Do Farmers Really Plant Apples for Their Income and Cherries for Their Retirement?

The Effects of Risk, Scope and Scale on Orchard Land Allocation

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Abstract

Most fruit growers in Central Washington that produce apples or cherries typically grow both. This is interesting given that important sources of complementarities which generate economies of scope, such as crop rotations, that motivate crop diversification throughout agriculture are not present. An alternative explanation is risk mitigation because apple and cherry yields and prices are somewhat uncorrelated. In this paper we attempt to evaluate the relative importance of economies of scope versus risk in motivating orchard crop diversification while accounting for economies of scale. To date, the literature on perennial crop supply response has not considered diversification and thus may be missing an important factor that determines farm level land allocation decisions which influence aggregate supply response.

Key Words: Acreage, Crop Diversification, Economies of Scope, Orchard Crop, Risk

JEL Classifications: Q12, Q15

Introduction

A majority of farmland owners that have land planted in apples or cherries in the orchard crop dominated region of Central Washington grow both. This could be due to complementarities in inputs that generate economies of scope or risk mitigation. Working in the opposite direction, there are significant scale economies related to procuring workers for harvesting and negotiating with processors. The economies of scope explanation is weakened by the fact that crop rotations, the major source of scope economies in agricultural production, are not present with perennial crops. However, economies of scope related to labor and machinery costs seem feasible. Apples and cherries have different harvest seasons. Assuming there are fixed costs associated with hiring workers, planting both apples and cherries could reduce peak worker demand for the farm and thus reduced production costs. The same goes for capital such as ladders or crop spray equipment. The benefits to orchard diversification to reduce risk management arise from the fact that apples and cherries respond differently to different types of weather. For example, cherries are very sensitive to rain that causes cracking, which has no significant effect on apples. Apples are sensitive to extreme heat events that occur in mid to late summer after cherries have already been harvested. Price volatility is also expected to be higher for cherries because apples can be stored for many months while cherries cannot.

To our knowledge this is the first paper to examine the role of farm level crop diversification in orchard supply decisions. The perennial crop supply literature has primarily relied on aggregate rather than farm-level data (Ady, 1949; Bateman, 1965; French, 1956; French and Bressler, 1962). A significant effort has been put into accounting for orchard stand age to consider both plantings and removals rather than just looking at net change (French and Matthews, 1971; French, King, and Minami, 1985; Devadoss and Luckstead, 2010). Other papers have considered risk mitigation in perennial crop planting decisions, although they did not analyzed multiple orchard crops in a portfolio-type approach as we do here (Dorfman and Heien, 1989; Akiyama and Trivedi, 1987; Knapp, 1987; Kalaitzandonakes and Shonkwiler, 1992). Our objective in this study is to empirically test the role of risk management through diversification while controlling for economies of scope to better understand orchard crop supply decisions at the farm level.

In contrast, the role of crop diversification for risk management in agriculture for annual crops is well developed. Lin, Dean and Moore (1974) conducted empirical tests on whether the farmer maximizes profit or utility of income and found evidence of risk aversion. Scott and Baker (1972) used a mean-variance frontier approach to calculate the optimal combination of enterprises for a farm under farm risk. Di Falco and Perrings (2005) analyzed the impact of financial assistance to farms on crop biodiversity under uncertainty both theoretically and empirically. They found that risk aversion is an important driving force for crop biodiversity conservation. Di Falco and Chavas (2009) investigated how crop diversity contributes to farm productivity and risk exposure, their results showed diversification reduces the cost of risk. Pope, LaFrance and Just (2011) built a structural intertemporal model of asset arbitrage equilibrium and estimated the risk preference parameter to be statistically different from zero and positive indicating risk aversion using data from the 1990s for the North Central region of US crop production as well as market and bond returns.

Looking specifically at the tension between economies of scale and scope, Baumol (1977) showed that product diversification induces economies of scope. Pope and Prescott (1980) used a reduced functional form to regress diversification on farm size, ownership, financial income and other variables. They found a significant relationship between diversification and farm size.

Chavas and Aliber (1993) used a nonparametric approach to analyze economies of scope of a sample of Wisconsin farms. Their conclusion was that most farms exhibit substantial economies of scope and such economies tend to decline sharply with the size of the enterprise. Weiss and Briglauer (2000) empirically examined the impact of various farm and household characteristics such as farm size, the off-farm employment status, the farm operator's age and schooling, and the number of family members on the level and the dynamics of on-farm diversification. Their results showed that smaller farms that are more specialized tend to increase the degree of specialization over time more quickly than large farms. Morrison Paul and Nehring (2005) found diversification is clearly productive.

Chavas and Di Falco (2012) is a recent and theoretically rich attempt to deal with the trickier question of attempting to disentangle economies of scope from risk in motivating diversification. Our paper uses their approach to decompose risk and economies of scope in the farmer's objective function and analyze the orchard land allocation problem by disentangling risk management and economies of scope. Apple and cherry production in Washington State is an ideal context in which to estimate this model. Apples and cherries have similar annual costs and land suitability. Labor costs are significant for both and access to regional processing centers is important. The mix of apple and cherry orchards in Washington State presents an intriguing opportunity to empirically identify the effects of economies of scope and risk management on perennial orchard land allocation.

Model

In our model a representative farmer maximizes the expected utility of land revenue by allocating orchard acreage across crops. We assume there are only two crops available, apples and cherries. The farmer can also control the orchard total acreage by renting or leasing land.

$$\max_{x,L} EU\big(\pi(x,L)\big)$$

Where π denotes total revenue, $x \in [0,1]$ is the share of land for growing apple and $1-x$ denotes the percentage of land for growing cherries, L is the total acreage of orchard land. According to Arrow (1965) and Pratt (1964), expected utility equals utility of certainty equivalent, *CE.*

$$EU\big(\pi(x,L)\big) = U\Big(CE\big(\pi(x,L)\big)\Big)$$

Therefore, maximizing expected utility is equivalent to maximizing *CE* given utility increases monotonically with certainty equivalent.

$$\max_{x,L} CE\big(\pi(x,L)\big)$$

From Arrow (1965) and Pratt (1964), it is known that *CE* equals expected revenue minus risk premium, *R*.

$$CE\big(\pi(x,L)\big) = E\big(\pi(x,L)\big) - R$$

Following Chavas and Di Falco 2012, the risk premium is given by:

$$R = r\frac{var\big(\pi(x,L)\big)}{E\big(\pi(x,L)\big)}$$

where *r* is risk aversion parameter. $var(\pi)$ represents the variance of land revenue.

There are four factors that affect land revenue: revenue from growing apples, revenue from growing cherries, land rental income, and economies of scope. Let *A* and *C* denote revenue per acre for growing apples and cherries and *P* be the land rental price.

$$\pi(x,L) = xAL + (1-x)CL - PL - \varphi\left(\frac{1}{2} - x\right)^2$$

The last term represents economies of scope, and φ denotes the economies of scope parameter, which means how much more acre revenue the farmer can achieve when she decides the share of land for apple more closer to $\frac{1}{2}$. When apples and cherries are evenly mixed $x = \frac{1}{2}$ and the fourth term achieves a maximum.

Expected and variance of land revenue can then be written as [1]

$$E\big(\pi(x,L)\big) = E\left(xAL + (1-x)CL - PL - \varphi\left(\frac{1}{2} - x\right)^2\right) = L[\Theta x + \Psi] - \varphi\left(\frac{1}{2} - x\right)^2$$

$$var\big(\pi(x,L)\big) = var\left(xAL + (1-x)CL - PL - \varphi\left(\frac{1}{2} - x\right)^2\right) = L^2[\Pi x^2 + 2\Omega x + \epsilon]$$

Let us define:

$\Theta = E(A) - E(C)$

$\Psi = E(C) - E(P)$

$\Pi = var(A) + var(C) - 2cov(A,C)$

$\Omega = cov(A,C) - var(C) - cov(A,P) + cov(C,P)$

$\epsilon = var(C) + var(P) - 2cov(C,P)$

Where $\Theta, \Psi, \Pi, \Omega$ and ϵ can be calculated from historical data.

Therefore, our objective function becomes

$$\max_{x,L} CE\big(\pi(x,L)\big) = \max_{x,L} L[\Theta x + \Psi] - \varphi\left(\frac{1}{2} - x\right)^2 - \frac{r \cdot L^2[\Pi x^2 + 2\Omega x + \epsilon]}{L[\Theta x + \Psi] - \varphi\left(\frac{1}{2} - x\right)^2}$$

Taking first order conditions of the certainty equivalent function with respect to x and L, we obtain

$$\frac{\partial CE\big(\pi(x,L)\big)}{\partial x} = 0 \Rightarrow$$

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[1] The derivations are attached in the appendix.

$$
\begin{aligned}
&[L\Theta + \varphi \cdot (1-2x)]\left[L[\Theta x + \Psi] - \varphi\left(\frac{1}{2} - x\right)^2\right]^2 - r \\
&\qquad \cdot L^2 \left[[2\Pi x + 2\Omega]\left[L[\Theta x + \Psi] - \varphi\left(\frac{1}{2} - x\right)^2\right] - \big(L\Theta + \varphi \cdot (1-2x)\big) \right. \\
&\qquad \left. \cdot (\Pi x^2 + 2\Omega x + \epsilon) \right] = 0
\end{aligned}
$$

$$
\frac{\partial CE\big(\pi(x,L)\big)}{\partial L} = 0 \Rightarrow
$$

$$
\begin{aligned}
&[\Theta x + \Psi]\left[L[\Theta x + \Psi] - \varphi\left(\frac{1}{2} - x\right)^2\right]^2 \\
&\qquad - [\Pi x^2 + 2\Omega x + \epsilon]\left[2r \cdot L\left[L[\Theta x + \Psi] - \varphi\left(\frac{1}{2} - x\right)^2\right] - r \cdot L^2[\Theta x + \Psi]\right] = 0
\end{aligned}
$$

These two equations can be used as estimating equations. Since these two estimating equations are of implicit and nonlinear form, we use nonlinear least squares to estimate the risk aversion parameter *r* and the economies of scope parameter φ.

Even though we use the approach from Chavas and Di Falco (2012) to decompose risk and economies of scope, it is important to recognize that we have much more limited data than they had. Also, our research questions are somewhat different. They assume that risk management incentive and economies of scope incentive for crop diversification are already there and try to calculate different contributions from both incentives using historical production data. So Chavas and Di Falco (2012) assume that the farmer is risk averse and pick a value from the literature for the risk coefficient. However, our goal is to test whether the two incentives for orchard crop combination exist or not, and they do exist, we want to quantify their influences. Thus, we estimate the risk management incentive, through the risk aversion parameter, and the parameter for economies of scope incentive in land coverage decision from our farm level data.

Another difference to the Chavas and Di Falco (2012) in this research is that we consider different risk sources. They consider risk only from production processes and they estimate a production function. We include information on revenue of each crop which incorporates both yield and price risk.

Data

As discussed previously, instead of aggregate data we use field and individual land-owner level data for apple and cherry orchards in Washington State in 2012. The land-owner data is obtained from Washington State Parcel Land Database, and land cover data is from the Washington State Cropland Data Layer. Land allocation by landowner is measured by spatially joining the land cover data with the land ownership parcel maps in a geographic information system (GIS). There are total 492 observations with orchard size ranging from 1 acre to 1635 acres in our data set.

However, total orchard acreage has an effect on the crop choice decision. Small orchards have fewer resources and limited capacity to manage too many varieties so they tend to focus on fewer crops (Pope and Prescott 1980, Chavas and Aliber 1993). From our data, we can also see this trend. Figures 1 and 2 show the distributions of the crop combinations for orchard sizes of less than and larger than 15 acres respectively. Of the orchards smaller than 15 acres 61.86 per cent of orchards are single crop orchards. On the contrary, single crop orchards account for only 19.92 per cent in orchards larger than 15 acres. Therefore, in order to avoid the influence of small farm size, we eliminate the orchards with orchard size less than 16 acres which leaves us a total of 256 observations. Figure 3 shows the kernel density estimate for the orchard sizes in the 256 observations. Table 1 summarizes our data set.

In order to solve the optimal land allocation problem, data is required to calculate expected revenue and risk for growing apples and cherries, as well as the land leasing option. Revenue per acre of growing apple and cherry as well as land cash rent in Washington State was derived from USDA-NASS data (USDA-NASS 2014)[2]. Since the revenue from a significant distance in the past will have little impact on current cultivation decision, we selected the most recent ten years from 2001 to 2011 as the time window for data. To obtain the real price data, the revenue data is deflated by the producer price index for all commodities. The PPI data was obtained from Federal Reserve Economic Data[3] with 1982 as the base year. The nominal and real revenue per acre are shown in Figures 4 and 5. We use the mean and variance of the deflated data to denote expected revenue and risk of growing apples and cherries in the estimation, which are listed in Tables 2 and 3. From the data, we can see that cherries have higher average returns and higher variance, therefore cherry revenues are more volatile compared to apples.

Estimation

The first step in our analysis is to get a sense of optimal land allocations assuming that risk is the only motivation for diversification. The fact that this ignores production technologies means we can just think of it as a portfolio problem so that we can use a simple Markowitz approach to identify an efficient frontier. Figure 6 shows that if a farmer has three options to use orchard land, apple, cherry and land leasing, they chooses land use to minimize the revenue variance maintaining a desired expected revenue,. Then an efficient crops combination frontier can be obtained. To have higher expected revenue, they assume a higher level of risk. The optimal land use for different levels of desired expected revenue can also be calculated as shown in Table 4.

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[2] See http://www.nass.usda.gov/Statistics_by_State/Washington/Historic_Data/

[3] See http://research.stlouisfed.org/fred2/series/PPIACO

We use nonlinear least squares method to estimate the parameters, φ and r in the two estimating equations derived in section 2.

We first set two residual functions.

$$u_{1,i} = [L_i\Theta + \varphi \cdot (1 - 2x_i)]\left[L_i[\Theta x_i + \Psi] - \varphi\left(\frac{1}{2} - x_i\right)^2\right]^2 - r \cdot L_i{}^2\left[[2\Pi x_i + 2\Omega]\left[L_i[\Theta x_i + \Psi] - \varphi\left(\frac{1}{2} - x_i\right)^2\right] - \big(L_i\Theta + \varphi \cdot (1 - 2x_i)\big) \cdot (\Pi x_i{}^2 + 2\Omega x_i + \epsilon)\right]$$

$$u_{2,i} = [\Theta x_i + \Psi]\left[L_i[\Theta x_i + \Psi] - \varphi\left(\frac{1}{2} - x_i\right)^2\right]^2 - [\Pi x_i{}^2 + 2\Omega x_i + \epsilon]\left[2r \cdot L_i\left[L_i[\Theta x_i + \Psi] - \varphi\left(\frac{1}{2} - x_i\right)^2\right] - r \cdot L_i{}^2[\Theta x_i + \Psi]\right]$$

From the per acre revenue data, we calculate $\Theta = -0.33725, \Psi = 5.222654, \Pi = 1.591106, \Omega = -0.8974, \epsilon = 1.25406$.

The residual vectors and variance covariance matrix are as following

$\boldsymbol{u}_i = \big(u_{1,i}, u_{2,i}\big)'$; $\Sigma = \frac{1}{n}\sum_i(\boldsymbol{u}_i\boldsymbol{u}_i{}')$

Where n is the number of observations in our sample.

Multivariate non-linear least squares solves the equation:

$$\min_{\varphi,r}\sum_i \boldsymbol{u}_i{}'\Sigma\boldsymbol{u}_i$$

Numerical methods are used for solving this nonlinear minimization problem. Convergence criterion is chosen to be 0.000000001.

Results and Discussion

At first, we run our model using the whole 256 observations with orchard size from 16 to 1635 acres. The estimation converges and both parameter estimates are statistically significantly different from zero at 1% level shown in table 5.

As we can see from the estimation results, the parameter of scope economies is positive and more than 200. This implies that economies of scope play an important role when orchard farmers consider allocation of their orchard land among crops in Washington State. This finding is also consistent with the previous literature (Baumol 1977, Weiss and Briglauer 2000, Morrison Paul and Nehring 2005). However, the risk coefficient is negative. Under CRRA preferences, $U(\pi) = \frac{\pi^{1-\alpha}}{1-\alpha}$, relative risk aversion coefficient[4] $\alpha = 2 \cdot r = -3.67$. This implies that on average the apple and cherry farmers in Washington State are revenue risk preferring. They are willing to earn a revenue risk premium by taking a risk to grow more cherries.

Because orchard size plays a role on farmer's risk preference and the effect of economies of scope, we also consider economies of scale in this paper. We do the same estimation for the orchards smaller and larger than 100 acres separately. The estimation results are listed in table 5 too, as we can see, all estimates are significantly different from zero. Hence, both incentives have their own effects on the crops diversification for apple and cherry orchards in Washington State. Interestingly, the absolute values of both parameters are much smaller for small orchards than large orchards. This can be interpreted as economies of scope have less effect on small orchards. Also the willingness to earn a revenue risk premium by taking a risk is smaller for small orchard than large orchard. This makes sense because small orchards tend to have high average cost. Mixing crops for small orchard is not as helpful as large orchard in reducing cost. For the same

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[4] See page 47 of Chavas and Di Falco 2012

reason of scale economies, the capacity of assuming risk declines as orchard size shrinks. Therefore, small orchard farmers is not as willing as large orchard farmers to take a risk and earn a revenue risk premium. This finding is consistent with the previous literature (Pope and Prescott 1980, Chavas and Aliber 1993, Weiss and Briglauer 2000).

Our model can be also used to predict optimal crop combination. Since the effect of economies of scope depends on orchard size, we predict optimal crop combination for orchards smaller and larger than 100 acres respectively using the estimated parameter values of scope economies above. Given the total orchard acreage fixed, the optimal crop combinations are drawn in figure 7 (orchard size less than 100 acres) and figure 8 (orchard size larger than 100 acres) for four different risk preference scenarios. From the figures we can see that as orchard land size grows, the farmer should concentrate on growing more cherries. And, we can also see that as a farmer becomes more risk averse, more acreage should be allocated to apples.

Compared with Markowitz approach, our approach has several advantages in predicting optimal crop combination. Firstly, instead of only minimizing risk, we include the factor of economies of scope in the optimal crop combination decision. Also we count for economies of scale, because scope effect varies as orchard size changes. Secondly, risk preference is subject to vary. Since individual's risk preference is different, our approach can give optimal acreage allocation depending on a particular relative risk aversion coefficient.

Conclusion

To our knowledge, this is the first paper that applies the approach from Chavas and Di Falco (2012) to identify the roles of risk management and economies of scope in orchard crops diversification. Using the field and individual owner level data of apple and cherry orchards in

Washington State, our estimation results show that the two incentives in crop diversification are statistical significant. Economies of scope play an important role in diversifying orchard crops. Instead of risk aversion, surprisingly, the farmers are willing to take a risk to earn a revenue risk premium when they make decisions about their orchard land coverage. We also count for economies of scale in our analysis. From the results, the effect of economies of scope declines as orchard size becomes small. Farmers with small orchard are less willing to take a revenue risk as those with large orchard. We also predict the optimal crop combination for farms with different sizes and risk preferences using our model.

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Appendix

$$E\big(\pi(x,L)\big) = E\left(xAL + (1-x)CL - PL - \varphi\left(\frac{1}{2}-x\right)^2\right)$$

$$= \ xL\cdot E(A) + (1-x)L\cdot E(C) - L\cdot E(P) - \varphi\left(\frac{1}{2}-x\right)^2$$

$$= L\Big[\big(E(A)-E(C)\big)x + E(C) - E(P)\Big] - \varphi\left(\frac{1}{2}-x\right)^2 = L[\Theta x + \Psi] - \varphi\left(\frac{1}{2}-x\right)^2$$

$$var\big(\pi(x,L)\big) = var\left(xAL + (1-x)CL - PL - \varphi\left(\frac{1}{2}-x\right)^2\right)$$

$$= var(xAL + (1-x)CL - PL)$$

$$\begin{aligned}= {} & x^2L^2var(A) + (1-x)^2L^2var(C) - L^2var(P) + 2x(1-x)L^2cov(A,C) - 2xL^2cov(A,P) \\ & - 2(1-x)L^2cov(C,P)\end{aligned}$$

$$\begin{aligned}= {} & L^2[x^2var(A) + var(C) - 2xvar(C) + x^2var(C) - var(P) + 2xcov(A,C) - 2x^2cov(A,C) \\ & - 2xcov(A,P) - 2cov(C,P) + 2xcov(C,P)]\end{aligned}$$

$$\begin{aligned}= {} & L^2\big[[var(A) + var(C) - 2cov(A,C)]x^2 + 2[cov(A,C) - var(C) - cov(A,P) + cov(C,P)]x \\ & + var(C) - var(P) - 2cov(C,P)\big] = L^2[\Pi x^2 + 2\Omega x + \epsilon]\end{aligned}$$

Tables and Figures

Table 1: Data description

	No. of obs	Mean	Standard error	Maximum	Minimum
Total acre	256	89.3789	139.5137	1635	16
Apple share	256	0.6560	0.2942	1	0

Table 2: Mean of acre revenue

	Apple	Cherry	Land cash rent
Mean	5.013546	5.350798	0.128144

Data source: USDA Unit: 1000 dollar/acre

Table 3: Variance covariance matrix of acre revenue

	Apple	Cherry	Land cash rent
Apple	1.052724	0.356988	0.001201
Cherry	0.356988	1.252357	-0.00083
Land cash rent	0.001201	-0.00083	0.000043

Data source: USDA Unit: 1000 dollar/acre

Table 4: Prediction for optimal land use using Markowitz approach

Desired expected revenue	5	5.05	5.1	5.15	5.2	5.25	5.3	5.35
Apple share	51.31%	51.84%	52.37%	52.89%	44.71%	29.89%	15.06%	0.24%
Cherry share	45.29%	45.75%	46.21%	46.68%	55.29%	70.11%	84.94%	99.76%
Land leasing share	3.40%	2.41%	1.42%	0.43%	0.00%	0.00%	0.00%	0.00%

Table 5: Nonlinear least square estimation Results

	Observations	φ	r
Whole sample size	256	223.2685*** (3.5160)	-1.8327*** (0.0072)
Orchard size < 100	189	14.0062*** (2.8993)	-0.5695*** (0.1079)
Orchard size > 100	67	224.3586*** (6.6574)	-1.8328*** (0.01354)

***: Statistically significant at 1% level

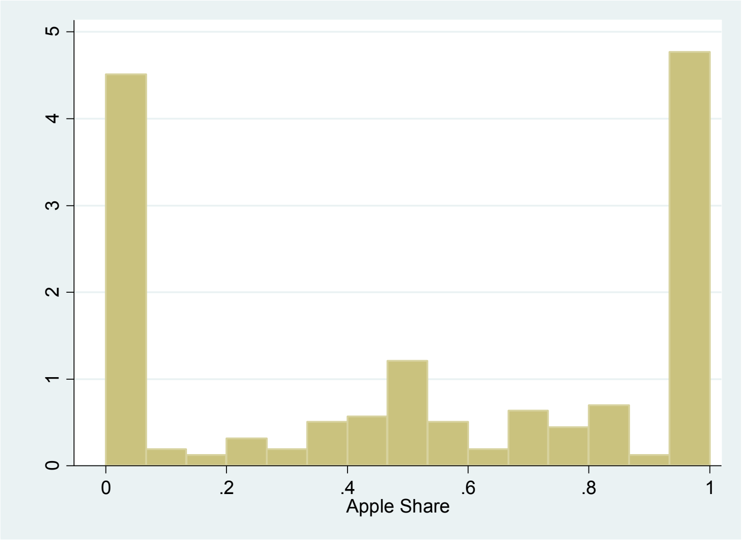

Figure 1: Distribution of crops combination for orchards smaller than 15 acres

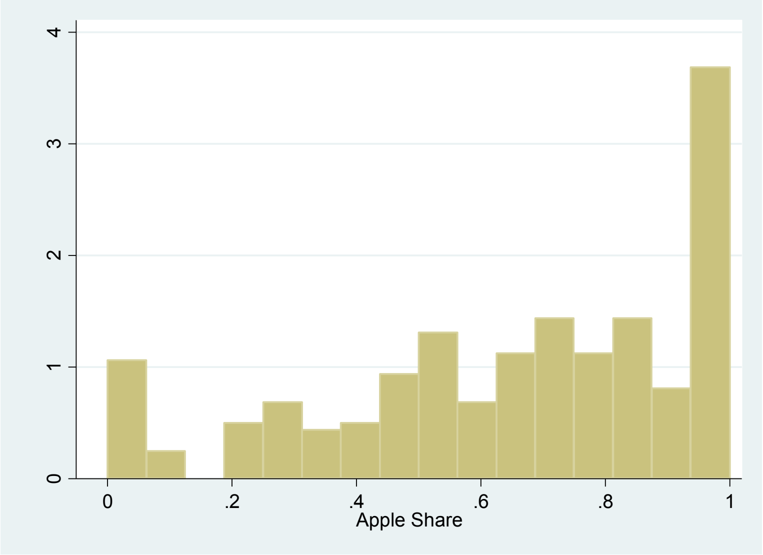

Figure 2: Distribution of crops combination for orchards greater than 15 acres

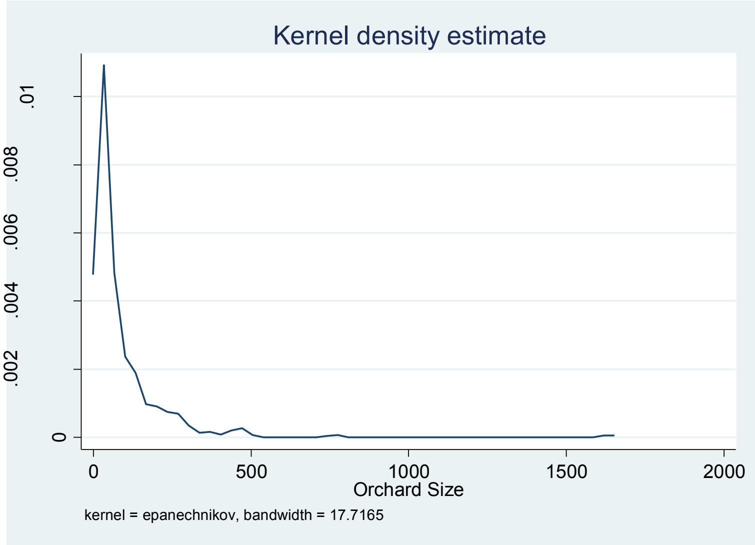

Figure 3: Kernel density estimate for the orchard size data

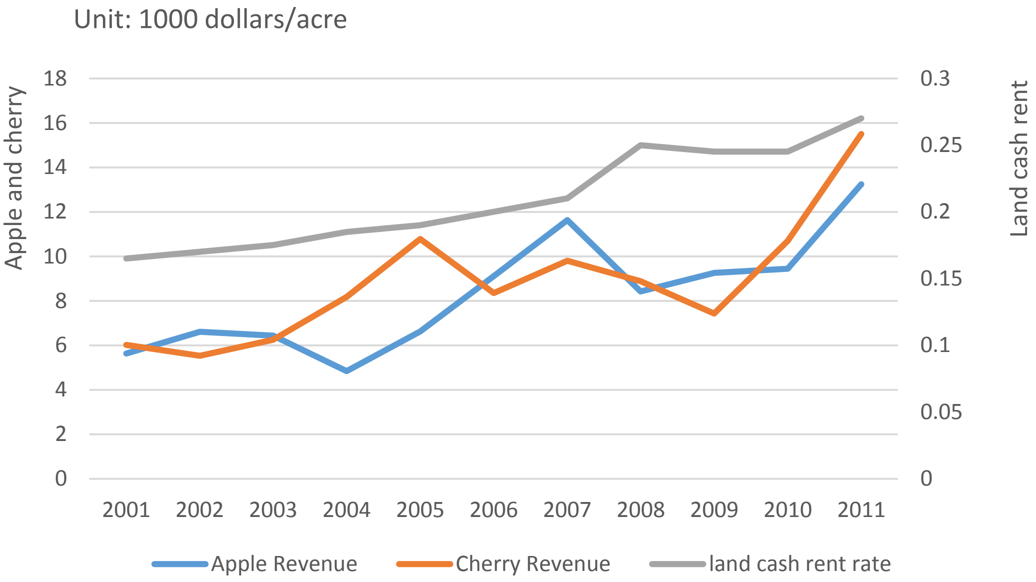

Figure 4: Nomial acre revenue from 2001 to 2011

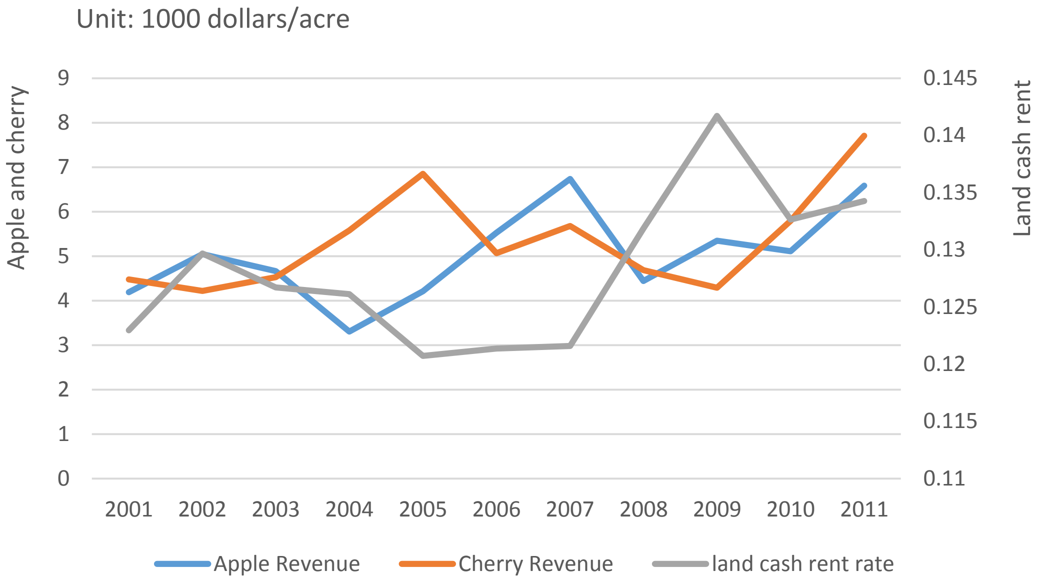

Figure 5: Real acre revenue from 2001 to 2011

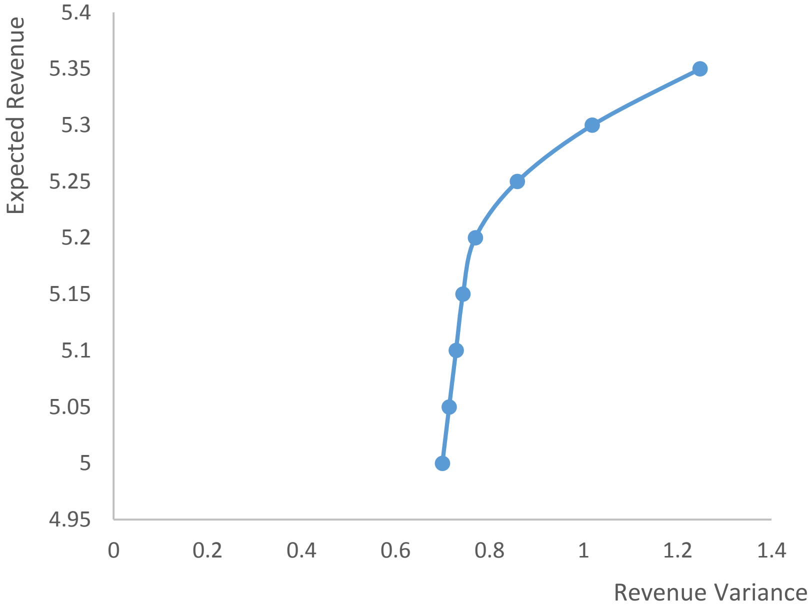

Figure 6: Efficient crops combination frontier

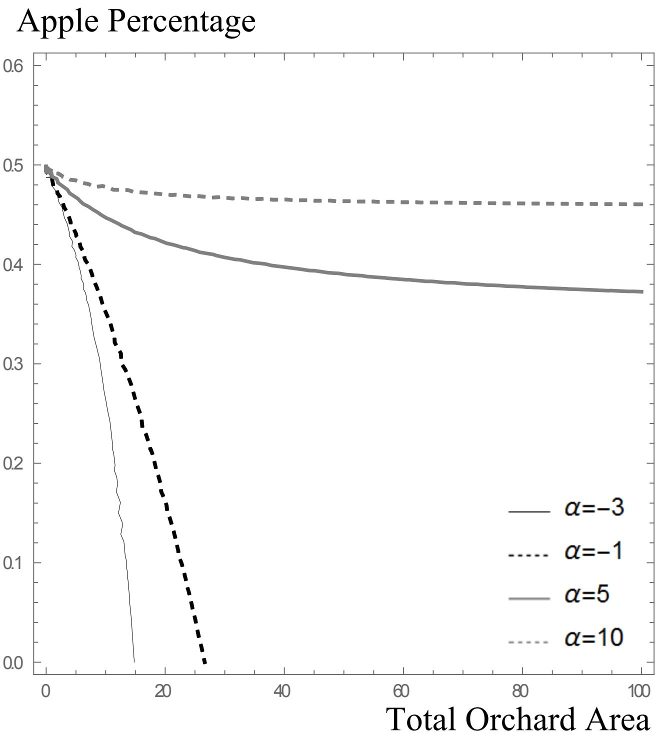

Figure 7: Optimal apple percentage for orchard smaller than 100 acres when relative risk coefficient = -3, -1, 5, 10

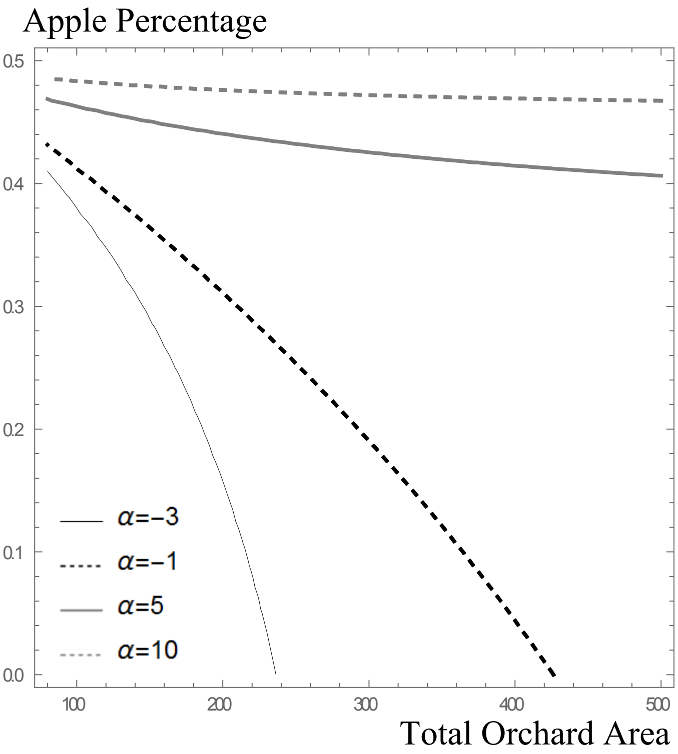

Figure 8: Optimal apple percentage for orchard larger than 100 acres when relative risk coefficient = -3, -1, 5, 10