JOINT MODELING AND SIMULATION OF AUTOCORRELATED NON-NORMAL TIME SERIES: AN APPLICATION TO RISK AND RETURN ANALYSIS[1]

by

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Improved simulation techniques are important for conducting a more rigorous risk analysis (Ramirez 1994). However, methods that can be used for a truly realistic simulation of future price and yield outcomes in diversified cropping systems are scarce. Ramirez (1997) develops and applies a multivariate model of non-normal, heteroskedastic, time-trending yields. This study develops a complementary model that can account for autocorrelation, non-normality (kurtosis and skewness), the variance, and the changing expected values of sets of time-series random variables, such as commodity prices, as well as for the correlation among those variables.

The technique is flexible and accurate since it includes one or more parameters to control each of those statistical attributes, and efficient because it estimates all of the parameters jointly, in a multivariate setup. It can be used for simulating probability density functions (pdf's) and cdf's that precisely reflect those characteristics. The technique is applied it to analyze the risk and returns of a diversified tropical agroforestry system using the safety-first criteria.

Agroforestry System Data

Cocoa and plantain are important commodities grown in Central and South America and in other tropical regions of the world. Agroforestry technologies including 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 could 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. Simple mean production levels for each time-period have to be used because of data limitations, and the attention is focused on prices for the risk analysis to test and validate the procedure developed in this study.

The technologies incorporate different proportions of cocoa (C) and plantain (P) (1C (1C:1P), 2C (2C:1P), 3C (3C:1P), 2P (2P:1C) y 3P (3P:1C)) with a fixed total density of 1111 plants per hectare of both crops. A high-density treatment with 1111 plants of each crop per hectare (CP) is also included. The tree-crop component 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. Cocoa, plantain and *Cordia* prices received by farmers are obtained from reliable secondary sources (International Monetary Fund (IMF), Costa Rica's National Production Council and the Costa Rican Forestry Chamber) and transformed to real 1997 U.S. dollars using the Consumer Price Index (CPI) reported by the IMF.

The Model

Ramirez (1997) results can be used to formulate a multivariate model of autocorrelated time-series dependent variables that are non-normally distributed and correlated among each other. Following Judge et al. (1985), let $\mathbf{\Phi_j} = \sigma_j^2\boldsymbol{\psi}_\mathbf{j}$ be the covariance matrix of the error term. Let $\mathbf{P_j}$ be an n×n matrix such as $\mathbf{P_j}'\mathbf{P_j} = \boldsymbol{\psi}_\mathbf{j}^{-1}$, $\mathbf{Y_j^* = P_jY_j}$ (an n×1 vector) and $\mathbf{X_j^* = P_jX_j}$ (an n×k matrix), where $\mathbf{Y_j}$ and $\mathbf{X_j}$ are the vector and matrix of original dependent and independent variables. Because of the choice of $\mathbf{P_j}$, the transformed regression error-term $\mathbf{P_j(Y_j - X_j}\boldsymbol{\beta}_\mathbf{j})$ = $(\mathbf{P_jY_j - P_jX_j}\boldsymbol{\beta}_\mathbf{j}) = (\mathbf{Y_j^* - X_j^*B_j})$ is iid. The concentrated log-likelihood function is:

(1) $\quad NLL_j = \{ -(n/2)\ln(\sigma_j^2) - (1/2)\ln|\boldsymbol{\psi}_\mathbf{j}| - \{(\mathbf{Y_j^* - X_j^*}\boldsymbol{\beta}_\mathbf{j})'(\mathbf{Y_j^* - X_j^*}\boldsymbol{\beta}_\mathbf{j})/2\sigma_j^2 \}$

Equation (1) can be used to specify a variety of autocorrelated models depending on the choice of $\mathbf{P_j}$ (Judge et al., 1985). A single equation model that can accommodate non-normality (kurtosis and/or right or left skewness) and autocorrelation can be obtained by applying the transformation in Ramirez (1997) to $\mathbf{Y_j*}$, given $\mathbf{X_j*}$. When the dependent variable vector $\mathbf{Y_j}$, and therefore the error-term vector ($\mathbf{Y_j}$–$\mathbf{X_j\beta_j}$), is autocorrelated, a first transformation $\mathbf{P_jY_j=Y_j*}$ and $\mathbf{P_jX_j=X_j*}$ is used to obtain a non autocorrelated error-term ($\mathbf{Y_j*-X_j*\beta_j}$). This is then transformed to a normal error-term vector $\mathbf{V_j}$ through Ramirez (1997) transformation. The concentrated log-likelihood function for the j^{th} single equation model is:

$$(2) \qquad NNLL_j = -0.5\times\ln|\boldsymbol{\psi_j}| + \sum_{i=1}^{n} \ln(G_{ji}) - \sum_{i=1}^{n} 0.5\times H_{ji}^2 \}; \text{ where:}$$

$$G_{ji}=F(\Theta_j,\mu_j)/\{\sigma_j(1+R_{ji}^2)^{1/2})\}; \qquad H_{ji}=\Theta_j^{-1}\mathrm{Ln}\{R_{ji}+(1+R_{ji}^2)^{1/2}\}-\mu_j;$$

$$R_{ji}=((\Theta_jF(\Theta_j,\mu_j)/\sigma_j)(Y_{ji}*-\mathbf{X_{ji}*\beta_j}-\sigma_j/\Theta_j); \qquad F(\Theta,\mu)=\{e(0.5\Theta^2)\}\{e(\Theta\mu)-e(-\Theta\mu)\}/2;$$

and i=1,…,n refers to the observations. The first term in equation (2) is the natural logarithm of the Jacobian of the first transformation and the second term is the natural logarithm of the Jacobian of the second transformation. H_{ji} is the inverse of Ramirez (1997) transformation to normality. The multivariate form of equation (2) results from applying Ramirez (1997) transformation to a set of m "transformed" n×1 non-normal random errors, $\mathbf{Y_j*-X_j*\beta_j}$ (j=1,...,m), where $\mathbf{Y_j}=\mathbf{P_jY_j}$, $\mathbf{X_j*}=\mathbf{P_jX_j}$. It is assumed that the transformed set of random vectors $\mathbf{V_j}$ has a multivariate normal distribution with means μ_j (j=1,...,m) and covariance matrix $\boldsymbol{\Sigma}$. The non-diagonal elements of $\boldsymbol{\Sigma}$ (σ_{kl}) account for the covariance between the M variables of interest. The concentrated multivariate log-likelihood function is:

$$(3) \qquad MNNLL = \{ -(n/2)\times\ln|\boldsymbol{\Sigma}| - 0.5\times\sum_{j=1}^{m}[\ln(|\boldsymbol{\psi_j}|)] + \sum_{i=1}^{n}\sum_{j=1}^{m}[\ln(G_{ji})] - 0.5\times\sum_{i=1}^{n}\sum_{j=1}^{m}[\{\mathbf{H_i}*(\boldsymbol{\Sigma}^{-1})\}.*\mathbf{H_i}] \}$$

where $\boldsymbol{\Sigma}$ is an M×M positive semi-definite matrix with unit diagonal elements and non-diagonal elements σ_{jk}; G_{ji} is as defined in equation (2) if $\mathbf{Y_j}$ (and thus $\mathbf{Y_j*}$) is not normally distributed or $G_{ji}=\sigma_j^{-1}$ if $\mathbf{Y_j}$ is normally distributed; and $\mathbf{H_i}$ is a 1xm row vector with elements H_{ji} (j=1,...,m) also defined in equation (2) if $\mathbf{Y_j}$ is not normally distributed and $H_{ji}=(Y_{ji}*-X_{ji}*\boldsymbol{\beta_j})/\sigma_j$ if $\mathbf{Y_j}$ is normally distributed. The operator * indicates a matrix multiplication; and .* indicates an element by element matrix multiplication. The concentrated multivariate log-likelihood function (equation (3)) links the univariate functions (equation (2)) through the cross-error-term covariance matrix $\boldsymbol{\Sigma}$. A weighted form of the concentrated log-likelihood function given in equation (3) has to be used when working with time-series data sets of different lengths (Ramirez, 1999).

If the error term of the j^{th} equation ($\mathbf{Y_j}-\mathbf{X_j}\boldsymbol{\beta_j}$) is believed to be autocorrelated, $\mathbf{P_j}$ and $\boldsymbol{\psi_j}$ must be specified to make equation (3) or (4) operational. Judge et al. (1985) derives $\mathbf{P_j}$ and $|\boldsymbol{\psi_j}|$ for the first-order autoregressive processes assumed in this study and for higher-order autoregressive processes. It can be shown that in the proposed model:

(5) $$E[\mathbf{Y_j}] = E[\mathbf{P_j^{-1}Y_j*}] = \mathbf{P_j^{-1}}E\left[\,[\{\sigma_j/\Theta_j F(\Theta_j,\mu_j)\}\sinh(\Theta_j\mathbf{V_j})]+\mathbf{X_j*}\boldsymbol{\beta_j}-\sigma_j/\Theta_j\right] = \mathbf{P_j^{-1}X_j*}\boldsymbol{\beta_j} = \mathbf{X_j}\boldsymbol{\beta_j}$$

as in the case of a standard autocorrelated normal-error linear regression model; and:

(6) $$\mathrm{Var}[\mathbf{Y_j}] = \mathrm{Var}[\mathbf{P_j^{-1}Y_j*}] = (\mathbf{P_j^{-1}})'\mathrm{Var}[\mathbf{Y_j*}]\mathbf{P_j^{-1}} = \sigma^2_j G(\Theta_j,\mu_j)\boldsymbol{\psi_j}$$

Equation (5) indicates that the covariance matrix of the non-normally distributed $\mathbf{Y_j}$ is similar to that of a normal but not necessarily independently and identically distributed dependent variable. If $\boldsymbol{\psi_j}$ (and thus $\mathbf{P_j}$) are identity matrices $\mathbf{Y_j}$ remains identically distributed. Autocorrelation is modeled through $\boldsymbol{\psi_j}$ and the implied $\mathbf{P_j}$. Ramirez (1999) provides the formula for the best linear unbiased predictor used to forecast the means of the dependent variable distributions in this study.

Risk, Stability and Return Analysis

The net annual income (NAI) from a given technology depends on production and input costs, and on the uncertain output prices, which are modeled, forecasted and simulated for the years 1998-2009 using the techniques described above. The NAI is:

(12) $NAI_{ij}, = Yc_{ij} * Pc_j - Cc_{ij} + Yp_{ij} \times Pp_j - Cp_{ij} + Yco_{ij} \times Pco_j - Cco_{ij}$

where NAI_{ij} is the net annual income per hectare (ha) from technology i in year j; and Yc_{ij}, Yp_{ij}, Yco_{ij}; Pc_j, Pp_j, Pco_j; and Cc_{ij}, Cp_{ij}, Cco_{ij} are cocoa, plantain and *Cordia* production per ha for technology i in year j; real cocoa, plantain and *Cordia* prices in year j; and real cocoa, plantain and *Cordia* production costs per ha for technology i in year j; respectively.

The present value of the net income from technology i (NPV_i) is obtained by adding the present values of the NAI_{ij} during the 12 years (j) of analysis. A real discount rate of 6% was used to calculate the present values. Each of 20,000 3x12 (3 crop prices, 12 years) matrices of forecasted/simulated prices yields an estimation/simulation of a net annual income value for each of the technologies NPV_i (i=3C, 2C, 1C, 2P, 3P, CP, CC, PP). The 20,000 estimated/simulated NPV 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 is evaluated by estimating the probability that the 12-year NPV_i did not reach three alternative pre-established minima based on the annual income necessary for an average rural family to maintain a standard of living above the poverty level (MIPPE, INRENARE, CATIE and UICN, 1992): U.S.$6,948, U.S.$10,422 and U.S.$13,896 per ha.

Price Analysis and Simulation Results

The maximum likelihood estimation results for the multivariate, non-normal, autocorrelated time-trending model of cocoa, plantain and *Cordia* prices are given 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 $\rho_3 = 0.3856$ 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 (Ramirez, 1999). Cocoa prices also show autocorrelation (ρ_1=0.3842).

None of the covariance parameters are statistically significant in this case. A restricted model (θ_3=μ_3=ρ_2=σ_{12}=σ_{13}=σ_{23}=0) is estimated (Table 1), where all of the parameters are statistically significant at the 99% level. Following Ramirez (1997), a likelihood ratio test is conducted (MLRT=2x{MVFLF1-MVRLF1}=1.010≈χ^2_6), which does not reject the null hypothesis Ho: θ_3=μ_3=ρ_2 =σ_{12}=σ_{13}= σ_{23}=0, at the 90% level. Statistically, the restricted model is 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.

Figure 1 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 non-normal model (Table 1). Ramírez (1997) 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.$2.00/pound in excess of the median of U.S.$0.80 are still probable in 1998, while prices of U.S.$0.40 bellow 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 later are annual crops and their supply is more susceptible to weather phenomena and pest attack affecting key producing areas. 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. Also, 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.

Finally in Figure 1 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. The cocoa pdf, for example, shifts to the right from 1998 to 2003, and back to the left in 2008.

Expected Net Benefits, Stability and Risk Results

Figure 2 shows the simulated cumulative density functions (cdf's) for the present value of the net income from the 6 agroforestry system and 3 monoculture technologies under analysis. Table 2 summarizes their means, variances, skewness and kurtosis coefficients, and Table 3 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 NPV's of the technologies with a higher proportion of this crop (Figure 2). In the case of 3C, for example, 50% of the NPV's are expected to be below and 50% above U.S.$15,000; however, NPV's of less than U.S.$11,500 are highly unlikely while there is a 10% probability of obtaining a NPV greater that U.S.$21,000. 3P, in contrast, has a very similar minimum likely NPV, a median NPV of U.S.$13,200, but a maximum of only U.S.$19,000.

The technologies with a higher proportion of cocoa (3C, 2C and 1C) are the less risky regardless of the minimum income level required (Figure 2), and they render the highest mean NPV's (Table 2). 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 NPV's, but variances that are 3 to 5 times smaller. Because of the non-normality, however, larger variances do not imply higher risk in this case; they are mostly due to the extended upper tails of the cdf's.

The monocultures and the high-density cocoa-plantain system (CP) fare poorly in the analysis. They show substantially lower mean NPV's and significantly higher risk levels than any of the agroforestry systems, regardless of the minimum income level required (Tables 2 and 3). A comparison of the expected net annual benefits with the previously established minimum income requirement of U.S.$579-1,158/ha/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 regards to risk, as defined in this study, all technologies but LL are feasible if only 50% of the minimum required income (MRI) has to come from farming, and 3C, 2C, 1C, 2P and 3P still exhibit very low risk levels when 75% of the MRI has to 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 3). Risk levels as defined in this study will vary depending on the MRI and the farm size, but can be recalculated using Figure 2.

Conclusions and Recommendations

This study presents a technique that can model and simulate the expected values, variances and covariances of sets of correlated time-series dependent variables that are autocorrelated and non-normal (right or left skewed and kurtotic). The technique is flexible because it includes one or more parameters to control each of those statistical attributes, and efficient because it estimates all of the parameters jointly, in a multivariate setup. A model of autocorrelated, non-normal (kurtotic and right skewed) time-trending prices, and heteroscedastic, non-normal (kurtotic and left-skewed), time-trending crop yields, and all of the possible underlying correlations, could be implemented for a more precise simulation and risk and return analysis, combining the method developed in this study and the models in Ramírez (1997), which are fully compatible.

In the selected application, a detailed analysis of expected annual net income flows, their present values, stability and risk, provide evidence in favor of diversified cocoa-plantain-*Cordia* agroforestry system technologies vs. the traditional monocultures. Systems with a higher proportion of cocoa to plantain are favored during the 1998-2010 period, 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, specially considering the high levels of risk associated with all technologies during the 1998-2010 period. However, they are closely related to the assumption of an average farm size of 4 ha's. It is clear that, 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 vs. the traditional cocoa or plantain monocultures.

Table 1. Maximum likelihood estimation results for the multivariate, non-normal, autocorrelated time-trending model of cocoa, plantain and *Cordia* prices.

	UNRESTRICTED MODEL			**RESTRICTED MODEL**		
Parameter	**Estimate**	**Std. Error**	**P-Value**	**Estimate**	**Std. Error**	**P-Value**
ρ_1	0.384	0.066	1.000	0.376	0.057	1.000
ρ_2	-0.085	0.188	0.674	-	-	-
ρ_3	0.386	0.130	0.998	0.397	0.057	1.000
θ_1	1.132	0.286	1.000	1.170	0.226	1.000
μ_1	1.668	0.617	0.996	1.616	0.327	1.000
σ_1	0.571	0.139	1.000	0.572	0.087	1.000
β_{01}	1.904	0.284	1.000	1.928	0.201	1.000
β_{11}	-0.012	0.007	0.953	-0.013	0.004	0.998
θ_2	0.705	0.356	0.974	0.711	0.203	1.000
μ_2	16.193	3.162	1.000	16.200	0.109	1.000
σ_2	0.491	0.168	0.998	0.498	0.101	1.000
β_{02}	2.998	0.113	1.000	2.995	0.087	1.000
β_{12}	-0.014	0.008	0.952	-0.013	0.005	0.995
θ_3	0.000	-	-	-	-	-
μ_3	0.000	-	-	-	-	-
σ_3	16.451	2.046	1.000	16.380	2.405	1.000
β_{03}	66.423	3.073	1.000	64.798	6.962	1.000
β_{13}	2.975	0.478	1.000	3.104	0.458	1.000
σ_{12}	0.031	0.160	0.576	-	-	-
σ_{13}	-0.052	0.161	0.626	-	-	-
σ_{23}	0.179	0.211	0.800	-	-	-
	MVFLF1	-45.668		MVRLF1	-46.173	

Note: Estimation and simulation was conducted using the GAUSS 2.01 matrix algebra language, specifically, the OPTMUM procedure was used for maximum likelihood estimation. MVFLF and MVRLF are the maximum values of the concentrated full as restricted likelihood functions, respectively.

Table 2. Means, variances, skewness and kurtosis coefficients of the simulated NPV's 6 agroforestry system and 3 monoculture technologies, based on autocorrelated non-normal and normal commodity price models.

	NON-NORMAL MODELS				NORMAL MODELS	
TECH.	**MEAN**	**VARIANCE**	**SKEW.**	**KURT.**	**MEAN**	**VARIANCE**
CC	10195.12	15987.85	2.37	9.75	3945.06	5279.19
PP	10574.11	483.29	0.84	1.28	8968.21	329.86
LL	2306.47	128.08	0.00	-0.10	1877.06	131.80
1C	14354.53	7080.48	2.50	11.57	9099.90	2343.95
2C	15293.99	11896.56	2.52	11.60	9023.30	3905.68
3C	16176.93	15527.29	2.54	11.79	9246.12	5097.67
2P	13416.94	3042.76	2.25	9.86	9334.64	1072.49
3P	13479.11	2098.63	2.02	8.36	9774.70	794.16
CP	10932.10	6803.93	2.47	11.52	5656.34	2299.78

Notes: VARIANCE = Variance/1000, SKEW. = Skewness coefficient, KURT. = Kurtosis coefficient. SKEW. and KURT. are not shown for the normal models; they are between -0.05 and 0.05 in all cases.

Table 4. Levels of risk of 6 agroforestry system and 3 monoculture technologies, based on autocorrelated non-normal and normal commodity price models.

	NON-NORMAL MODELS			NORMAL MODELS		
TECHOLOGY	**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

Note: RISK1, RISK2 and RISK3 require that 50, 75 and 100% of the previously established minimum family income level is obtained from farming.

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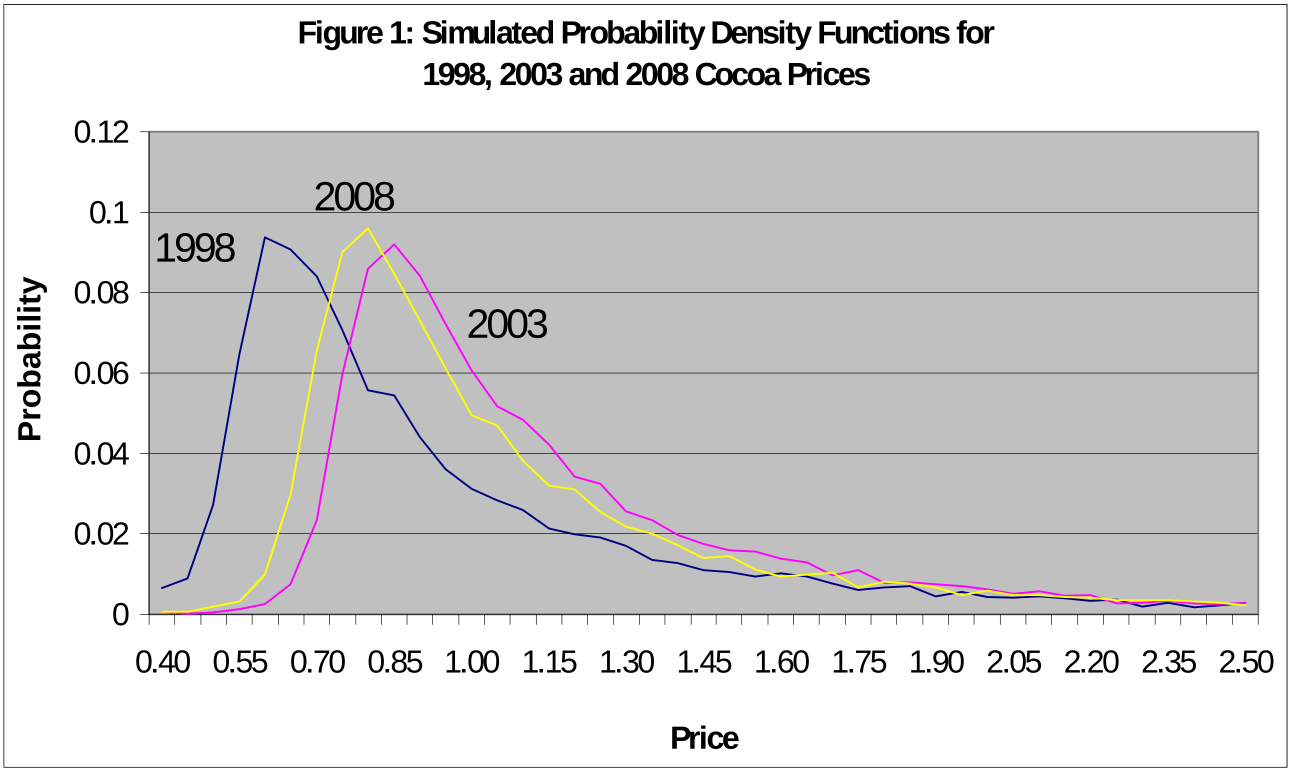
Figure 1: Simulated Probability Density Functions for
1998, 2003 and 2008 Cocoa Prices
Probability
Price
1998
2008
2003
0.12
0.1
0.08
0.06
0.04
0.02
0
0.40
0.55
0.70
0.85
1.00
1.15
1.30
1.45
1.60
1.75
1.90
2.05
2.20
2.35
2.50

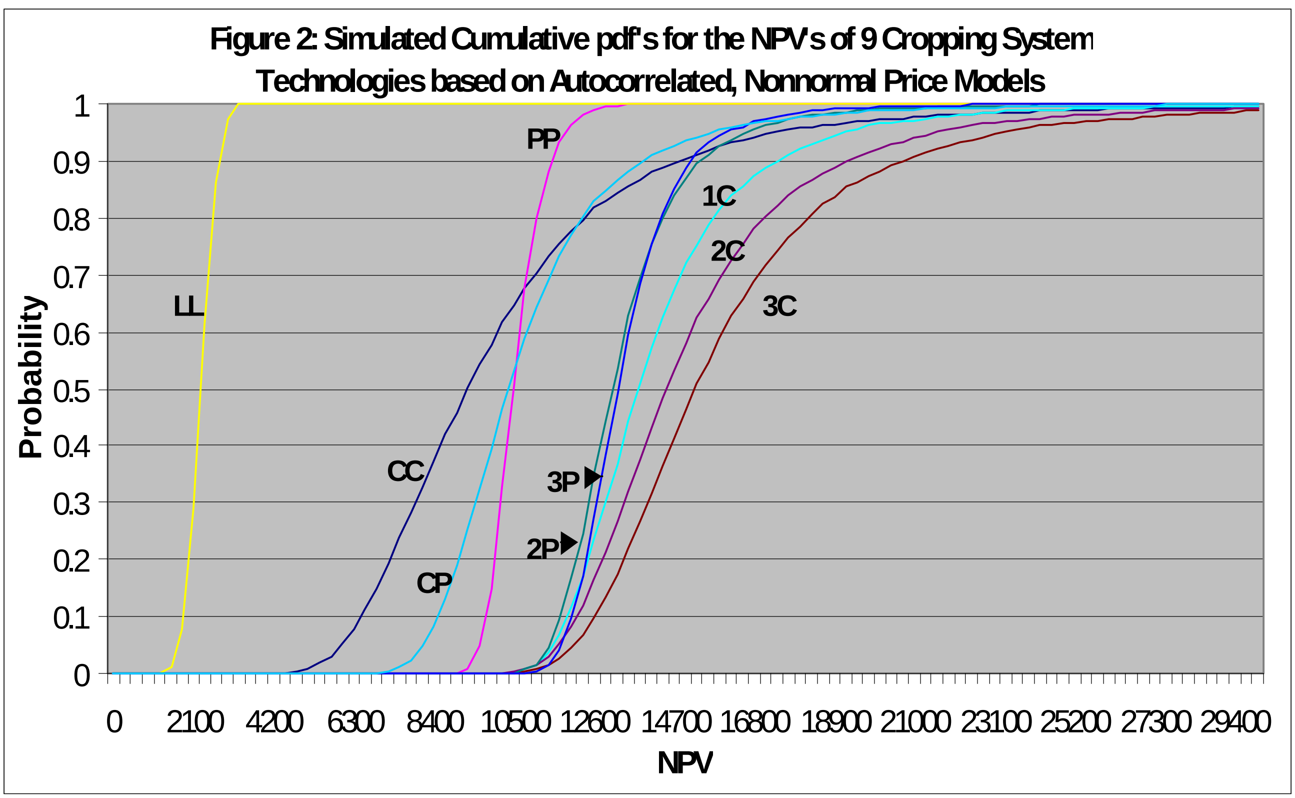
Figure 2: Simulated Cumulative pdf's for the NPV's of 9 Cropping System
Technologies based on Autocorrelated, Nonnormal Price Models
Probability
NPV
LL
PP
CC
CP
3P
2P
1C
2C
3C
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2100
4200
6300
8400
10500
12600
14700
16800
18900
21000
23100
25200
27300
29400