Table 1, the participation levels, measured as acres enrolled in the program as a share of total planted or bearing acres, were greater than 50 percent for most perennial crops in 2014, and the average national participation level was approximately 70 percent. However, this general trend is not consistent across all states. The participation level for cherries, peaches, and pears is relatively low in New York, and single-crop insurance products are unavailable for pears, plums, and strawberries in Michigan.[1] We also observe the availability of high tunnels (sometimes referred to as climatic modification technologies) for fruit and vegetable producers in the Northeast as an alternative risk management tool. High tunnels are used to mitigate weather risks and also enable an extended growing and harvest window that may lead to higher prices for fruit sold in periods with low supply (Lang 2009). In addition to high tunnels and standard crop insurance products, there is interest among some stakeholders for weather-index-based insurance products to hedge against specific weather perils commonly facing specialty crop growers.

Fruit growers are increasingly interested in better understanding how the adoption of high tunnels, compared to market-based tools such as crop insurance, will affect yields, local food sales, and farm profitability. Although there is an abundance of literature examining risk management strategies for program crops in the United States, there is very little research evaluating the economic implications of adopting various risk management strategies for specialty crop producers (Lindsey et al. 2009, Belasco et al. 2013). The purpose of this study is to develop a framework to evaluate various risk management strategies—including high tunnels, crop insurance, and weather insurance—for small- to medium-sized fruit crop growers in the Eastern United States. For each system we simulate a distribution of prices, yields, and costs over 20 years to consider the typical life cycle of a perennial fruit orchard. We provide results that evaluate and rank the different risk management strategies using various criteria.

Our empirical example focuses on fresh sweet cherry production in Michigan and New York State. We focus on sweet cherries in Michigan and New York

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[1] While no crop-specific insurance products are available for pears, plums, and strawberries in Michigan, the USDA Risk Management Agency introduced the Whole Farm Revenue Protection (WFRP) program in 2014 that provides revenue insurance to farms in all states that produce a variety of crops, especially the diversified production of fruits and vegetables.

Table 1. Federal Crop Insurance for Perennial Fruit Crops: Participation Rates and Liabilities in 2014

					Participation Rate: Selected States and National Level						
Crop	**FCIP**	**RMA Acres**	**Liabilities**	**NASS Acres**	**California**	**Washington**	**Oregon**	**Florida**	**Michigan**	**New York**	**U.S.**
Almonds	APH	720,494	2,187,339,139	860,000	0.84						0.84
Apples	APH	248,643	1,089,063,482	327,380	0.37	0.89	0.52		0.78	0.81	0.76
Apricots	APH	6,251	14,327,516	10,840	0.57	0.69					0.58
Avocados	APH	38,209	84,425,927	59,600	0.69			0.30			0.64
Bananas	APH	409	1,486,924	900							0.45
Blueberries	APH	65,885	176,740,045	82,630	0.76	0.49	0.28	0.60	0.67	N/A	0.80
Boysenberries				500			N/A				N/A
Cherries	ARH	89,248	465,331,157	127,950	0.88	0.89	0.40		0.53	0.24	0.70
Citrus	APH/ DOL/ ARH	669,444	1,117,368,802	782,300	0.85			0.87			0.86
Cranberries	APH	32,101	99,912,594	40,500		0.34	0.40				0.79
Dates				8,200							N/A
Figs	APH	4,076	5,820,584	7,200	0.57						0.57
Grapes	APH	604,927	1,489,814,925	1,049,600	0.57	0.80	0.32		0.73	0.56	0.58
Guavas				100							N/A
Hazelnuts				30,000			N/A				N/A
Kiwifruits				3,900	N/A						N/A
Macadamia nuts	APH	11,934	18,957,463	160,000							0.07
Nectarines	APH	16,629	34,480,839	22,600	0.33	0.54					0.74
Olives	APH	25,336	28,511,163	40,000	0.63						0.63

Papayas	APH	57	241,573	1,300							0.04
Peaches	APH	71,813	166,306,198	102,750	0.81	0.46			0.74	0.32	0.70
Pears	APH	33,342	97,450,589	49,300	0.75	0.70	0.69		N/A	0.05	0.68
Pecans	PRV	157,723	237,339,887	466,144	0.53			0.07			0.34
Pistachios	APH	92,172	295,237,074	215,000	0.42						0.43
Plums	APH	14,272	22,970,621	20,500	0.74	0.54	0.45		N/A		0.70
Prunes	APH	45,798	78,590,431	48,000	0.95						0.95
Raisins	DOL		191,891,457	200,000	N/A						N/A
Raspberries				18,050	N/A	N/A	N/A				N/A
Strawberries	ARH	26	325,080	61,310	0.001	N/A	N/A	N/A	N/A	N/A	0.0004
Table grapes	APH	81,321	285,944,613	110,000	0.74						0.74
Walnuts	APH	148,493	349,109,949	290,000	0.51						0.51
Total		3,178,603	8,538,988,032	4,730,410	0.62	0.80	0.28	0.84	0.66	0.64	0.72

Source: Aggregate data from RMA (2014) and NASS (2014a, 2014b). Bearing acres for pecans is from 2012 Census of Agriculture (NASS 2014e).
Note: An empty cell indicates that the state does not produce (or produces very little) of the crop; N/A indicates either that the state does produce the crop but that crop insurance is not currently available, or that there is no insured acreage for that crop in the Summary of Business Report from RMA (2014).

State for three reasons. First, there is growing demand for sweet cherries produced in the Eastern United States, and the top-producing regions in the East are Michigan and New York. Second, sweet cherries are one of the most profitable fruit crops and therefore present the greatest opportunity to employ different risk management strategies. Third, and perhaps most importantly, sweet cherry producers face a host of weather-related risks in the Eastern United States, which greatly increase the financial risks associated with producing and marketing this crop.

Risk Management for Specialty Crops

Various unfavorable weather conditions affect specialty crop production, which has led to an increase in the attention given to risk management strategies by growers. Perennial fruit crops in the Northeast are particularly vulnerable to a wide range of weather perils. Frost injuries during the bloom period in late spring have severely affected yields for apples, cherries, and grapes in the Northeast in 2002, 2007, and 2012 (Baule et al. 2014). For cherry production, there is also a significant risk associated with fruit cracking due to heavy rainfall during the harvest season (Lang 2013). Fruit cracking occurs during the fruit ripening stage when excessive water is absorbed through the fruit surface or through the root system, and the skin splits or "cracks" (Simon 2006). Fruit that has cracked due to excessive water is not marketable. Figure 1 presents the frequency of two weather events for sweet cherry production in Michigan and New York between 1984 and 2013. The thick bar shows the occurrence of spring frost before and during the bloom stage in Maple City, Michigan measured on the left vertical axis. The thin lines represent the frequency of excessive rainfall during the harvest season (in Maple City, Michigan and in Sodus Center, New York) measured on the right vertical axis.

The U.S. federal crop insurance program (FCIP) is a safety net that provides ex ante protection against price, yield, or revenue risks facing agricultural producers (Barnett 2014). Total acres insured have nearly tripled from 1989, with approximately 85 percent of major field crop acreage now enrolled. The Federal Crop Insurance Reform Act of 1994 and the Agricultural Risk Protection Act of 2000 both provided additional incentives for enrollment, including higher premium subsidies. Although the increase in premium subsidies was for both major field crops and specialty crops, the participation level in federal crop insurance programs has historically been higher for field crop growers than for fruit and vegetable growers. Acres enrolled in the program as a share of total planted or bearing acres has increased from 17 percent to 73 percent between 1990 and 2011 for fruits and nuts, and from 16 percent to 32 percent for vegetable crops during the same period (RMA 2013).

Revenue-based plans, such as actual revenue history (ARH), have been implemented on a pilot basis for cherries, navel oranges, and strawberries starting in 2009, 2011, and 2012 respectively (FCIC 2010). Under the ARH plan, historical revenue, rather than historical yield, is insured against losses

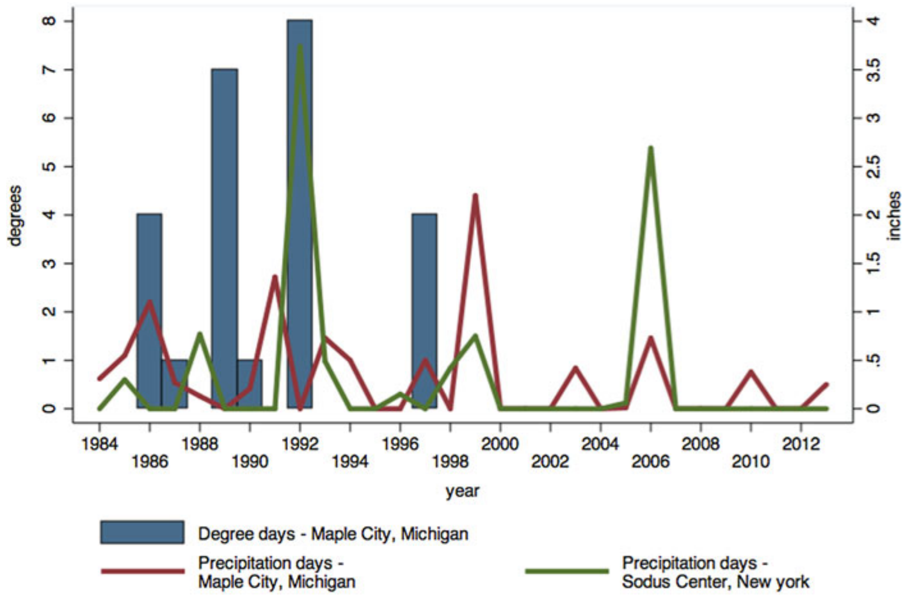

Figure 1. Spring frost and rain-induced cracking events facing sweet cherry growers in Michigan and New York, 1984–2013. Source: NCEI (2013); Murray (2011); NASS (2006). Note: *Degree days* measures the sum of the daily differences between the critical temperatures killing 90 percent of the buds during the growth stage in late spring and the observed temperatures. *Precipitation days* measures the sum of daily precipitation events that exceed 1 inch during the harvest season, which is used to describe a potential rain-cracking event for sweet cherries. The absence of degree days in New York State indicates that there were no observed frost events following the description given above.

from yield shortfalls, inadequate market prices, or both. For the ARH pilot program that was available to sweet cherry producers in Michigan between 2010 and 2013, state-level participation rates ranged between 44 percent and 55 percent. There were differences in participation rates across coverage levels for this pilot program in Michigan; the 75 percent coverage level accounted for the largest share of total insured acres.

Weather insurance payoffs are derived from cause-oriented weather outcomes that are free from potential manipulation by insurance participants, and therefore weather insurance reduces the costly administrative and operational expenses associated with monitoring farmer behavior. Such transparency between the insured and the insurer relieves concerns of the adverse selection problem and may lower the transaction costs incurred from asymmetric information between two parties (Moschini and Hennessy 2001, Barnett 2014). Given several advantages of weather-index-based insurance over traditional crop insurance programs, weather insurance schemes have been regarded as a potentially effective risk management tool among major program crop producers (Turvey 2001, Vedenov and Barnett 2004, Musshoff, Odening, and Xu 2011). For application to specialty crops, Turvey, Weersink, and Chiang (2006) developed a unique method to price weather insurance products for ice wine. Fleege et al. (2004) found improved income from using weather derivatives to hedge against heat risk for nectarines, raisin grapes, and almonds in California. The use of weather insurance has also attracted the attention of policy makers. Under the Agricultural Act of 2014, subsidized pilot products for weather-index-based insurance became available in 2015 for crops that have no available insurance products or have low participation rates for existing insurance products (Chite 2014).

High tunnels are temporary, unheated greenhouses that provide a protected environment for various fruits, vegetables, and cut flowers (Carey et al. 2009). Modified growing conditions within the tunnel, via temperature, sunlight, moisture, and pest control may increase marketable yields and enhance fruit quality compared to crops produced in an open field (Waterer 2003, Demchak 2009). Furthermore, if the use of high tunnels can effectively extend the harvest window for a crop, it is expected that it will allow producers to capture premium prices for these crops that are available earlier in the season (Conner et al. 2009, Ward, Drost, and Whyte 2011, Curtis et al. 2014). Others have found that the use of high tunnels may lead to greater economic benefits compared to crop insurance in the production of oranges and strawberries (Lindsey et al. 2009, Belasco et al. 2013). Part of the interest in high tunnels is due to initiatives within the Environmental Quality Incentives Program (EQIP) that began to provide cost-sharing funds for high tunnel production systems that extend the growing season in an environmentally friendly and energy-efficient manner (NRCS 2011).

However, little is known about the economic implications of using high tunnels for perennial fruit production in the Northeast and Great Lake regions, because the technology has not been widely adopted. Costs for various high tunnel systems are available, yet the benefits from such systems are difficult to assess ex ante. The economic benefits of adopting high tunnels in these regions depend largely on premiums expected for higher quality fruit and fruit that can be produced and marketed earlier in the season (Waterer 2003, Robinson and Dominguez 2013, Maughan et al. 2015).

Conceptual Framework

We develop a simulation model to characterize the distribution of revenues and costs associated with adoption of risk management strategies for sweet cherries in Michigan and New York State. We evaluate the effects for a status quo system plus systems using either high tunnels (the climatic modification technology), revenue-based crop insurance, or weather insurance. We examine and compare the net returns over a 20-year period in a net present value (NPV) analysis. It is possible that a grower will decide to adopt multiple risk management strategies. However, in our analysis we examine each risk management system separately. Because the risk management strategies for sweet cherries in this region are all relatively new, we expect that producers are primarily interested in the relative merits of the systems and will initially consider adoption of individual systems. While an application is made to fresh sweet cherry production in Michigan and New York here, the framework could be used to assess similar questions for other perennial specialty crops in humid continental climate regions where producers have the option to invest in alternative production technologies and purchase insurance products.

The net returns from risk management strategy S is shown in equation 1, where subscript r denotes a region, and subscript t denotes time:

$$(1) \qquad \pi^{S}_{r,t} = \underbrace{P_{r,t} \cdot Q_{r,t} - C^{S}_{r,t}}_{\text{net returns from crop sale and production, } NR^{C}_{r,t}} + \underbrace{I^{S}_{r,t}(\phi) - \gamma^{S}_{r,t}}_{\text{net return from insurance participation, } NR^{I}_{r,t}}$$

$$\text{where} \quad r = \text{MI, NY}; \; t = 1, \ldots, 20$$

In equation 1, $\pi^{S}_{r,t}$ represents the profit per acre for system S, which is comprised of net returns from the harvest, $NR^{C}_{r,t}$, and net returns from purchasing insurance, $NR^{I}_{r,t}$. $P_{r,t}$ and $Q_{r,t}$ are the market price and yield, and their product represents the future gross revenue, $R_{r,t} = P_{r,t} \cdot Q_{r,t}$. Production cost, $C^{S}_{r,t} = C_{r,t} + \chi_{r,t}$, is comprised of the cost under the baseline that is held constant under all scenarios, $C_{r,t}$, and the technology cost (the high tunnel in this study), $\chi_{r,t}$, which includes both the one-time construction cost of the high tunnel and its associated annual variable cost. $I^{S}_{r,t}$ and $\gamma^{S}_{r,t}$ represent the indemnities and the premiums, respectively, for different insurance products. In the case of the federal crop insurance program, ϕ is the level of coverage used to determine the indemnity payout and the associated subsidy. In the analysis of the weather insurance products, ϕ represents the weather index used to determine the payout function that insures farmers against the crop loss caused by a specific weather event, as well as the premiums.

Uncertainty in future price and production associated with unexpected weather events requires us to carefully consider the stochastic process for prices and yields. Price and Wetzstein (1999) modeled stochastic peach prices and yields, and therefore the stochastic revenue, to determine the optimal entry and exit revenue threshold decision in orchard investment. Richards and Manfredo (2003) priced the revenue insurance for grapes using similar stochastic processes for both price and yield. Uncertainty in price, P, and yield, Q, for sweet cherries could be represented by a geometric Brownian motion process:

$$\frac{\mathrm{d}P}{P} = \mu_P \mathrm{d}t + \sigma_P \mathrm{d}z_P \tag{2}$$

and

$$\frac{\mathrm{d}Q}{Q} = \mu_Q \mathrm{d}t + \sigma_Q \mathrm{d}z_Q, \tag{3}$$

where $\mathrm{d}P$ and $\mathrm{d}Q$ represent the change in per-acre price and in per-acre tons of fruit, μ is the drift rate or rate of change in price and yields, and σ is the standard deviation. The percentage change in price and yield, dP/P and $\mathrm{d}Q/Q$, are normally distributed with mean μT and variance $\sigma^2 T$, with increment change in time T. The Wiener process, denoted by $\mathrm{d}z$, represents the time-independent random shock that follows a standard normal distribution and defines the correlation between variables ($\mathrm{d}z_P \mathrm{d}z_Q = \rho \mathrm{d}t$, $\mathrm{d}z_P^2 = \mathrm{d}z_Q^2 = \mathrm{d}t$), and ρ is the correlation coefficient between price and yield.

Applying Ito's Lemma, the stochastic process of gross revenue, $R = PQ$, follows the geometric Brownian motion (Turvey, Woodard, and Liu 2014):

$$\frac{\mathrm{d}R}{R} = \frac{\partial R}{\partial P}\mathrm{d}P + \frac{\partial R}{\partial Q}\mathrm{d}Q + \frac{1}{2}\frac{\partial^2 R}{\partial P^2}\mathrm{d}P^2 + \frac{1}{2}\frac{\partial^2 R}{\partial Q^2}\mathrm{d}Q^2 + \frac{1}{2}\frac{\partial^2 R}{\partial P \partial Q}\mathrm{d}P\mathrm{d}Q \tag{4}$$

where $\partial R/\partial P = Q$, $\partial R/\partial Q = P$, $\partial^2 R/\partial P^2 = 0$, $\partial^2 R/\partial Q^2 = 0$ and $\partial^2 R/\partial P \partial Q = 1$. Substituting (2) and (3) into (4) gives the stochastic process for revenue:

$$\mathrm{d}R = \mu_R R \mathrm{d}t + \sigma_P R \mathrm{d}z_P + \sigma_Q R \mathrm{d}z_Q \tag{5}$$

where $\mu_R = \mu_P + \mu_Q + \rho\sigma_P\sigma_Q$; R is lognormally distributed such that the percentage change in R over time interval T, is normally distributed with mean $\mu_R T$ and variance, $\sigma_R^2 T$, where $\sigma_R^2 = \sigma_P + \sigma_Q + 2\rho\sigma_P\sigma_Q$. By Ito's lemma, the differential of change in logarithm of R over time, $\mathrm{d}\ln(R)$, occurs with normally distributed mean $(\mu_R - (1/2)\sigma_R^2)T$ and variance $\sigma_R^2 T$ (Turvey, Woodard, and Liu 2014). Annual forecasted crop revenue could then be derived from the following lognormal Ito's process:

$$R_t = R_{t-1} e^{((\mu_P + \mu_Q - (1/2)\sigma_P^2 - (1/2)\sigma_Q^2)\mathrm{d}t + N(0,1,\rho)(\sigma_P^2 + \sigma_Q^2 + 2\rho\sigma_P\sigma_Q)^{1/2}\sqrt{\mathrm{d}t})}. \tag{6}$$

Market price and yield data for fresh sweet cherries in Michigan and New York are available from the USDA's National Agricultural Statistical Service from 1984 to 2013 (NASS 2014a).[2] Detailed annual cost data for sweet cherry production are not available for Michigan and New York, and therefore we use data from California, Washington, and Oregon to characterize costs in Michigan and New York State (Galinato, Gallardo, and Taylor 2010, Grant et al. 2011, West et al. 2012). These studies recognized that perennial fruit crops have large establishment costs, annual variable costs, and annual revenue that begins once fruit is produced (typically in the 4th or 5th year in the life cycle of an orchard). We follow this logic in our analysis and include marketable yields (and hence revenue) beginning in year five. However, in our analysis we ignore the initial investment costs for land, trees, and other materials needed to establish an orchard. We assume that the general orchard establishment costs are the same across the risk management strategies (and treat the costs for the high tunnels as an additional establishment cost in that system); effectively we assume that an operator has decided to invest in an orchard, and our analysis provides the analysis to compare the economic effects of adopting different risk-management strategies.

In the cost and return studies that were conducted in the Western U.S. regions for sweet cherries, the total per-acre costs range from \$9,848 to \$14,456, while the corresponding crop sales per acre range from \$11,900 to \$22,400, and the resulting cost-revenue ratio ranges from 45 percent to 86 percent. To generate net return flows in our framework, we project future costs by multiplying the gross revenue simulated in equation 6 with an average cost-revenue ratio as shown in equation 7, specific to Michigan and New York respectively,

$$C_{\mathrm{r,t}} = R_{\mathrm{r,t}} \cdot \left(\frac{\tilde{C}}{\bar{\tilde{R}}} \right), \tag{7}$$

In equation 7, $\tilde{C}/\tilde{R}$ represents the historical cost-revenue ratio and is multiplied by a specific distribution function that is used as a proxy to characterize the cost and revenue relationship, where $\tilde{R}$ denotes the historical revenue flows. We use Producer Purchase Index for "Other Fruits and Berries" between 1984 and 2013 (BLS 2014) to retrieve the historical cost flows, $\tilde{C}$.

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[2] The most ideal dataset for yield is at the county or the farm level. However, these data are not available for sweet cherries and we use state-level yield data for the simulation analysis. The bearing acreage is only available for total sweet cherry production; therefore the yield per acre is used as a proxy for fresh sweet cherries. Because the price in New York is not disclosed for sweet cherries in fresh use, we assume, based on anecdotal evidence from growers, that 90 percent of sweet cherry production goes to the fresh market.

Calculating Net Returns in Each System

The general framework presented in equation 1 is used to quantify the net returns in each system. The forecasted net returns for growers of sweet cherries in region *r* (Michigan or New York) under the baseline (status quo) scenario are simply:

$$\pi^{B}_{r,t} = R_{r,t} - C_{r,t}, \tag{8}$$

where the simulated gross revenues and costs are calculated following equations 6 and 7, respectively. We expand on the calculation of net returns in the baseline system to consider specific factors affecting revenues and costs in each of the other three systems.

High Tunnels

Relative to the net returns described above, the adoption of high tunnels to mitigate risk will lead to increased costs and potentially higher revenue flows. The calculation of net returns in the system that includes high tunnels is outlined in equation 9:

$$\pi^{HT}_{r,t} = \tau \cdot R_{r,t} - (C_{r,t} + \chi_{r,t}), \tag{9}$$

where τ represents the revenue multiplier due to improvements in fruit quality, increases in yield, and increases in the per-unit price associated with an advanced marketing window. From available experimental data that describe yields and prices for sweet cherries produced under high tunnels in New York during 2010 and 2012, the crop value per acre under the high tunnel system is expected to vary from 1.27 to 3.4 times higher than the crop value without high tunnels. Similar experimental data from research at Michigan State University shows that the value of the crop produced in high tunnels is between 1.3 to 2.5 times higher than the value for fruit produced in an open field.[3] We consider a range of values between 25 percent and 150 percent (or equivalent revenue multipliers between 1.25 and 2.50) to describe this premium for fruit produced in a high tunnel.

The cost of establishing high tunnels is approximately $40,000 per acre. While high tunnel structures could remain relatively maintenance free, other variable costs including plastic covers every four years ($4,000 per acre) and annual

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[3] The high tunnel field data and phenological stage estimates for sweet cherries in New York and Michigan were collected from research trials at the New York State Experiment Station and Michigan State University; detailed information is available upon request.

labor costs for various tasks ($1,200 per acre) are expected (Blomgren and Frisch 2007). All of these additional costs specific to the high tunnel system are captured in $\chi_{r,t}$.

Revenue-based Crop Insurance

Focusing on the ARH pilot program for sweet cherries, the calculation used to determine net returns for a grower adopting crop insurance needs to consider the costs of enrolling in the program as well as the indemnity. Net returns to the grower are outlined in equation 10:

$$\pi^{CI}_{r,t} = \pi^{B}_{r,t} + I^{CI}_{r,t}(\delta_C) - \gamma^{CI}_{r,t}, \tag{10}$$

where $I^{CI}_{r,t}(\delta_C) = \mathrm{Max}(\delta_C \cdot \tilde{R}_r - R_{r,t}, 0)$ is the indemnity as a function of the coverage level, δ_C; $\pi^{B}_{r,t}$ is the same as it was defined in equation 8. Approved or certified revenue, denoted by $\tilde{R}_r$, is determined by the historical average of grower revenue based on the past four to ten years, while $R_{r,t}$ is the actual revenue in year *t* and region *r*. In our analysis, we simulate the actual revenue based on yield and price patterns observed between 1984 and 2013. The crop insurance premium is defined by:

$$\gamma^{CI}_{r,t} = E(\mathrm{Max}(\delta_C \cdot \tilde{R}_r - R_{r,t}, 0)) \cdot (1 - \zeta(\delta_C)). \tag{11}$$

For the premium to be actuarially fair, the pre-subsidy premium level is equal to the expected loss or the expected indemnity. The cost of insurance to the grower is determined by subtracting the subsidy (denoted as ζ) from the premium, which, as a percentage of the premium, varies by the level of coverage the grower selects. In our analysis, we consider all the coverage levels, from 50 percent to 75 percent, and subsidies from 67 percent to 55 percent (RMA 2015).

Weather Insurance

Weather insurance products are indexed to weather variables that are linked to specific events affecting crop size, crop prices, or crop quality. For sweet cherry production in the Northeast and in the Great Lakes region, spring frost and summer precipitation (leading to fruit cracking) are the two main weather risks. A hard frost in the late spring (after the budding process has begun) has the capacity to decrease bud survival through the flowering stage. Tolerance to the freezing temperature varies by stage of development as well as by growing environment and crop types; sweet cherries are relatively vulnerable to frost damage compared to other perennial stone fruit crops such as peaches and plums (Miranda, Santesteban, and Royo 2005).

Two types of weather-index-based insurance programs are considered in our analysis: frost insurance and harvest season rain insurance. The net returns to a grower who adopts weather insurance are described in equation 12.

$$\pi^{WI}_{r,t} = \pi^{B}_{r,t} + I^{WI}_{r,t}(W) - \gamma^{WI}_{r,t}(1-\psi), \quad \text{where} \\ WI = FI,\ RI;\ W = W^{F}_{r,t},\ W^{E}_{r,t},\ W^{C}_{r,t} \tag{12}$$

Here the frost insurance is denoted by FI, and harvest rain insurance is denoted as RI. The variable $W^{F}_{r,t}$ measures the occurrence of spring frost; $W^{F}_{r,t}$ is the sum of the daily deficit amount in observed temperature falling below the critical thresholds that cause 90 percent bud kill. Since FCIP began to subsidize weather-index-based insurance in 2015, we consider both the unsubsidized and subsidized scenario for weather insurance in our analysis. The subsidy rate is denoted by ψ in equation 12; we set it to 0 to consider the case with no subsidy and also to consider a range of subsidy rates from 10 percent to 50 percent. The indemnity function for frost insurance is:

$$I^{FI}_{r,t}(W^{F}_{r,t}) = \theta^{F}_{r} \cdot W^{F}_{r,t}, \tag{13}$$

where θ^{F}_{r} is the unit payout growers will receive for each degree deficit. The unknown frost index, $W^{F}_{r,t}$, is approximated by the probabilistic information on potential frost damages, denoted as $\tilde{W}^{F}_{r,\tilde{t}}$, generated using detailed historical weather records from 1984 to 2013 as shown in equation 14,

$$\tilde{W}^{F}_{r,\tilde{t}} = \sum_{s}\sum_{d} \text{Max}(Z^{C}_{r,s} - \tilde{Z}_{r,\tilde{t},s,d}, 0), \quad \text{where} \quad \tilde{t} = 1984, \ldots, 2013. \tag{14}$$

Here we use $Z^{C}_{r,s}$ to denote the critical temperature at stage s for 90 percent bud kill, which is commonly used to identify the bud injury at different stages of development (Murray 2011); $\tilde{Z}_{r,\tilde{t},s,\tilde{d}}$ is the daily temperature observed at stage s from 1984 to 2013; d denotes the number of days in each stage.

We consider two types of harvest rain insurance, and develop two indices to capture the effect of summer precipitation: an excess rain index, $W^{E}_{r,t}$, and a cumulative rain index, $W^{C}_{r,t}$. Similar to the design of the frost index, the excess rain index is characterized by the following indemnity function,

$$I^{RI}_{r,t}(W^{E}_{r,t}) = \theta^{E}_{r} \cdot W^{E,}_{r,t} \tag{15}$$

where $W^{E}_{r,t}$ is measured as the sum of daily rainfall during the harvest season exceeding the threshold that causes fruit cracking; and θ^{E}_{r} is the unit payout growers receive for every excess inch of rainfall. The excess rainfall index, $W^{\mathrm{E}}_{\mathrm{r,t}}$, is approximated by the probabilistic information on potential excess rain damages, denoted as $\tilde{W}^{\mathrm{E}}_{\mathrm{r},\tilde{t}}$, generated using detailed historical weather records from 1984 to 2013 as shown in equation 16,

$$\tilde{W}^{\mathrm{E}}_{\mathrm{r,t}} = \sum_{d} \mathrm{Max}(\tilde{V}_{\mathrm{r},\tilde{\mathrm{t}},\mathrm{d}} - V^{\mathrm{C}}_{\mathrm{r}}, 0), \quad \text{where} \quad \tilde{t} = 1984,\ldots,2013. \tag{16}$$

In equation 16, $V^{\mathrm{C}}_{\mathrm{r}}$ represents the precipitation threshold, $\tilde{V}_{\mathrm{r,}\ddot{\mathrm{A}}\mathrm{t,d}}$ is the daily precipitation during the period 1984 to 2013, and d denotes the length in days in the harvest season.

The cumulative rainfall index considers the sum of rainfall during the harvest season. Based on the historical precipitation data (Skees et al. 2001, Heimfarth and Musshoff 2011), the stochastic cumulative rainfall index is specified as

$$\tilde{W}^{\mathrm{C}}_{\mathrm{r},\tilde{\mathrm{t}}} = \sum_{d} \tilde{V}_{\mathrm{r},\tilde{\mathrm{t}},\mathrm{d}}, \quad \text{where} \quad \tilde{t} = 1984,\ldots,2013, \tag{17}$$

used to approximate the cumulative rainfall in a given period denoted by $W^{\mathrm{C}}_{\mathrm{r,t}}$ such that the payoff for the weather insurance is

$$I^{\mathrm{RI}}_{\mathrm{r,t}}(W^{\mathrm{C}}_{\mathrm{r,t}}) = \theta^{\mathrm{C}}_{\mathrm{r}} \cdot \mathrm{Max}(W^{\mathrm{C}}_{\mathrm{r,t}} - \tilde{W}_{\mathrm{r}}, 0), \tag{18}$$

where $\theta^{\mathrm{C}}_{\mathrm{r}}$ represents the per-unit amount the grower will be compensated if the observed accumulated rainfall level goes above the strike level, $\tilde{W}_{\mathrm{r}}$.

For all weather insurance products, the actuarially fair premiums are set as equal to the expected loss (or the expected indemnity) discounted by a risk-free interest rate, i, during time interval Δt, if an unfavorable weather event occurs. The calculation of the premium, denoted as $\gamma^{\mathrm{WI}}_{\mathrm{r,t}}$, is shown in equation 19

$$\gamma^{\mathrm{WI}}_{\mathrm{r,t}} = E(I^{\mathrm{WI}}_{\mathrm{r,t}}(W)) \cdot \exp(-i \cdot \Delta t). \tag{19}$$

To price the weather insurance products, we use detailed data on precipitation and temperature collected over the period 1984 to 2013 from the National Climatic Data Center. The weather data are used to specify late spring frost events and harvest rain events for sweet cherry production regions in Michigan and in New York (NCEI 2013). Leelanau County and Wayne County are the top sweet cherry producing counties in Michigan and New York, respectively; they account for 60 percent of total bearing acreage in Michigan and 48 percent of total bearing acreage in New York (NASS 2014d). Therefore, we collect the weather data for Maple City, Michigan and Sodus Center, New York as they are located in the representative counties and both have data available over the period from 1984 to 2013.[4]

Given agronomic information that describes the range of dates for specific crop development stages (i.e., green tip and the key bloom dates), we identify the critical times for spring frost (in April and early May) with temperatures that would kill 90 percent of the buds (Murray 2011) in the calculation of the frost index. Because the historical data in New York State do not show any cases of temperatures falling below the critical points, we do not consider this type of weather insurance product in New York. Our rainfall indices are generated based on the information that describes the typical harvest windows in late June and early July in both states (NASS 2006).

In our analysis we set the critical precipitation threshold in the rain index, $V_{\mathrm{r}}^{\mathrm{C}}$, to 1 inch; the maximum observed level for this index was 2.2 for Michigan and 3.74 for New York. We set the strike level in the cumulative rainfall index, $\tilde{W}_{\mathrm{r}}$, equal to the mean amount of accumulated rainfall between 1984 and 2013. According to the best-fit distribution of historical weather patterns, we use an exponential distribution to characterize all weather-related indices. The per-unit payouts for each weather index in each state are set by assuming that, in the worst year, indemnities received by the growers will not exceed 25 percent of the highest observed level of crop revenue. A series of simulations are then used to determine the prices and the indemnities for the various weather insurance products (Turvey, Weersink, and Chiang 2006, Musshoff, Odening, and Xu 2011).

Results

We use Monte Carlo simulation techniques to generate the annual net per-acre return over a 20-year period from adopting various risk management strategies for sweet cherry production in Michigan and New York. We consider the effects for a status quo scenario (no risk management strategy) plus four risk management strategies in Michigan and three risk management strategies in New York (as weather insurance related to frost is not relevant in New York State). Using an iterative procedure we calculate the net present value per acre for each system at a discount rate of 8 percent (Song, Zhao, and Swinton 2011). We also consider other discount rates within a reasonable range and

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[4] Using state-level yield data may lead to basis risks that would undermine the accuracy in pricing weather insurance and in empirically identifying the weather-yield relationship to determine the indemnities incurred from specific weather events. Basis risks here refer to both local basis risk and geographical basis risk. Choosing the counties that are the most representative growing regions for sweet cherries in Michigan and New York could reduce the geographical basis risk. However, it is difficult to remove the local basis risk where there exists a stochastic relationship between the specified weather indices and yield variation.

Table 2. Baseline Parameters Used in the Monte Carlo Simulation Analysis

	Original Data		Brownian Motion Process				
Simulation Parameters	**Mean**	**Standard Deviation**	**Initial Value (2013)**	**Drift**	**Volatility**	**Correlation**	**Cost-revenue Ratio**
Michigan							
Price	2,300	584.94	2,290	0.033	0.029	−0.43	Lognormal
Yield	2.97	0.96	3.47	−0.01	0.737		
Revenue			7,946	−0.245	0.725		
New York							
Price	2,210	768.86	3,370	0.054	0.185	−0.51	Triangle
Yield	1.52	0.51	1.49	−0.01	0.43		
Revenue			5,587	−0.068	0.374		

find that it does not change the general thrust of the results below. Table 2 shows the key parameters and distribution assumptions for prices and yields (in Michigan and New York) used in the simulation.

A summary of the results for Michigan is presented in Table 3, and a summary of the results for New York is presented in Table 4. The information in the tables summarizes the distribution of net returns to each risk management strategy. We show six levels of revenue premiums (ranging between 25 percent and 150 percent) for the fruit produced in the high tunnel system; the premiums are based on the observed revenue premiums for cherries produced in both open field and under high tunnels in field experiments in the two regions. We include six levels of coverage for crop insurance from 50 percent to 75 percent, and six subsidy levels for weather insurance from 0 to 50 percent.

The results in Table 3 show that, in Michigan, the high tunnel system yields the highest expected returns across all the risk management strategies when we assume a high revenue premium for the marketed fruit (at or above 150 percent). The expected returns to the crop insurance and weather insurance products are greater than the status quo across all the coverage and subsidy levels. The crop insurance strategy provides a relatively high level of expected returns that increase with the coverage level and a relatively low coefficient of variation that remains stable across coverage levels. The coefficient of variation results for the weather insurance products decrease with the subsidy level, indicating that weather insurance would be preferred only when subsidized and as subsidies to the premium increase. Harvest rain insurance generates higher returns compared to crop insurance and compared to high tunnels if we assume low revenue premiums (less than 125 percent). At the 5th percentile of the net returns distribution, the results show that the crop insurance is preferred to all other risk management strategies, and adoption of high tunnels is the riskiest strategy, regardless of the revenue premium. At the 95th percentile, the results show that all the strategies generate higher expected returns than the status quo and that the greatest return occurs with the adoption of the high tunnel system (for all revenue premium levels).

Table 4 shows that in New York State the expected net returns per acre with high tunnels (with a revenue premium at or above 125 percent) are the highest compared to all other strategies. With either crop insurance across the various coverage levels or with weather insurance (harvest rain insurance) across the various subsidy levels, we see higher net returns than with the status quo scenario. Similar to the results in Michigan, we also see that the crop insurance strategy does not always outperform the weather insurance strategy. Crop insurance leads to higher net returns compared to weather insurance only under the highest coverage level (at 75 percent coverage). Weather insurance starts to outperform crop insurance with coverage below 60 percent and when subsidies to premiums exceed 30 percent. The coefficient of variation is the highest for the high tunnel systems that assume higher revenue premiums. The coefficient of variation is relatively stable

Table 3. Summary Statistics for the NPV Results in Michigan ($/acre)

					Distribution Percentile			
System	**Expected Value**	**CV**	**Median**	**Skewness**	**5th**	**Positive**		**95th**
Status quo	4,956	8	2,778	20	−16,148	30th	516	27,738
High tunnel								
Revenue								
25%	−44,771	−6	−53,280	8	−166,497	85th	3,245	97,560
Premium								
50%	−32,808	−7	−48,449	−11	−162,003	85th	19,425	139,962
75%	−17,233	−26	−43,477	45	−156,011	80th	9,956	170,809
100%	−9,270	−34	−38,530	11	−147,693	75th	5,154	210,041
125%	5,368	71	−32,818	19	−145,986	70th	2,300	251,254
150%	18,935	31	−28,766	63	−140,795	70th	11,511	284,341
Crop insurance								
Coverage level								
75%	11,435	5	6,134	30	−10,567	20th	937	43,378
70%	11,088	5	6,216	29	−10,647	20th	1,152	41,765
65%	10,309	6	5,819	28	−11,256	20th	838	39,654
60%	9,667	6	5,540	28	−11,629	20th	642	38,180
55%	9,190	6	5,398	27	−11,909	20th	527	36,617
50%	8,639	6	5,169	26	−12,440	20th	368	35,216
Frost insurance (Degree days)								
Subsidy								
0%	5,688	12	257	31	−15,998	50th	257	33,589

Continued

Table 3. Continued

					Distribution Percentile			
System	Expected Value	CV	Median	Skewness	5th	Positive		95th
10%	6,203	11	772	31	−15,483	45th	10	34,104
20%	6,718	10	1,287	31	−14,968	45th	525	34,619
30%	7,233	9	1,802	31	−14,453	40th	369	35,133
40%	7,748	9	2,316	31	−13,938	35th	188	35,648
50%	8,262	8	2,831	31	−13,424	30th	31	36,163
Harvest rain insurance (Precipitation days)								
Subsidy								
0%	5,951	12	−723	29	−16,355	55th	162	36,597
10%	6,667	11	−7	29	−15,639	55th	878	37,313
20%	7,383	10	709	29	−14,923	50th	709	38,029
30%	8,099	9	1,425	29	−14,207	45th	586	38,745
40%	8,815	8	2,142	29	−13,491	40th	559	39,461
50%	9,531	8	2,858	29	−12,775	35th	562	40,177
Harvest rain insurance (Cumulative rainfall)								
Subsidy								
0%	5,789	13	−812	29	−16,686	55th	37	35,917
10%	6,520	11	−81	29	−15,956	55th	767	36,647
20%	7,250	10	649	29	−15,226	50th	649	37,377
30%	7,980	9	1,379	29	−14,495	45th	543	38,107
40%	8,710	8	2,109	29	−13,765	40th	556	38,837
50%	9,440	8	2,840	29	−13,035	35th	511	39,568

Table 4. Summary Statistics for the NPV Results in New York ($/acre)

					Distribution Percentile			
System	**Expected Value**	**CV**	**Median**	**Skewness**	**5th**	**Positive**		**95th**
Status quo	5,775	2	3,720	8	−3,487	20th	415	20,707
High tunnel								
Revenue								
25%	−39,266	−3	−49,168	6	−152,820	85th	15,231	98,106
Premium								
50%	−23,926	−6	−39,917	20	−141,579	75th	404	132,562
75%	−12,501	−10	−31,263	4	−133,557	70th	2,537	165,987
100%	1,085	130	−21,376	5	−126,591	65th	3,778	193,095
125%	16,846	10	−12,776	6	−122,315	60th	4,647	245,422
150%	28,941	6	−3,908	6	−113,837	55th	5,183	267,428
Crop insurance								
Coverage level								
75%	7,616	2	4,962	8	−2,214	15th	594	25,224
70%	7,353	2	4,817	8	−2,308	15th	511	24,154
65%	7,004	2	4,595	8	−2,512	15th	357	23,256
60%	6,781	2	4,487	8	−2,655	15th	312	22,580
55%	6,505	2	4,277	8	−2,884	15th	165	21,917
50%	6,307	2	4,142	8	−3,003	15th	49	21,429
Harvest rain insurance (Precipitation days)								
Subsidy								
0%	5,845	3	2,382	10	−4,571	35th	497	25,622

Continued

Table 4. Continued

					Distribution Percentile			
System	**Expected Value**	**CV**	**Median**	**Skewness**	**5th**	**Positive**		**95th**
10%	6,164	3	2,700	10	−4,252	30th	224	25,941
20%	6,482	2	3,019	10	−3,934	30th	543	26,259
30%	6,800	2	3,337	10	−3,615	25th	237	26,578
40%	7,119	2	3,656	10	−3,297	25th	555	26,896
50%	7,437	2	3,974	10	−2,979	20th	265	27,214
Harvest rain insurance (Cumulative rainfall)								
Subsidy								
0%	5,874	3	2,372	11	−4,563	35th	514	25,806
10%	6,191	3	2,690	11	−4,245	30th	249	26,123
20%	6,508	2	3,007	11	−3,928	30th	566	26,441
30%	6,826	2	3,325	11	−3,610	25th	245	26,758
40%	7,143	2	3,642	11	−3,293	25th	562	27,075
50%	7,461	2	3,959	11	−2,976	20th	279	27,393

(between 2 and 3) among the status quo, crop insurance, and weather insurance scenarios. At the 5th percentile, crop insurance would be the preferred strategy (the option with the smallest negative returns), followed by the status quo and weather insurance; at the 5th percentile, the least preferred strategy is high tunnels. At the 95th percentile, the weather insurance strategy generates higher net returns than the crop insurance strategy; however, overall the high tunnel strategy would generate the highest net return.

Discussion

Managing weather risk in the production of specialty crops in humid, cool temperature regions is critical for maintaining fruit quality, ensuring local supply, and generating sustainable profits for growers. The key weather risks involved in growing sweet cherries in Michigan and New York include late-spring frosts (that reduce the quantity of buds) and excessive rain during harvest season (that leads to fruit cracking). Various strategies to mitigate these risks are available and have been considered to some degree by industry stakeholders; these include high tunnels, crop insurance, and weather insurance. The efficacy of different risk management tools varies by region, by producers' attitudes toward risk, as well as by their exposure to weather events. The purpose of this research is to evaluate the long-term economic impacts of adopting the various risk management strategies for sweet cherry production in Michigan and New York. We develop a framework using Monte Carlo simulation methods that will help farm business managers make better-informed decisions on the adoption of various contemporary risk management tools for specialty crops.

We use historical yield, price, and weather data to simulate the expected net returns under different risk management scenarios. Our findings show that the adoption of high tunnels is the preferred strategy if a relatively large revenue multiplier is assumed.[5] All of the risk management options outperform the status quo system in both Michigan and New York. Overall, the results indicate that a higher revenue premium would be needed in Michigan (relative to New York) in order for the high tunnel system to dominate the insurance-based strategies.

This research adds to the growing body of work that examines risk management issues for specialty crops by focusing carefully on the tools that can be applied to perennial fruit crops in the Northeast and Great Lakes

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[5] Widespread adoption of high tunnels could increase the availability of early season fruit, and this in turn could reduce the capacity for the system to generate substantial revenue premiums for all producers. Given that high tunnels have not been widely adopted in New York State and Michigan, we assume that they will not be adopted in a significant way over the short-to-medium term and that modest levels of adoption will not have any dampening effects on the potential price premiums we use in our analysis.

region of the United States. We also contribute to the development of a modeling framework that could be used to study the economics of alternative risk management tools for a range of specialty crops facing substantial risks related to spring and summer weather events. Although we observe an increase in the number of subsidized crop insurance products available for specialty crop growers, it is not clear that the use of such products is the optimal strategy for managing risk by all fruit and vegetable producers in the Northeast and in the Great Lakes region. Our findings suggest that more consideration should be given to other risk management tools including the high tunnel initiative as part of the EQIP and the pilot weather-index-based insurance programs for specialty crops as proposed in the Agricultural Act of 2014.

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