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Risk and Returns of Diversified Cropping Systems Under Nonnormal, Cross-, and Autocorrelated Commodity Price Structures

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This study analyzes the risks of diversified tropical cropping systems that combine cocoa, plantain, and tree-crop components in different proportions versus traditional monocultures. A technique for modeling the expected values, variances, and covariances of correlated time-series variables that are autocorrelated and nonnormal (right or left skewed and kurtotic) is applied to simulate commodity prices. The importance of using simulated cumulative density functions (cdf's) which reflect the most important characteristics of the stochastic behavior of prices for analyzing risk and returns of diversified agricultural systems is demonstrated. The analysis provides evidence in favor of diversified cocoa-plantain-*Cordia* agroforestry system technologies versus the traditional monocultures.

Key words: agricultural risk analysis, autocorrelation, cross-correlation, diversified tropical cropping systems, multivariate nonnormal simulation

Introduction

Expected profitability and risk are two fundamental criteria for the evaluation of improved agricultural technologies (Mead et al.; Lin, Binns, and Lefkovitch; Marten). For multiperiod investments, the net present value (NPV) or the internal rate of return (IRR) associated with the flow of income and expenses through time can be used as an indicator of profitability. Risk can be assessed by the probability that the NPV or the IRR does not attain a preestablished minimum (Mead et al.), which is the basis for the safety-first criteria (Roy). Alternatively, stochastic dominance analysis (Meyer) can be used if the cumulative distribution functions (cdf's) of the NVP or the IRR are not normal. In both cases, precise estimates of the cdf's are required. Therefore, improved simulation techniques are important for conducting a rigorous risk analysis.

Anderson stresses the importance of modeling correlation, nonnormality, and changing variances around time/space trends/locations. Gallagher advances a univariate procedure to model and simulate random variables using the Gamma distribution. Taylor addresses the problem of multivariate, nonnormal simulation. Moss and Shonkwiler estimate yield distributions with a stochastic trend and nonnormal errors. However, methods that can be used for a truly realistic simulation of future price and yield outcomes in diversified cropping systems remain scarce.

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Yields have been found to be heteroskedastic over time and space, and nonnormally distributed with a tendency toward left-skewness because of widespread pest attack or weather phenomena occasionally causing abnormally low production. Yields of different crops have also been shown to be correlated among each other, even at aggregate levels, presumably because of unfavorable weather conditions affecting several crops simultaneously (Ramirez, Moss, and Boggess). Commodity prices, on the other hand, tend to be autocorrelated through time. Also, yield nonnormality could have implications for the probability distribution of prices during a given time period through the market equilibrium established by supply and demand interactions. Yield left-skewness (sporadic, unusually low yields) could result in price right-skewness (sporadic, unusually high prices), i.e., price upswings that are relatively more extreme than the downswings (Ramirez and Sosa). Because of the market linkages or as a result of macroeconomic cycles or agricultural policies, real commodity prices could also be correlated among each other.

All of the above factors are important when evaluating the risk exposure of diversified farms. Ramirez develops and applies a multivariate model of nonnormal, heteroskedastic, time-trending yields. Ramirez and Somarriba address the complementary issue of modeling and simulating autocorrelated, nonnormal, time-trending variables. Ramirez and Sosa apply the univariate version of Ramirez and Somarriba's procedures to analyze world coffee prices. In this study we use multivariate procedures to analyze the risk and returns of diversified agricultural systems under nonnormal, cross-, and autocorrelated commodity price structures.

The multivariate model accounts for existing price trends, autocorrelation, nonnormality (kurtosis and skewness), and intertemporal correlation between commodity prices. The estimated model is used for simulating cumulative density functions that reflect these characteristics. The simulated cdf's, in conjunction with the safety-first criteria, are used for the risk and return analysis. We demonstrate the importance of using cdf's which reflect the most important characteristics of the stochastic behavior of prices for analyzing risk and returns of diversified agricultural systems.

The Cropping Systems

Cocoa and plantain are important commodities grown throughout tropical Central and South America and in other tropical regions of the world. Diversified, agroforestry system technologies combining cocoa (*Theobroma cacao*), plantain (*Musa* AAB), and a fast-growing tree-crop component (*Cordia alliodora*) have been investigated as an alternative to the chronic instability of international cocoa prices. It is expected that adverse fluctuations in the yield or price of one crop will be compensated by favorable ones in another (Somarriba 1994).

The data for this study come from an on-farm experiment in southeast Costa Rica, where six agroforestry technologies based on assigning different shares of land to cultivate cocoa and plantain with a fixed share of the tree component were evaluated. Seven years of data have been collected. After this interval, cocoa production has just begun to level off. There are five years of stable plantain production data. Because the tree-crop component is not scheduled for harvesting until 2002, wood yields had to be estimated (Ludewigs).

These data limitations make it difficult to draw statistically sound inferences regarding the probability density functions (pdf's) of cocoa and plantain yields in an established agroforestry system, their potential nonnormality, and the correlation between them. Simple mean production levels for each time period must be used, and attention is focused on prices for the risk analysis to test and validate the procedure developed in this study. Input cost and production data were obtained from the experiment, which was established in 1990 on a farm in southwest Costa Rica. According to Holdridge's ecological "zones of life" system, this farm is located in a "tropical humid forest" life zone; it has highly alkaline soils of the Fluvaquentic Eutropept type, imperfect-to-moderate natural drainage, and is subject to an annual average precipitation of about 102 inches.

The experimental design is one block without repetitions, with one 2,500 square meter plot (50 × 50 meters) randomly assigned to each treatment or technology. The technologies incorporate different proportions of cocoa (C) and plantain (P) [1C (1C:1P), 2C (2C:1P), 3C (3C:1P), 2P (2P:1C), and 3P (3P:1C)], with a fixed total density of 1,111 plants per hectare of both crops. A high-density treatment (CP) with 1,111 plants of each crop per hectare is also included. The tree-crop component (*Cordia*) is always kept at a fixed density of 69 trees per hectare.

Secondary data on input cost and production are used for the cocoa (CC) and plantain (PP) monocultures, which are traditional in the region (Calvo and Somarriba; Somarriba 1993; von Platen). Cocoa prices received by farmers are on a fixed relation with international market prices. A local cooperative sells the product at the New York Commodities Exchange prices, and deducts U.S.$0.12/pound of dry cocoa for administrative, transportation, and marketing costs. International cocoa prices for the last 44 years (1954–97) are obtained from the International Monetary Fund (IMF) statistics. They are converted to real (1998) prices using the U.S.$ Consumer Price Index (CPI).

Costa Rica's National Production Council (CNP) maintains a record of weekly plantain prices paid to farmers in the region. However, the CNP only began collecting these data in 1993. The Integrated Agricultural Management Plan (PIMA) has tracked monthly prices at Costa Rica's plantain wholesale market since 1982. This latter series is first adjusted to real Costa Rican colones (¢) per bunch (of approximately 40 plantains) using the monthly CPI published by the Ministry of Economics, Industry, and Commerce, and then to real U.S.$ per bunch using the January 1998 exchange rate of 1U.S.$ = 250¢. A wholesale-to-farmgate adjustment factor of 0.5975 calculated for the 1993–97 period using the two overlapping price series is applied to estimate the plantain prices paid to farmers. The prices for wood from *Cordia alliodora* (*Cordia*) are also subject to local market forces. The wood is normally sold standing, and the buyer assumes the harvesting and transportation costs. Annual average *Cordia* prices paid to farmers in the southeast region of Costa Rica from 1982–97 are obtained from the Costa Rican Forestry Chamber and converted to real U.S.$.

The Model

Ramirez and Sosa estimate a univariate model that can accommodate nonnormality (kurtosis and/or right- or left-skewness) and autocorrelation, by maximizing the following concentrated log-likelihood function:

$$(1) \qquad L_u = -0.5\ln|\Phi| + \sum_{t=1}^{T}\left\{\ln(G_t) - 0.5H_t^2\right\},$$

where

$$G_t = F(\Theta, \mu)/\{\Theta\sigma(1 + R_t^2)^{1/2}\},$$

$$H_t = [\ln\{R_t + (1 + R_t^2)^{1/2}\}/\Theta] - \mu,$$

$$R_t = (F(\Theta, \mu)/\sigma)(Y_t^* - \mathbf{X}_t^*\beta - \sigma), \text{ and}$$

$$F(\Theta, \mu) = \exp(0.5\Theta^2)\{\exp(\Theta\mu) - \exp(-\Theta\mu)\}/2;$$

Y_t^* and $\mathbf{X}_t^*$ are the tth element and row vector of $\mathbf{Y}^* = \mathbf{PY}$ and $\mathbf{X}^* = \mathbf{PX}$, respectively, and $\mathbf{P}$ is a $\{T \times T\}$ transformation matrix such that $(\mathbf{P}'\mathbf{P})^{-1} = \Phi$, used to obtain a $\{T \times 1\}$ nonautocorrelated error-term vector $(\mathbf{Y}^* - \mathbf{X}^*\beta)$.

Equation (1) can be used to estimate a univariate model that accounts for nonnormality and autocorrelation, such as the international coffee price model in Ramirez and Sosa. Ramirez and Somarriba obtain the multivariate form of L_u by applying their proposed "normality transformation" to a set of M "transformed" nonnormal random errors, $\mathbf{Y}_j^* - \mathbf{X}_j^*\beta_j$ ($j = 1, \ldots, M$), where $\mathbf{Y}_j^* = \mathbf{P}_j\mathbf{Y}_j$, $\mathbf{X}_j^* = \mathbf{P}_j\mathbf{X}_j$, and $\mathbf{Y}_j$ and $\mathbf{X}_j$ are the original $\{T \times 1\}$ vectors and matrices of endogenous and exogenous variables, respectively. Two transformations are applied: that of Judge et al. to account for autocorrelation, and that of Ramirez and Somarriba to account for nonnormality. It is assumed that the transformed set of random vectors ($\mathbf{V}_j$) has a multivariate normal distribution with means μ_j ($j = 1, \ldots, M$) and correlation matrix Γ. The nondiagonal elements of Γ (γ_{jk}) account for the correlation between the M variables of interest. The concentrated log-likelihood function is:

$$(2) \qquad LL_m = -0.5\sum_{j=1}^{M}\ln(|\Phi_j|) + \sum_{t=1}^{T}\sum_{j=1}^{M}\left\{\ln(G_{jt}) - 0.5\left[(\mathbf{H}_t\Gamma^{-1}).*\mathbf{H}_t\right]\right\} - 0.5T\ln(|\Gamma|),$$

where Γ is an $\{M \times M\}$ positive semidefinite matrix with unit diagonal elements and nondiagonal elements γ_{jk}; $\Phi_j = (\mathbf{P}_j'\mathbf{P}_j)^{-1}$. If $\mathbf{Y}_j$ (and thus $\mathbf{Y}_j^*$) is not normally distributed, then

$$G_{jt} = F(\Theta_j, \mu_j)/\left(\sigma_j\Theta_j\left[1 + R_{jt}^2\right]^{1/2}\right),$$

where

$$R_{jt} = (F(\Theta_j, \mu_j)/\sigma_j)(Y_{jt}^* - \mathbf{X}_{jt}^*\beta_j + \sigma_j) \text{ and}$$

$$F(\Theta_j, \mu_j) = \exp(0.5\Theta_j)\{\exp(\Theta_j\mu_j) - \exp(-\Theta_j\mu_j)\}/2.$$

If $\mathbf{Y}_j$ is normally distributed, then $G_{jt} = \sigma_j^{-1}$. $\mathbf{H}_t$ is a $\{1 \times M\}$ row vector with elements $H_{jt} = [\ln\{R_{jt} + (1 + R_{jt}^2)^{1/2}\}/\Theta_j] - \mu_j$ ($j = 1, \ldots, M$) if $\mathbf{Y}_j$ is not normally distributed, and $H_{jt} = (Y_{jt}^* - \mathbf{X}_{jt}^*\beta_j)/\sigma_j$ if $\mathbf{Y}_j$ is normally distributed. The operator (.$*$) indicates an element-by-element matrix multiplication. The concentrated multivariate log-likelihood function [equation (2)] links the univariate functions [equation (1)] through the cross-error-term covariance matrix Γ.

When working with time series of different lengths, as in this study, a weighted form of the concentrated log-likelihood function in (2) must be used. This is specified by realizing that the joint pdf is univariate for the first T_{11} observations, bivariate for the second T_{12} observations, and is trivariate only for the last T_{123} observations:

$$(3)\quad LL_{nn} = \sum_{t=1}^{T}\sum_{j=1}^{M}\left\{\ln(G_{jt}) - 0.5\left[(\mathbf{H}_t\Gamma^{-1}).*\mathbf{H}_t\right]\right\} - 0.5T_{11}\ln|\Gamma_1| - 0.5T_{12}\ln|\Gamma_2| - 0.5T_{123}\ln|\Gamma_3| - (T_1/2T)\ln(|\Phi_1|) - (T_2/2T)\ln(|\Phi_2|) - (T_3/2T)\ln(|\Phi_3|),$$

where it is assumed that $M = 3$, T_{11} is the number of observations that are available about one variable only (Y_1), and Γ_1 is a $\{3\times3\}$ identity matrix; T_{12} is the number of observations that are available about two variables only (Y_1 and Y_2), and Γ_2 is a $\{3\times3\}$ matrix with diagonal elements equal to one and a pair of nonzero nondiagonal elements ($\gamma_{21} = \gamma_{12}$) to represent the covariance between those two variables; T_{123} is the number of observations that are available about all of the three variables in the model, and Γ_3 is a $\{3\times3\}$ full covariance matrix as described in (2). T_1, T_2, and T_3 denote the respective number of observations available on each of the three variables Y_1, Y_2, and Y_3. Notice that both G_{jt} and H_{jt} must be zero for the time periods when no observations on the jth variable are available.

The specific form of $\mathbf{P}_j$ and Φ_j must be known to make equation (2) or (3) operational. In the case of first-order autocorrelation, the element on the first row and column of $\mathbf{P}_j$ is $(1 - \rho_j^2)^{1/2}$, where ρ_j is the correlation coefficient between any two consecutive error terms. The remaining elements in the principal diagonal of $\mathbf{P}_j$ are ones. All elements immediately below the principal diagonal are equal to $-\rho_j$, and the remaining elements of $\mathbf{P}_j$ are zero. Further, $|\Phi_j| = |(\mathbf{P}_j'\mathbf{P}_j)^{-1}| = 1/(1 - \rho_j^2)$. Judge et al. also derive $\mathbf{P}_j$ and $|\Phi_j|$ for higher-order autoregressive processes.

In this model, $E[Y_{jt}] = \mathbf{X}_{jt}\beta_j$, i.e., the mean of the jth variable at time t is a linear function of a vector of independent variables ($\mathbf{X}_{jt}$) and a vector of slope coefficients (β_j). The variance of Y_{jt} is determined by σ_j. Two other parameters, θ_j and μ_j, control the degree of kurtosis and skewness of $\mathbf{Y}_j$. If $\Theta_j > 0$, and μ_j approaches 0, the distribution of $\mathbf{Y}_j$ becomes symmetric, but it remains kurtotic. Higher values of Θ_j cause increased kurtosis. If $\Theta_j > 0$, and $\mu_j > 0$, then $\mathbf{Y}_j$ has a kurtotic and right-skewed distribution, while $\mu_j < 0$ results in a kurtotic and left-skewed distribution. Following Ramirez and Somarriba, the parameter estimates for β_j, σ_j, ρ_j, Θ_j, μ_j, and the γ_{jk}'s ($j = 1, 2, 3; jk = 12, 13, 23$) are used to jointly simulate the future cdf's for the commodity prices of interest.

Risk and Return Analysis

The net annual income (NAI) from a given technology depends on two variables whose behavior is assumed known, production and input costs, and on the uncertain output prices. Cocoa, plantain, and *Cordia* prices are modeled, forecasted, and simulated for the years 1998–2009, using the techniques described above. The NAI is specified as:

$$(4)\qquad NAI_{it} = Yc_{it}Pc_t - Cc_{it} + Yp_{it}Pp_t - Cp_{it} + Yco_{it}Pco_t - Cco_{it},$$

where NAI_{it} is the net annual income per hectare from technology i in year t; Yc_{it}, Yp_{it}, and Yco_{it} are cocoa, plantain, and *Cordia* production per hectare for technology i in year t; Pc_t, Pp_t, and Pco_t are real cocoa, plantain, and *Cordia* prices in year t; and Cc_{it}, Cp_{it}, and Cco_{it} are real cocoa, plantain, and *Cordia* production costs per hectare for technology i in year t.

The present value of the net income from technology i (NPV_i) is obtained by adding the present values of the NAI_{it} during the 12 years (t) of analysis. A real discount rate of 6% was used to calculate the present values. Each of 20,000 $\{3 \times 12\}$ (three crop prices, 12 years) matrices of forecasted/simulated prices yields an estimation/simulation of a net annual income value for each technology's NPV_i (i = 3C, 2C, 1C, 2P, 3P, CP, CC, PP). The 20,000 estimated/simulated NPVs for each technology are classified in incremental categories of U.S.$200, starting from their minimum to build the corresponding empirical probability density and distribution functions used for the risk and return analysis.

Risk was evaluated by estimating the probability that the NPV_i did not reach a preestablished minimum given by the annual income necessary for an average rural family to maintain a standard of living above the poverty level. Studies from MIPPE, INRENARE, CATIE, and UICN suggest a per rural family income of U.S.$4,632/year for southern Costa Rica. Also, a typical family farms about four hectares (Dirección de Estadística y Censo; Somarriba 1993) and, in most instances, between 50% and 100% of the family income is derived from farming. Thus, three alternative minimum 12-year NPVs of U.S.$6,948, U.S.$10,422, and U.S.$13,896 per hectare were used for risk analysis, equivalent to U.S.$579, U.S.$868, and U.S.$1,158 per hectare/year.

Price Analysis and Simulation Results

The maximum-likelihood estimation results for the multivariate, nonnormal, autocorrelated, time-trending model of cocoa, plantain, and *Cordia* prices are reported in table 1. In the case of *Cordia*, the estimates for θ_3 and μ_3 are both equal to zero, indicating normality, while a statistically significant estimate of $\rho_3 = 0.386$ points to the presence of autocorrelation. Statistically significant estimates of θ_1 and θ_2, and μ_1 and μ_2, indicate that cocoa and plantain prices are not normal, and their probability density functions are kurtotic and skewed. Cocoa prices also show autocorrelation ($\rho_1 = 0.384$). Notice that none of the covariance parameters are statistically significant in this case. Therefore, a restricted model ($\theta_3 = \mu_3 = \rho_2 = \sigma_{12} = \sigma_{13} = \sigma_{23} = 0$) is estimated (table 1), where all of the parameters are statistically significant at the 1% level.

A likelihood-ratio test (MLRT = $2 \times \{\text{MVFLF1} - \text{MVRLF1}\} = 1.010 \approx \chi^2_6$) does not reject the null hypothesis (H_0: $\theta_3 = \mu_3 = \rho_2 = \sigma_{12} = \sigma_{13} = \sigma_{23} = 0$) at the 10% level, indicating that the restricted model is statistically valid. The slope parameter estimates (β_{11}, β_{12}, and β_{13}) predict that real cocoa and plantain prices decrease at a rate of U.S.$0.013/pound and U.S.$0.013/bunch, while *Cordia* prices increase at a rate of U.S.$3.10/$m^3$ per year.

Table 2 shows the maximum-likelihood estimation results for a multivariate autocorrelated model under the assumption that all prices are normally distributed. As before, ρ_2, σ_{12}, and σ_{23} are not statistically significant; however, σ_{13} is significant at the 5% level. A restricted ($\rho_2 = \sigma_{12} = \sigma_{23}$) normal model is estimated and the likelihood-ratio test (MLRT = $2 \times \{\text{MVFLF2} - \text{MVRLF2}\} = 0.872 \approx \chi^2_3$) does not reject the null hypothesis (H_0: $\rho_2 = \sigma_{12} = \sigma_{23} = 0$) at the 10% level.

Table 1. Maximum-Likelihood Estimation Results for the Multivariate, Non-normal, Autocorrelated, Time-Trending Model of Cocoa (series 1), Plantain (series 2), and *Cordia* (series 3) Prices

	UNRESTRICTED MODEL			RESTRICTED MODEL		
Parameter	Estimate	Std. Error	p-Value	Estimate	Std. Error	p-Value
ρ_1	0.384	0.066	0.0000	0.376	0.055	0.0000
ρ_2	-0.085	0.188	0.3260	—	—	—
ρ_3	0.386	0.130	0.0020	0.397	0.059	0.0000
θ_1	1.132	0.286	0.0000	1.170	0.226	0.0000
μ_1	1.668	0.617	0.0040	1.616	0.327	0.0000
σ_1	0.571	0.139	0.0000	0.572	0.087	0.0000
β_{01}	1.904	0.284	0.0000	1.928	0.201	0.0000
β_{11}	-0.012	0.007	0.0470	-0.013	0.004	0.0020
θ_2	0.705	0.356	0.0260	0.711	0.203	0.0000
μ_2	16.193	3.162	0.0000	16.200	0.109	0.0000
σ_2	0.491	0.168	0.0020	0.498	0.101	0.0000
β_{02}	2.998	0.113	0.0000	2.995	0.087	0.0000
β_{12}	-0.014	0.008	0.0480	-0.013	0.005	0.0050
θ_3	0.000	—	—	—	—	—
μ_3	0.000	—	—	—	—	—
σ_3	16.451	2.046	0.0000	16.380	2.405	0.0000
β_{03}	66.423	3.073	0.0000	64.798	6.962	0.0000
β_{13}	2.975	0.478	0.0000	3.104	0.458	0.0000
σ_{12}	0.031	0.160	0.4240	—	—	—
σ_{13}	-0.052	0.161	0.3740	—	—	—
σ_{23}	0.179	0.211	0.2000	—	—	—
	MVFLF1 = -45.668			MVRLF1 = -46.173		

Notes: Estimation and simulation were conducted using GAUSS 386i; specifically, the OPTMUM procedure was used for maximum-likelihood estimation. In the last row, MVFLF1 and MVRLF1 are the maximum values of the concentrated full and restricted nonnormal likelihood functions, respectively.

The apparent covariance between cocoa and *Cordia* prices when ignoring non-normality is intriguing. There is no reason to expect nonspurious correlation between cocoa and *Cordia* prices, much less a negative correlation. Atlantic-Caribbean weather phenomena could affect both regional cocoa and plantain yields, but are less likely to impact three-crop production systems countrywide, since *Cordia* is mostly grown in plantations or intercropped with coffee in Costa Rica's Central Valley. Further, unlike plantain and *Cordia*, cocoa prices are determined in large international markets, where Costa Rica (or even the entire Caribbean basin) is not a key player.

Since the normal model is nested relative to the nonnormal model, the results from the latter are more reliable, especially considering that a likelihood ratio test (MLRT = $2 \times \{\text{MVFLF1} - \text{MVRLF2}\} = 41.886 \approx \chi_4^2$) strongly rejects ($p = 0.000$) the null hypothesis

Table 2. Maximum-Likelihood Estimation Results for the Multivariate, Autocorrelated, Time-Trending Model of Cocoa (series 1), Plantain (series 2), and *Cordia* (series 3) Prices Under the Assumption of Normality

	UNRESTRICTED MODEL			RESTRICTED MODEL		
Parameter	Estimate	Std. Error	p-Value	Estimate	Std. Error	p-Value
ρ_1	0.493	0.082	0.0000	0.493	0.081	0.0000
ρ_2	0.011	0.178	0.4760	—	—	—
ρ_3	0.310	0.149	0.0200	0.302	0.134	0.0140
β_{01}	2.215	0.317	0.0000	2.215	0.307	0.0000
β_{11}	-0.028	0.012	0.0130	-0.028	0.012	0.0130
σ_1	0.572	0.068	0.0000	0.572	0.067	0.0000
β_{02}	3.091	0.185	0.0000	3.145	0.169	0.0000
β_{12}	-0.026	0.019	0.0940	-0.032	0.018	0.0390
σ_2	0.335	0.059	0.0000	0.337	0.060	0.0000
β_{03}	77.295	11.824	0.0000	77.810	7.974	0.0000
β_{13}	2.207	0.885	0.0080	2.168	0.627	0.0000
σ_3	16.739	2.723	0.0000	16.822	2.069	0.0000
σ_{12}	0.012	0.153	0.4680	—	—	—
σ_{13}	-0.320	0.174	0.0350	-0.326	0.145	0.0140
σ_{23}	0.194	0.211	0.1810	—	—	—
	MVFLF2 = -66.611			MVRLF2 = -67.047		

Notes: Estimation and simulation were conducted using GAUSS 386i; specifically, the OPTMUM procedure was used for maximum-likelihood estimation. In the last row, MVFLF2 and MVRLF2 are the maximum values of the concentrated full and restricted normal likelihood functions, respectively.

of normality for cocoa and plantain prices. Figure 1 shows the observed and expected cocoa prices according to the normal and nonnormal models. The recurring presence of consecutive observations above and below the trend line is typically a sign of positive autocorrelation. The autocorrelated forecast lasts until the year 2002, when the residual effect of the last price cycle wears off; then, the predictions merge with the expected long-term price trend. Of particular interest for the risk and return analysis is the strong recovery in cocoa international prices predicted by the nonnormal model after a long period of underperformance. The normal model forecasts a weaker recovery.

The nonnormal model predicts that cocoa and plantain prices will decrease at a considerably slower pace, while it forecasts that *Cordia* prices will increase faster. McDonald and White demonstrate that accounting for nonnormality can increase the precision with which slope parameters are estimated. The nonnormal model yields much more accurate estimates of the cocoa and plantain price trends, since the standard errors for the slope parameter estimates are 300% and 360% lower than under normality. The multivariate nonnormal model also yields a modestly (37%) lower slope-coefficient standard error for the normally behaved *Cordia* prices.

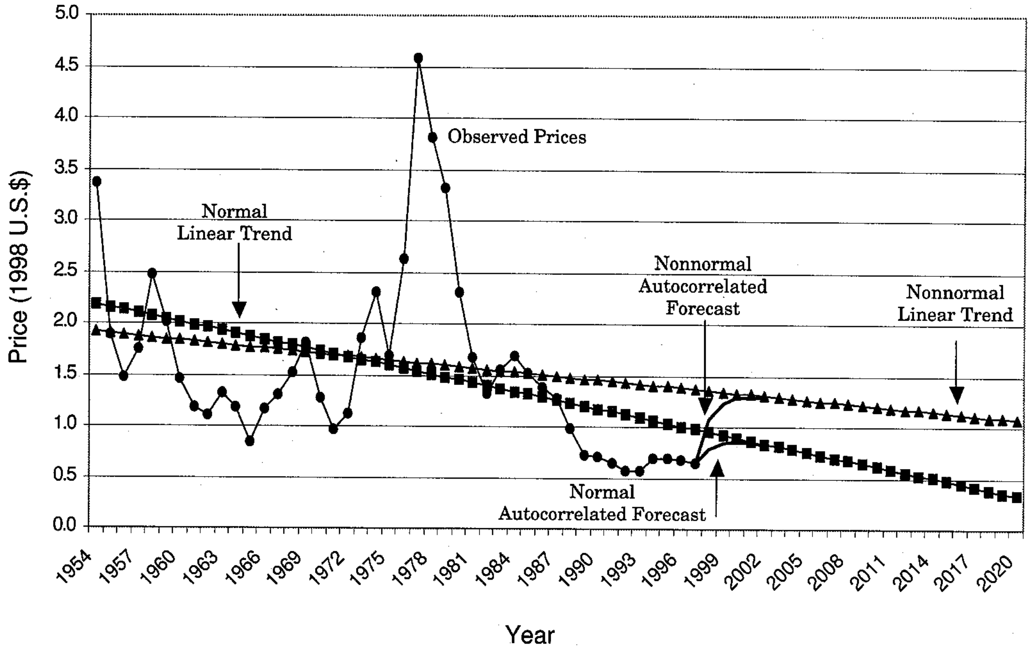

Figure 1. Observed and expected cocoa prices

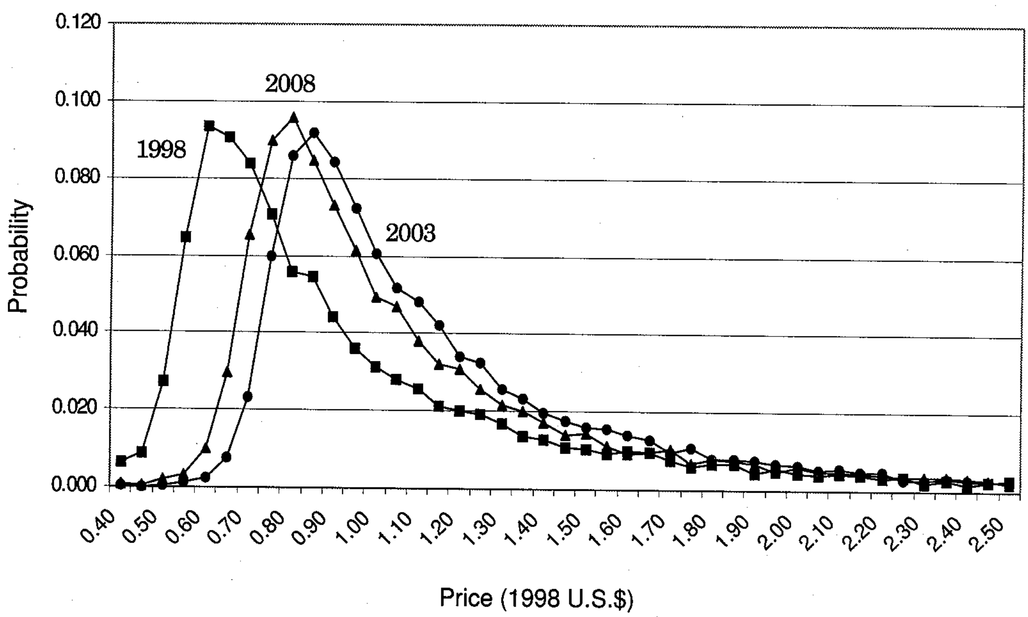

Figure 2. Simulated probability density functions for 1998, 2003, and 2008 cocoa prices

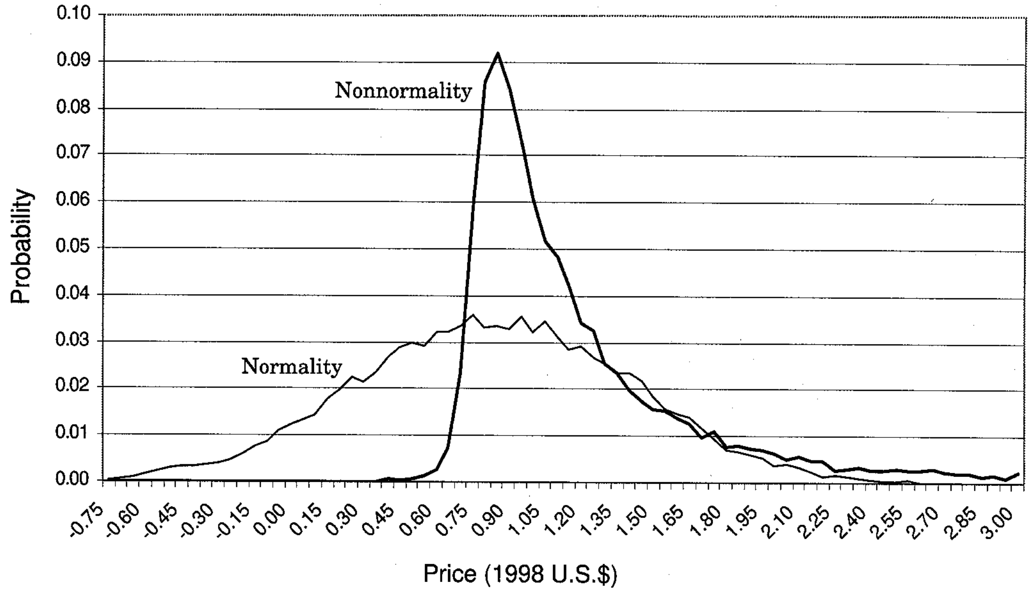

Figure 3. Simulated pdf's for 2003 cocoa prices under normality and nonnormality

Figure 2 shows the probability density functions of 1998, 2003, and 2008 cocoa prices forecasted/simulated using the technique described above, and the parameter estimates for the restricted nonnormal model (table 1). Ramirez finds that aggregate crop yields tend to be left-skewed. The inverse relation between supply shifts and the market equilibrium price would suggest that the pdf's of commodity prices could be right-skewed. The probability distribution of cocoa prices is indeed extremely skewed to the right. Prices of U.S.\$2/pound in excess of the median of U.S.\$0.80 are still probable in 1998, while prices of U.S.\$0.40 below it are highly unlikely. The plantain pdf's are also skewed to the right, although less severely, while the simulated *Cordia* price distributions appear to be normal.

The differences between the *Cordia* and the cocoa and plantain price analysis results could be related to the fact that the latter are annual crops and their supply is more susceptible to weather phenomena and pest attack. Sudden supply shortages may cause extreme temporary price hikes, but comparably large excesses in supply and the resulting sharp downward price swings are less likely. In contrast, *Cordia* is a tree crop less susceptible to widespread weather phenomena and pest attack. In addition, it can be harvested between 8 and 15 years after planting, a decision often affected by price. The former conditions favor a more stable supply and prices during any given year. In figure 2 also notice that, because of the model's design, the shapes of the pdf's do not change over time, except for their location which shifts according to the autocorrelated forecasts of the expected prices (figure 1). The cocoa pdf, for example, shifts to the right from 1998 to 2003, and back to the left in 2008 (figure 2).

Figure 3 illustrates a key aspect that will influence the risk and return analysis. Under the assumption of normality, the extreme cocoa price upswings in past years have to be accounted for through the variance only. Therefore, almost 20% of the mass of the simulated pdf for 2003, for example, is located below zero. This is completely unrealistic considering that real cocoa prices have never been below U.S.$0.57/pound. The nonnormal pdf is able to account for the upward variability through a combination of extreme kurtosis and right-skewness, and exhibits a shape that is more consistent with the data. A similar, although less extreme, phenomenon is observed in the case of plantain prices.

Results of Risk and Return Analysis

Figures 4 and 5 show the simulated cumulative density functions (cdf's) for the present value of the net income from the six agroforestry system and three monoculture technologies under analysis, based on autocorrelated nonnormal and normal commodity price models, respectively. Table 3 summarizes their means, variances, skewness, and kurtosis coefficients, and table 4 presents the levels of risk calculated according to the definition given above. Notice the impact of the severe right-skewness of cocoa prices on the cdf's of the net present values of the technologies with a higher proportion of this crop (figure 4).

In the case of 3C, for example, 50% of the NPVs are expected to be below and 50% above U.S.$15,000; however, NPVs of less than U.S.$11,500 are highly unlikely, while there is a 10% probability of obtaining an NPV greater than U.S.$21,000. In contrast, 3P has a very similar minimum likely NPV, a median NPV of U.S.$13,200, but a maximum of only U.S.$19,000.

Under the more realistic nonnormal price models, the agroforestry systems with a higher proportion of cocoa (3C, 2C, and 1C) are the least risky regardless of the minimum income level required (figure 4), and they render the highest mean NPVs (table 3). Their variances, however, are also very high. A standard mean-variance analysis may favor the plantain-intensive systems (2P or 3P), which yield slightly lower mean NPVs, but variances that are three to five times smaller. Because of the nonnormality, however, larger variances do not imply higher risk in this case; they are mostly due to the extended upper tails of the cdf's.

In general, the monocultures and the high-density cocoa-plantain system (CP) fare poorly in the nonnormal analysis. They show substantially lower mean NPVs and significantly higher risk levels than any of the agroforestry systems, regardless of the minimum income level required (tables 3 and 4). That is not the case when nonnormality is ignored. When only 50% of the minimum income required has to come from farming, PP seems less risky than 3C, 2C, and 1C and, in general, the plantain-intensive systems (2P and 3P) appear superior. If the analysis were based on the normal price models, the 3P technology would be recommended because of its higher expected NPV and lower risk levels (tables 3 and 4; figure 5).

A key difference between the normal and nonnormal analyses is the more pronounced descent in cocoa and plantain prices and the slower increments in *Cordia* prices predicted by the normal price model. By 2010, the last year of the evaluation, expected cocoa prices are 50% lower than those predicted by the nonnormal model, while plantain prices are 15% lower and *Cordia* prices 13% higher. Under the assumption of normality, the cocoa-intensive systems' risk and return performance worsens because of the relatively lower expected cocoa prices predicted. In addition, a risk analysis based on the normal price model penalizes cocoa in this case, because of its more left-skewed price distribution. The distortion on the price pdf's (illustrated in figure 3), due to the extreme upward variability of cocoa prices that cannot be properly modeled under normality, translates into NPV cdf's that extend too far to the left (figure 5 versus figure 4).

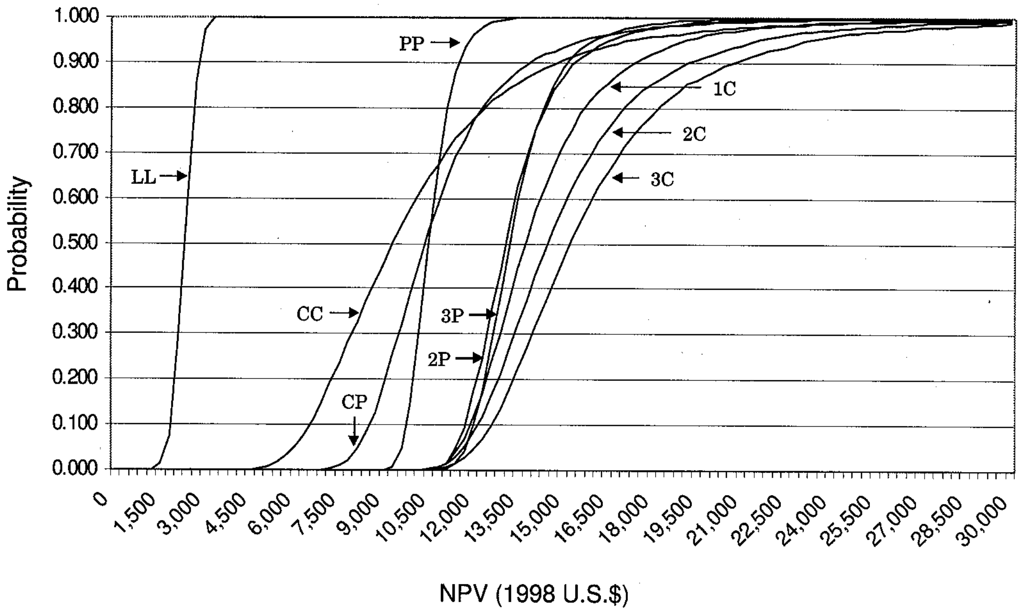

Figure 4. Simulated cdf's for the NPVs of nine technologies based on autocorrelated, nonnormal price models

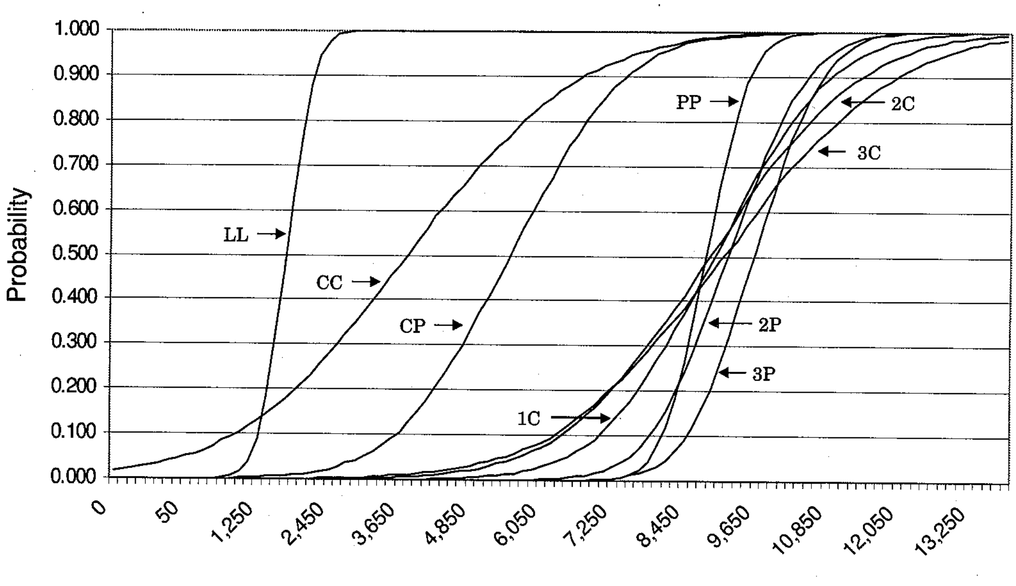

Figure 5. Simulated cdf's for the NPVs of nine technologies based on autocorrelated but normal price models

Table 3. Means, Variances, Skewness, and Kurtosis Coefficients of the Simulated NPVs for the Six Agroforestry System and Three Monoculture Technologies: Autocorrelated Nonnormal and Normal Commodity Price Models

	NONNORMAL MODELS				NORMAL MODELS	
Technology[a]	Mean	Variance	Skewness Coefficient	Kurtosis Coefficient	Mean	Variance
CC	10,195.12	15,987.85	2.37	9.75	3,945.06	5,279.19
PP	10,574.11	483.29	0.84	1.28	8,968.21	329.86
LL	2,306.47	128.08	0.00	-0.10	1,877.06	131.80
1C	14,354.53	7,080.48	2.50	11.57	9,099.90	2,343.95
2C	15,293.99	11,896.56	2.52	11.60	9,023.30	3,905.68
3C	16,176.93	15,527.29	2.54	11.79	9,246.12	5,097.67
2P	13,416.94	3,042.76	2.25	9.86	9,334.64	1,072.49
3P	13,479.11	2,098.63	2.02	8.36	9,774.70	794.16
CP	10,932.10	6,803.93	2.47	11.52	5,656.34	2,299.78

Notes: Variance = variance/1,000. Skewness and kurtosis coefficients are not shown for the normal models; they are between -0.05 and 0.05 in all cases.

[a] CC, PP, and LL represent the traditional cocoa, plantain, and *Cordia* (laurel) monocultures; 1C = 1C:1P, 2C = 2C:1P, 3C = 3C:1P, 2P = 2P:1C, 3P = 3P:1C, where 1C:1P implies one cocoa plant for each one plantain plant, 2C:1P denotes two cocoa plants for each one plantain plant, etc., with a fixed total density of 1,111 plants/hectare of both crops. CP is a high-density treatment with 1,111 plants of each crop per hectare. The tree-crop component (*Cordia*) is always kept at a fixed density of 69 trees/hectare.

Table 4. Levels of Risk for the Six Agroforestry System and Three Monoculture Technologies: Autocorrelated Nonnormal and Normal Commodity Price Models

	NONNORMAL MODELS			NORMAL MODELS		
Technology[a]	Risk1	Risk2	Risk3	Risk1	Risk2	Risk3
CC	0.147	0.616	0.867	0.914	0.999	1.000
PP	0.000	0.329	0.999	0.001	0.993	1.000
LL	1.000	1.000	1.000	1.000	1.000	1.000
1C	0.000	0.000	0.508	0.090	0.800	1.000
2C	0.000	0.001	0.374	0.163	0.756	0.995
3C	0.000	0.000	0.268	0.168	0.701	0.984
2P	0.000	0.000	0.696	0.017	0.848	1.000
3P	0.000	0.000	0.686	0.002	0.761	1.000
CP	0.001	0.463	0.898	0.829	1.000	1.000

Notes: Risk1, Risk2, and Risk3 require that 50%, 75%, and 100%, respectively, of the previously established minimum family income level is obtained from farming.

[a] For definitions of technologies, refer to table 3, footnote a.

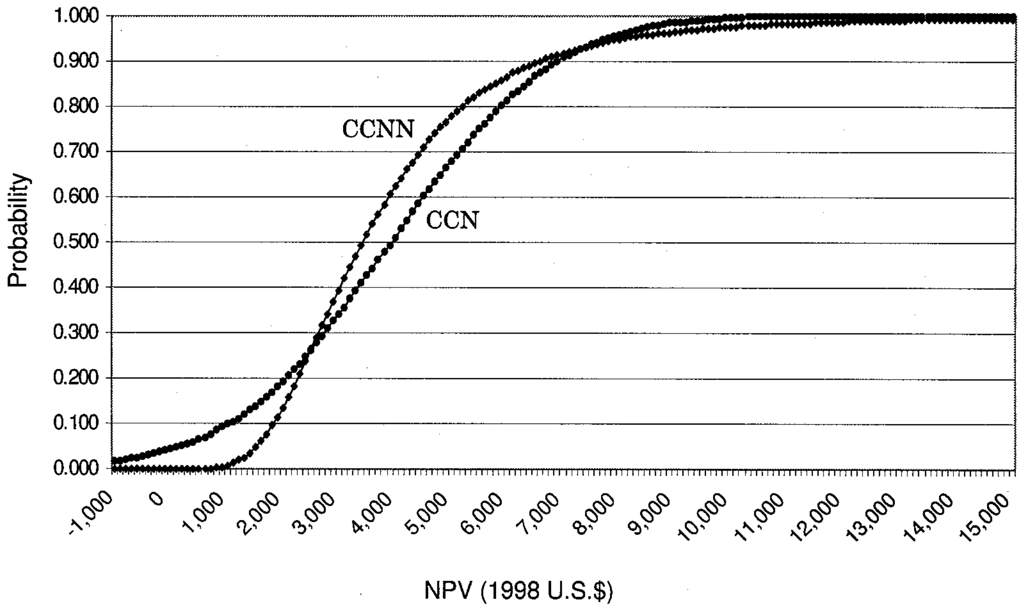

Figure 6. Shifted cdf's for the NPVs of cocoa monocultures under normality (CCN) and nonnormality (CCNN)

To further explore this effect, the NPV cdf for the cocoa monoculture under nonnormality is shifted so that it has the same mean and variance as the cdf under normality (figure 6). The normal cdf, having to be symmetric about its mean and median, tends to overestimate risk levels at the lower end in this case. Under nonnormality, two economic variables may have the same mean and variance, but exhibit different risk profiles. An NPV with a lower mean and a higher variance cannot be automatically ruled out. The first and second central moments are no longer sufficient indicators of risk, and more detailed analyses based on precise estimates of the corresponding cdf's, such as the one conducted in this study, become necessary.

A comparison of the expected net annual benefits with the minimum income requirement of U.S.$579–$1,158 per hectare/year indicates that CC, CP, and LL are not feasible unless the farmer has an external source of income to support his/her household for extended periods of time. The remaining technologies are feasible according to this criterion; they drop below the annual income threshold during some years, but it is estimated that savings from previous years are enough to compensate for the deficits. In regard to risk as defined in this study, all technologies except LL are feasible if only 50% of the minimum required income (MRI) must come from farming, and 3C, 2C, 1C, 2P, and 3P still exhibit very low risk levels when 75% of the MRI must come from farming. However, only 3C presents a barely acceptable risk profile under the more strict condition that farming is the only source of income (table 4). Risk levels as defined in this study will vary depending on the MRI and the farm size, but can be recalculated using figure 4.

Conclusions and Recommendations

This study applies a recently developed technique that can model and simulate the expected values, variances, and covariances of sets of correlated time-series variables which are autocorrelated and nonnormal (right or left skewed and kurtotic). It demonstrates the importance of taking into account both autocorrelation and nonnormality in applied risk and return analysis.

A detailed analysis of net income flows, their present values, and related risk measures provides evidence in favor of diversified cocoa-plantain-*Cordia* agroforestry system technologies versus the traditional monocultures. Systems with a higher proportion of cocoa to plantain are favored during 1998–2010, but this is influenced by the model's prediction of a strong rebound in cocoa prices. As future price cycles develop, a more balanced system could perform better.

The forecasted long-term decreasing trend for both cocoa and plantain prices is worrisome, especially considering the high levels of risk associated with all technologies during the 1998–2010 period. However, these high risk levels are closely related to the assumption of an average farm size of four hectares. Clearly, in the long run, farms of that size will not be able to remain solvent unless significant technological change takes place. The upward long-term trend in the price of the wood from the tree component (*Cordia*) is another argument in favor of the agroforestry systems versus the traditional cocoa or plantain monocultures.

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