The Single Index Market Model in Agriculture

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This study illustrates the differences in empirical results due to data measurements and estimating procedures when applying the single index market model in agriculture. Gross and net return betas along with systematic and unsystematic risk proportions are estimated and found to be different. The stochastic coefficients model is used to show the difference in beta-risk estimates compared with the traditional fixed coefficients OLS procedure. A third estimating technique, weighted least squares/Prais Winsten method, is also proposed.

Introduction

Risk management is an important element in the farmer's decision making process given alternative production possibilities with limited resources. Traditionally, risk-return analysis in agriculture has been conducted using risk programming models. Mean-variance (EV) analysis based on Markowitz portfolio decision theory is the traditional framework for most risk-return analysis in agriculture. Quadratic programming (QP) along with linear programming/minimization of total absolute deviation (LP/MOTAD) are the most popular methods in the agricultural economics literature on risk-return analysis. Examples of QP applications include those of Musser and Stamoulis, Barry and Willmann, and Scott and Baker. Examples of LP/MOTAD empirical studies include those of Brink and McCarl, Persaud and Mapp, and Shurley. A comprehensive review of these techniques and their underlying conceptual foundations can be found in Anderson et al. and Barry.

The complexity of mathematical programming and difficulty of application have led to alternative risk-return analysis methods. Borrowing from the financial economics field, Collins and Barry proposed the use of the single index market (SIM) model (Sharpe), a computationally simpler technique in analyzing agricultural risk. They discuss three primary advantages of the SIM model over the traditional risk analysis methods. First, the SIM model beta-risk measure is a more general risk measure than the usual variance and coefficient of variation risk measures since the set of beta-risk measures approximates the full variance-covariance matrix. Second, risk programming methods will likely produce infeasible results when there is a high degree of correlation in the data set causing near-singular variance-covariance matrix. Third, it has also been shown that the SIM model risk measures may provide better representation of future risk measures than the full variance-covariance matrix.

Several studies have used the SIM model in farm management problems. However, no consensus has developed on the proper indicators of individual farm product returns. In addition, these studies differ in estimation techniques with the parameters of the SIM model often estimated by ordinary least squares. This paper aims to illustrate the changes in risk measures when different indicators for farm product returns in agriculture are used and to compare the results of using different approaches in estimating the SIM model. The indicators used are deflated and detrended gross and net returns while the estimating methods employed are ordinary least squares (OLS), weighted least squares/Prais Winsten (WLS-PW), and stochastic coefficients regression method (SCM).

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Past Studies

The beta coefficient of the market model was estimated by Barry to determine risk premiums required to hold farm real estate in a well diversified market portfolio. Regional annual rates of returns on farm real estate and a weighted market index comprised of annual returns on stocks, bonds and farm real estate were regressed using the Cochrane-Orcutt iterative method. Barry reported low beta values which implied that investments in farm real estate contributed minor systematic risk to a well-diversified portfolio. Collins and Barry estimated risk-return measures for California Imperial Valley crops using the SIM model. The beta-risk measures were estimated with OLS using individual crop net returns and the aggregate of all the net returns as the market proxy. Of the twelve crops analyzed, only tomatoes, carrots, and onions had betas greater than 1.0 indicating high systematic risks for these type of products.

Turvey and Driver used the market model to examine systematic and unsystematic risks for Ontario agriculture. Following Johnson's analytical framework for testing the separation theorem, the authors used gross returns rather than net returns in estimating betas for 28 agricultural products. The market index was indicated by the mean gross revenue of the farm sector portfolio. They found that vegetable products had higher systematic risks than grain products, results similar to those found by Collins and Barry. Lopez-Pereira et al. employed the SIM model to study diversification opportunities for hog producers. They used firm-level monthly budgeted rates of return rather than the state or regional level annual rates of return used in other studies. Two of the eight farm products included in the study had betas greater than 1.0 indicating high systematic risks.

Two important observations can be made based on these studies. First, none of these studies offers explicit guidance on what type of data should be used i.e. gross returns or net returns. For example, Turvey and Driver used gross returns by assuming that factor prices and factor mix are deterministic implying that the variability associated with gross returns and net returns are the same. The results of their study indicated that opportunities for diversification are limited due to the large degree of systematic risk within agriculture. Collins and Barry used net returns for their California study and found a large degree of nonsystematic risk.[1]

Second, by using OLS or Cochrane-Orcutt's regression method, these studies implicitly assume that systematic risk is constant through time. Bos and Newbold found strong evidence for rejecting the constant systematic risk against the alternative of stochastic systematic risk. A recent paper by Hutchinson and McKillop strongly argued the possibility that the relative measure of systematic risk is nonstationary over time.

Contrasting the results of past studies is difficult due to significant differences in problem focus, data measurement, and estimating approaches. Turvey and Driver acknowledged that systematic risk measurement differ given different definitions of revenue and portfolio. The goal of this paper is to estimate the magnitude of these differences using alternative data measurements and estimation approaches on the same farm portfolio.

Portfolio Choice

The portfolio choice model involves two performance measures: the expected return and the risk associated with that return. The literature discusses two types of risk. Systematic or nondiversifiable risk is inherent in the portfolio and cannot be eliminated through diversification. Unsystematic or diversifiable risk is not correlated with the market portfolio and can be decreased through further diversification.

The expected return of a portfolio is

$$(1) \qquad E(Rm) = \Sigma\ Wi\ E(Ri),$$

where E(Rm) is the expected return of the portfolio, E(Ri) is the expected return of asset i, Wi is the proportion of portfolio in asset i, and n is the number of assets in the portfolio. Risk in portfolio analysis is usually measured by the variance (or standard deviation) of the portfolio, which is a function of the standard deviation of the individual assets and the correlation among the assets. Portfolio variance is calculated as

$$(2) \qquad \sigma^2_p = \Sigma\ \Sigma\ W_i\ W_j\ P_{ij}\ \sigma i\ \sigma_j$$

where σ^2_p = portfolio variance, P_{ij} = correlation coefficient between assets i and j, and σ_i = standard deviation of asset i. Each asset contained in the market portfolio has both systematic and unsystematic risk while the market portfolio by definition has only systematic risk. The systematic risk of asset i corresponds to how much asset i and the market portfolio are related over time. This relationship can be expressed through the SIM model, which assumes that each asset's return is linearly

[1] Differences between Collins and Barry's results and Turvey and Driver's results could be caused not only by the use of net and gross returns but also by several other factors. First, Collins and Barry used deflated net returns data of a smaller farm portfolio (12 products) while Turvey and Driver used nominal gross returns data of a bigger farm portfolio (28 products). Second, Turvey and Driver measured systematic and unsystematic risks based on standard deviations while Collins and Barry used variances.

related to the market portfolio return (R_p) and random error (e_i).

$$R_i = \beta_0 + \beta_i R_p + e_i. \quad (3)$$

The beta coefficient (β_i) measures the response of asset i to changes in the market portfolio return and is used as the relative measure of asset i's systematic risk. The systematic risk of asset i is computed as $\beta_i\sigma_p$, which is equivalent to $P_{ip}\sigma_i$. Since the market risk (σ_p) is common to all assets, the beta coefficient (β_i) is then used as the relative measure of systematic risk. For example, if β_i is greater than one, changes in the market portfolio return will cause higher fluctuations in asset i's returns and vice-versa. The beta coefficient can also be estimated as

$$\beta_i = P_{ip}\sigma_i\sigma_p / \sigma^2, \quad (4)$$

where P_{ip} is the correlation coefficient for asset i and the market portfolio, and σ_p is the standard deviation of the market portfolio. Following Turvey and Driver, the systematic risk portion can then be computed as $P_{ip}\sigma_i$ while the unsystematic risk portion is derived as $(1 - P_{ip})\sigma_i$.

Model Application

The SIM model discussed in the earlier section was applied to Delaware agriculture. The farm sector market portfolio includes eighteen farm products (four field crops, seven livestock, and seven fruits and vegetables including potatoes) which together comprise 95% of Delaware farm sector's returns. The gross and net returns from these farm products were initially not deflated and detrended. However, for short-run problems, inflation and general increases in productivity are not traditionally considered risks. Thus, the gross and net returns data were deflated by the general inflation index and detrended.[2]

Annual gross and net returns data for 1960–85 were estimated as follows. Gross return is defined as the dollar value of production for each of the eighteen farm activities. Whenever the value of production data were not available, total production was multiplied by the average annual price to obtain the dollar value of production. The value of production data set was collected from the Delaware Agricultural Statistics and from the Delaware Department of Agriculture.

To estimate net returns, production cost data had to be gathered. Cost of production is defined as the cost incurred in growing a crop or raising livestock. Inasmuch as not all cost data were available for Delaware agriculture, data from neighboring states and national estimates were used as proxies. For example, the National Broiler Council provided cost for producing poultry. Cost data for vegetable production were from the Extension Service, Rutgers University (Dhillon and Latimer). Production cost data for fruits were from the Extension Service, Cornell University (Snyder). Cost data for major field crops and other products were from the Extension Service, University of Maryland (Stevens). Net returns data were then estimated by deducting gross returns from the production cost data. The market return was represented by the unweighted aggregate of the individual product returns.

Equation (3) was initially estimated using OLS for the 1960–72 and 1973–85 time periods and the Chow test for parameter stability was conducted on the beta coefficient.[3] The initial OLS regression results showed autocorrelation problems as indicated by the Durbin-Watson values. Another estimation problem not normally recognized in previous SIM studies is the presence of nonconstant error variance or heteroscedasticity. The OLS residuals were plotted against the market return for the eighteen farm products. In general, the graphical plots showed that error variability changes at an increasing rate as the market return changes. In addition, the Goldfeld-Quandt test was used to formally test for the presence of heteroskedasticity. To correct for the nonconstant error variance problem, weighted least squares (WLS) is recommended (Pindyck and Rubinfeld). To solve for both the nonconstant error variance and autocorrelation problems, a second estimating procedure was used which combined the WLS and Prais-Winsten[4] procedures (WLS-PW). Based on the graphical plots, the error variance was assumed as equal to its own variance multiplied by the squared term of the market return variable.

The WLS-PW method was applied by rewriting (3) as

$$(R_i/R_p) = \beta_o^* \, 1/R_p + \beta_i^* \, R_p/R_p + e_i, \quad (5)$$

where β_o^* is the new slope of the equation and β_i^* is the new intercept. The Prais-Winsten procedure

[2] A reviewer noted that inflation and general increases in productivity could raise the systematic risk portion. It was then suggested that the data be deflated and detrended, which was adopted in this study.

[3] See Resler and others for an excellent discussion on why classical tests for structural shifts may be of little value and can be misleading.

[4] A reviewer recommended the use of the Prais-Winsten procedure, which is a generalization of the Cochrane-Orcutt method in correcting for autocorrelation.

was then applied to (5) to correct for autocorrelation. To restate the results back into equation (3)'s context, the estimated results of equation (5) were multiplied through by R_p.

Stochastic Coefficients Model

As argued by Bos and Newbold, the specification of the systematic risk in the single index market model assumes that systematic risk is fixed through time. Numerous studies[5] in the finance literature support the concept that systematic risk should vary through time given changes in the micro and macro environment. Presumably, the same is true in the application of SIM model in agriculture (Hutchinson and McKillop). Following Swamy et al., equation (3) can be respecified as a first order variant of the generalized ARIMA time varying coefficients model originally proposed by Swamy and Tinsley.

$$R_{it} = \beta_{i,t} X_t, \tag{6}$$

$$\beta_{i,t} - \bar{\beta}_i = \Theta (\beta_{i,t-1} - \bar{\beta}_i) + \alpha_{i,t}, \tag{7}$$

where $\beta_{i,t}$ is now assumed to follow a first-order stationary process with its first moment represented by $\bar{\beta}_i$. The variable X_t represents the vector of explanatory variables which in this case is comprised of the unit element for the intercept term and the market return variable (R_p). The error term $\alpha_{i,t}$ is white noise with mean zero and constant covariance matrix. The parameter Θ is the correlation coefficient between adjacent values of $\beta_{i,t}$.[6] A complete discussion of SCM is provided by Swamy and Tinsley.

Recently, SCM has been used extensively in the agricultural economics literature by Conway et al., Leblanc et al., and Conway. SCM was applied to both the net and gross returns data using the SWAMSLEY (Swamy and Tinsley) computer program which is a data-based iterative estimation procedure. Initial estimates of the covariance and correlation matrices are arbitrarily chosen based on the data and through several iterations, efficient and consistent estimates of the parameters are obtained. The mean values of the stochastic coefficients from the iteration with the smallest root mean square error are then selected.

Empirical Results

Six farm products under both the gross and net returns categories exhibited a nonconstant error variance, using the Goldfeld and Quandt test (Table 1). These products were cattle, turkey, chicken, eggs, potatoes, and snap beans for gross returns and grain corn, barley, turkey, chicken, broilers, and sweet corn for net returns. For the autocorrelation problem, twelve products under the gross returns category and eight products under the net returns classification were affected. The gross returns products were soybeans, wheat, barley, cattle, turkey, chicken, dairy, eggs, hogs, sweet corn, tomatoes, and snap beans. The net returns products were grain corn, cattle, chicken, dairy, eggs, hogs, peaches, and sweet corn. The test results showed that five products in the gross returns category and three products in the net returns category were affected by both autocorrelation and heteroscedasticity.

The beta-risk coefficients are presented in Table 2 for both gross and net returns using the three estimating techniques. The results of the Chow test for parameter stability using gross returns showed that twelve products for OLS estimates and ten WLS-PW estimates had unstable parameters for the 1960–85 period. At least fourteen products using OLS and twelve products using WLS-PW for net returns data also had unstable parameter estimates. In these instances, estimates for each subperiod are reported. These results support the argument that systematic risk may not be constant through time.

Mixed results were found in the magnitudes of the relative measure of systematic risk based on the three estimating procedures using gross returns data. As an example, the OLS betas for soybeans were less than 1.0 but both the WLS-PW and SCM betas were greater than 1.0. In contrast, grain corn betas for all three procedures were greater than 1.0. The OLS and WLS-PW betas for broilers were greater than 1.0 during the 1960–72 period but were less than 1.0 during the 1973–85 period. The SCM mean beta for broiler was less than 1.0 indicating relatively stable systematic risk. Some products had similar gross-returns betas for all three methods, and some products had similar net-return betas using the three techniques. Most of the net-return betas, however, were different in magnitude.

Often the betas differed considerably when using gross versus net returns. For example, the soybeans WLS-PW beta using gross returns was 1.715 while the WLS-PW net returns beta was only 0.665. A more extreme example are the betas estimated for barley, which were all positive for the gross returns data and negative for the net returns data. Another

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[5] See Bos and Newbold for references on these studies.

[6] A generalization of the first order autoregressive model in the scalar case is the vector first order autoregressive model in which Θ is a k by k matrix of fixed but unknown coefficients assuming there are k explanatory variables. The interested reader is also referred to the Swamy et al. paper for further discussion of the SCM approach and why it is not appropriate to arbitrarily specify a white noise additive error term to (6).

Table 1. Test Statistics for Heteroscedasticity and Autocorrelation: Delaware Agriculture, 1960–85[1]

	Goldfeld-Quandt Test		Durbin-Watson Test	
Products	Gross	Net	Gross	Net
Field Crops				
Soybeans	1.56*	2.84*	1.24	1.50**
Grain Corn	1.04*	8.25	1.68*	1.21
Wheat	3.04*	2.00*	1.24	2.49*
Barley	1.57*	16.24	1.16	2.32*
Livestock/Poultry				
Cattle	49.80	2.26*	0.92	0.81
Turkey	4.75	3.21	0.96	2.09*
Chicken	40.81	22.78	0.42	0.68
Broilers	1.19*	5.05	1.47*	1.65*
Dairy	1.97*	1.54*	0.72	0.87
Eggs	5.41	2.95*	0.96	0.44
Hogs	1.01*	2.51*	0.72	1.25
Fruits & Vegetables				
Potatoes	3.81	1.38*	2.02*	1.99*
Apples	1.32*	1.10*	1.94*	1.75*
Green Peas	2.88*	1.89*	1.69*	1.75*
Peaches	2.22*	1.19*	1.60*	0.74
Sweet Corn	1.42*	3.64	0.84	0.56
Tomatoes	1.89*	2.26*	1.29	2.11*
Snap Beans	16.15	2.26*	1.08	1.98*

[1]Tests are conducted on deflated and detrended data. Test statistics with one asterisk do not reject the null hypothesis at 5% significance level. Test statistics with two asterisks are in the inconclusive range.

case is dairy, which had a very small WLS-PW gross return beta compared to its corresponding net returns beta. Potatoes, on the other hand, had a WLS-PW beta of 1.328 using gross returns while the net returns beta was only .342. Some products had similar WLS-PW betas for both gross and net returns, including snap beans, sweet corn, eggs, and cattle.

Except for barley, all SCM field crop betas using both gross and net returns were greater than 1.0. With the exception of hogs, however, the SCM betas for livestock and poultry products were generally different when using either gross or net returns. The same is true for the SCM betas for fruits and vegetables. A similar trend can be observed for the OLS results. Some OLS gross and net returns betas were different such as those for barley, turkey, chicken, hogs, apples, and green peas, while others such as broilers, eggs, and potatoes were similar.

Table 3 presents the estimated systematic and unsystematic risk proportions. Eleven of the eighteen products had similar systematic and unsystematic risk proportions regardless of whether gross or net returns were used. However, the other farm products had completely different results. The systematic risk proportion was found to be large for broilers, potatoes, apples, and snap beans when using gross returns and the opposite was found for barley. Eight of the farm products in the portfolio had over 50% systematic risk when using gross returns while only five products had greater than 50% systematic risk when using net returns. Over half of the farm products had larger proportions of systematic risk when using gross returns compared to the net returns systematic risk proportion.

Some General Implications

In view of the increasing popularity of the SIM model in agriculture, it is important to ascertain whether the SIM empirical results are robust enough in terms of data measurement and estimating procedures. This is a significant undertaking if one wants to use the SIM model results in deriving the Sharpe EV frontier (Collins and Barry). Gross and net returns beta coefficients were estimated along with systematic and unsystematic risk proportions for Delaware agriculture. Several important implications were derived from the empirical results.

First, the gross returns betas were generally different from the net returns betas. An extension of this result implies that the Sharpe EV frontier could also be different depending on the data measurement. Thus, one cannot generalize the SIM results when data measurement is not consistent. It could also be argued that the use of gross returns advocate

Table 2. Gross & Net Returns Beta Coefficients Using OLS, WLS-PW and SCM: Delaware Agriculture, 1960–85[1]

	Gross Returns			Net Returns		
Products	OLS	WLS-PW	SCM	OLS	WLS-PW	SCM
Field Crops						
Soybeans	0.149	1.715*	2.091*	1.176	0.665	1.092
	0.700			0.167		
Grain Corn	2.896*	2.609*	2.090*	2.970*	3.492*	1.022
	1.518*	1.689*		−2.076	0.061	
Wheat	−0.203	−0.326	2.144*	0.303	0.809	4.055*
	1.384	1.106		1.442	5.479	
Barley	0.991	0.961*	0.845*	−5.521	−10.167	−9.451
	1.335			−13.401	−21.591	
Livestock/Poultry						
Cattle	−0.534	−0.012	−3.473	0.297	0.251	−0.501
	−0.988	−3.908		−1.114	−2.090	
Turkey	0.887	1.188	1.146	−0.296	−0.421	0.143
				−0.153	−0.139	
Chicken	−0.267	−0.439*	0.368	−2.125*	−2.919*	13.227
	6.048*	4.776		−3.404	−5.954	
Broilers	1.125*	1.118*	0.605*	1.782*	1.259	1.368
	0.901*	0.870*		1.398	1.241*	
Dairy	0.158	0.137	0.323*	2.598*	3.487*	1.548
	−0.265			−0.794	−4.242	
Eggs	0.330*	0.342*	0.377*	0.114	0.158	0.033
				0.493*	0.286	
Hogs	0.516	0.656	1.227	1.837*	1.498*	1.799*
	0.596	0.387				
Fruits & Vegetables						
Potatoes	1.444*	1.328*	2.090*	1.216*	0.342	0.621
Apples	0.731	−0.164	0.964*	0.042	−0.554	0.222
	0.051	−0.114		2.010		
Green Peas	0.636	0.527	0.752	−0.050	−0.359	−0.079
Peaches	−0.112	−0.318	0.366	0.318	0.368	−0.120
Sweet Corn	0.631	0.588	−1.00*	0.674	0.722	1.781*
	1.203	1.381		0.415	1.051	
Tomatoes	−0.226	−0.001	−0.055	−0.589	0.046	−0.603
	1.023	1.048		−0.514	0.445	
Snap Beans	2.335*	1.292	1.451*	0.462	1.200	0.309
		2.717		2.283	1.516	

[1]Mean values for the estimated stochastic parameters are presented for the SCM results. Coefficients with asterisks are significant at 5 percent level. A product with two betas implies that based on the Chow test, equality of parameter estimates for the periods' 1960–72 and 1973–85 was rejected. If the null hypothesis was rejected, two beta estimates corresponding to the two time periods are reported.

Table 3. Systematic and Unsystematic Risk Proportions for Delaware Farm Sector Portfolio, 1960–85

Products	Systematic Risk (percent)		Unsystematic Risk (percent)	
	Gross	Net	Gross	Net
Field Crops				
Soybeans	86.86	65.60	13.14	34.40
Grain Corn	97.42	92.63	2.58	7.37
Wheat	67.43	67.44	32.57	32.56
Barley	42.05	80.48	57.95	19.52
Livestock/Poultry				
Cattle	0.97	1.50	99.03	98.50
Turkey	8.19	0.32	91.81	99.68
Chicken	3.02	1.82	96.98	98.18
Broilers	94.12	22.48	5.88	77.52
Dairy	24.04	0.01	75.96	99.99
Eggs	32.56	2.18	67.44	97.82
Hogs	65.60	75.96	34.40	24.04
Fruits & Vegetables				
Potatoes	86.86	32.56	13.14	67.44
Apples	75.96	10.99	24.04	89.01
Green Peas	13.14	0.04	86.86	99.96
Peaches	0.23	3.02	99.77	96.98
Sweet Corn	0.23	10.99	99.77	89.01
Tomatoes	2.27	0.97	97.73	99.03
Snap Beans	61.83	22.48	38.17	77.52

output maximization vis a vis profit maximization which is consistent with the use of net returns. In addition, the proper measure also depends on the particular decision problem, i.e., gross returns can be used for short-run problems while net returns are considered appropriate for long-run problems.

Second, major differences were found in the systematic and unsystematic risk proportions. Turvey and Driver, who used gross returns, concluded that systematic risks are very high in agriculture. On the other hand, Collins and Barry, using net returns, reported that the unsystematic risks are larger than the systematic risks. This study found that some products had similar risk proportions regardless of the data measurement, while other products had completely different risk proportions. In general, the unsystematic risk proportion was larger when using net returns, which is consistent with Collins and Barry's results.[7]

Third, three estimating procedures were used on both gross and net returns data and different beta coefficients were found. As discussed by Bos and Newbold, a strong argument exists for the beta coefficient to be nonstationary over time. Inasmuch as most of the parameters estimated in this study rejected the null hypothesis of parameter stability, SCM is the most logical technique to use in estimating nonconstant systematic risk. In addition, as discussed by Swamy and Tinsley, SCM allows for more general specifications of the error processes to incorporate the complicated mixture of serially correlated and heteroscedastic error terms. Finally, the results of this study emphasize the importance of using consistent data measurement and estimating procedure if the SIM model results are to be of practical use in agricultural porfolio decisions.

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[7] It is difficult to compare the results of this study using gross returns with those of Turvey and Driver because their gross returns data were not deflated and detrended. This study's data set is more consistent with Collins and Barry's study which used deflated net returns data. To clarify this issue, the systematic and unsystematic risk proportions were reestimated using gross returns data that were not adjusted for inflation and trend. It was found that 13 products had very large systematic risk component with 12 of the 13 products having more than 90% systematic risk proportion. These results are then consistent with those of Turvey and Driver. As discussed earlier, unadjusted data may contain trends that can raise the systematic risk proportion.

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