Production Risk Revisited in a Stochastic Frontier Framework:
Evaluating Noise and Inefficiency in Cover Crop Systems

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Short abstract:

This paper investigates both production risk and technical inefficiency in a general stochastic frontier framework that is consistent with the Just-Pope framework. After applying the model to two separate cash crop-cover crop systems, the more general stochastic frontier model is found to reorder the noisiness of alternative cover crop regimes.

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The specifications of residuals from the deterministic portion of a production model play a central role in two generally separate analytic frameworks. Risk analysis in a Just-Pope framework (1978 and 1979) involves recovering the residuals and using them to investigate the marginal effects of inputs on production risk, or noise. One of the specification requirements of the Just-Pope framework is that there be no *a priori* restrictions on the marginal risk effects so that an input to production could be either risk increasing or risk decreasing. Recent empirical applications include Smale *et al*., Traxler *et al*., and Tveterås, among others.

Alternatively, inefficiency analysis in a stochastic frontier framework involves specifying both a white noise component and a one-sided inefficiency component to the residuals. Recent empirical applications (including Morrison-Paul, Johnston, and Frengley; Goaied and Ayed-Mouelhi; Cuesta; Reinhard, Lovell, and Thijssen; Battese and Broca; Ahmad and Bravo-Ureta; Kirkley, Squires, and Strand; and Kumbhakar and Heshmati) generally focus only on the inefficiency component to estimate technical inefficiency and the marginal effects of inputs on inefficiency. Here again, there are no restrictions on the marginal inefficiency effects so that an input could be either efficiency increasing or decreasing. Almost all research in this framework, however, ignores marginal effects on the noise component despite the fact that the stochastic frontier model is consistent with the Just-Pope model. First Kumbhakar, and later Battese, Rambaldi, and Wan may provide the only instances of combining noise and inefficiency analysis in a single framework. These authors suggest that a combined framework is beneficial because, first, it provides more credible estimates of inefficiency and, second, it simultaneously accounts for two integral aspects of producers' technology decisions.

The present paper investigates both production risk and technical inefficiency in a stochastic frontier framework that is consistent with the Just-Pope framework.[1] With this type of combined framework, one can investigate whether the addition of a one-sided inefficiency component will alter any empirically estimated marginal effects that inputs have on the noise component. In other words, this approach allows us to investigate whether inputs remain risk increasing (or decreasing) even after accounting for inefficiency in a stochastic frontier framework.

The empirical applications presented here involve two agronomic experiments – one for Tennessee cotton and one for Maryland corn – designed to evaluate alternative cover crop regimes. Planted after a cash crop, cover crops such as wheat, hairy vetch, or crimson clover are often used to improve the overall productivity or profitability of the cash crop. The relationship between the cover and cash crop is a difficult one to describe, however. Some cover crops such as vetch, clover, or peas can add nitrogen, while wheat and other non-legumes can decrease nitrogen availability. Moreover, the use of covers can break certain pest cycles, but it can also add to pest pressures by helping to create a favorable habitat for pests. With these uncertainties in mind, it is perhaps not surprising that the adoption of cover crop systems is not wide spread, particularly in cotton. One potential barrier to adoption, therefore, is the potential for cover crops to increase the variability of yield in the cash crop.

Among the few attempts to investigate the riskiness of cotton-cover systems, Giesler, Paxton, and Millhollon found that a hairy vetch winter cover followed by cotton with no applied

[1] Emerging also is a third framework, based on research by Chambers and Quiggin, that explains production decisions in a state-contingent framework, which is more general that other two frameworks discussed in the present paper (see for example, Chambers and Quiggin 2001a, 1998, 1997, and 1996; and Quiggin and Chambers 1998a and 1998b. Chambers and Quiggin (2001b) specifically relate the state-contingent framework to the Just-Pope framework and offer a generalized Just-Pope specification that has the desirable property of being smoothly differentiable in *ex post* output.

nitrogen fertilizer was "risk efficient" for a wide range of absolute risk aversion. Additionally, Larson *et al*. found that vetch or winter wheat covers could, under some nitrogen rates and tillage regimes, reduced yield variability.

While little work has focused on the riskiness of corn-cover systems, Chambers *et al*. report that conservative estimates of corn yield grown with no cover or a wheat cover are 40 to 50 percent below optimistic estimates. Alternatively, conservative estimates of corn yield grown with a vetch or Austrian pea cover are only 10 to 20 percent below optimistic estimates. While the Chambers *et al*. results are not based on a Just-Pope of stochastic frontier framework, they suggest that, for the corn-cover systems they investigate, legume covers such as vetch or peas may reduce corn yield variability.

The paper's next section presents the theoretical and econometric model associated with the Just-Pope and stochastic frontier frameworks, in which particular attention is paid to the stochastic component of production. The following section describes experimental data from the two agronomic experiments. The paper's last two sections present the results and implications.

A Single Analytic Framework

A production function consistent with both the Just-Pope and the stochastic frontier analytic frameworks is given by

(1) $$y_{it} = f(\mathbf{x}_{it},\beta) + r\ ,$$

where y_{it} is a scalar output of producer i, $i = 1, \ldots, I$, at time t, $t = 1, \ldots, T$, $\mathbf{x}_{it}$ is a vector of N inputs used by producer i, $f(\mathbf{x}_{it},\beta)$ is the deterministic part of the production frontier, β is a vector of technology parameters to be estimated, and r is a residual component that can take a number of forms, depending on the analytic framework.

In the typical Just-Pope framework, the residual component takes the form:

(2) $$r = r_{JP} = g(\mathbf{z}_{it};\gamma)^{½}\varepsilon_{it},$$

where $\mathbf{z}_{it}$ is input vector that may or may not equal $\mathbf{x}_{it}$, $g(\mathbf{z}_{it};\gamma)$ is the variance function, or noise component, γ is a vector of variance parameters, and ε_{it} is the exogenous production shock.

In the stochastic frontier framework, the residual component can take the form:

(3) $$r = r_{SF} = h^v(\mathbf{z}^v_{it};\delta^v)^{½}v_{it} - h^u(\mathbf{z}^u_{it};\delta^u)u_{it} ,$$

where $h^v(\mathbf{z}^v_{it}; \delta^v)$ is a noise function, $h^u(\mathbf{z}^u_{it}; \delta^u)$ is an inefficiency function, $\mathbf{z}^u_{it}$ and $\mathbf{z}^v_{it}$ are input vectors that may or may not equal each other or $\mathbf{x}_{it}$, γ, δ^v, and δ^u are parameter vectors, v_{it} is a two-sided exogenous production shock associated with noise and u_{it} is a one-sided exogenous inefficiency term. The representation in (3) is a generalization of the models used by Kumbhakar or Battese, Rambaldi, and Wan, who both essentially require $h^v(.)^{½} = h^u(.)$, $\mathbf{z}^v_{it} = \mathbf{z}^u_{it}$, and $\delta^v = \delta^u$. The flexible representation in (3) allows inputs to have separate marginal effects on noise and inefficiency.

The subscripts i and t index the producer and the time period and suggest that that the framework can be applied to panel data. It is of course possible, however, to apply the model to either time series or cross section data. In that case, there would be only one producer ($I = 1$) or one time period ($T = 1$), respectively. In the case of cross sectional data, the notational subscript t will be suppressed.

The two frameworks are easily reconciled by noting that the Just-Pope model is a special case of the stochastic frontier model. More specifically, if $u = 0$ in equation (3) so that there is no inefficiency component, r_{SF} is equivalent to r_{JP}. Also note that if $v = 0$ in equation (3) so that there is no noise component, the stochastic frontier model reduces to a so-called deterministic frontier model. These special cases are reinforced by the often-used notation that $\varepsilon = v - u$.

Estimation of the Just-Pope model given by equation (1) and (2) is generally accomplished by applying least squares to a parameterized form of $f(\mathbf{x}_i;\beta)$, calculating the natural logarithm of the squared residuals, and estimating a parameterized form of $g(\mathbf{z}_{it};\gamma)$. Marginal risk effects are given by $\frac{\partial g(\mathbf{z}_i,\gamma)}{\partial z_i}$, which may be positive or negative. Finally, $f(\mathbf{x}_i;\beta)$ can be re-estimated by generalized least squares.

Estimation of the stochastic frontier model given by equation (3) is more difficult. Unless the extra information provided by panel data is sufficient, strong distributional assumptions are required for v and u.[2] If the data represent a cross section (where $T = 1$), for example, three assumptions are often made: (i) The v_i are distributed *i.i.d.* normal with zero mean, *i.e.*,

$$v_i \sim i.i.d.\ N(0,\sigma^2_v);$$

(ii) The u_i are assumed to be distributed according to a one-sided distribution, usually *i.i.d.* non-negative half normal with a zero mean, i.e.,

$$u_i \sim i.i.d.\ N^+(0,\sigma^2_u)$$

(although other one-sided distributions such as the exponential could be used). (iii) The u_i and v_i distributed independently of each other, and of the regressors. Under the these assumptions, Kumbhakar and Lovell note that the marginal density function of $\varepsilon = v - u$ for a cross section is

(4) $$f^c(\varepsilon) = \frac{2}{\sigma}\phi\left(\frac{\varepsilon}{\sigma}\right)\cdot \mathrm{F}\left(-\frac{\varepsilon\lambda}{\sigma}\right),$$

where $\sigma = (\sigma^2_u + \sigma^2_v)^{1/2}$, $\lambda = \sigma_u/\sigma_v$, and $\mathrm{F}(\cdot)$ and $\phi(\cdot)$ are the standard normal cumulative distribution and density functions. Kumbhakar and Lovell note that the re-parameterization of

[2] See Kumbhakar and Lovell for a thorough discussion of when the distributional assumptions can be relaxed.

σ^2_v and σ^2_u to σ and λ is convenient because λ provides an indication of the relative contributions of u and v to ε.

For a cross sectional sample of I producers, equation (4) leads to the following log likelihood function:

(5)
$$\ln L^c = \text{constant} - I \ln \sigma + \sum_i \ln \mathrm{F}\left(-\frac{\varepsilon_i \lambda}{\sigma}\right) - \frac{1}{2\sigma^2}\sum_i \varepsilon_i^2 .$$

Maximum likelihood estimation based on (5) will generate estimates of $\varepsilon_i = v_i - u_i$, but extraction of individual information of the u_i (or v_i) requires the conditional distribution of u_i given ε_i, which Jondrow *et al.* derive. The mean of this conditional distribution serves as a point estimator for u_i and is given by

(6)
$$E(u_i \mid \varepsilon_i) = \sigma^* \left[\frac{\phi(\varepsilon_i \lambda / \sigma)}{1 - \mathrm{F}\,(\varepsilon_i \lambda / \sigma)} - \frac{\varepsilon_i \lambda}{\sigma}\right],$$

where $\sigma^* = \sigma_u \sigma_v / \sigma$. [3]

If $T > 1$ so the data represent a panel, equations (4), (5), and (6) are slightly modified. Kumbhakar and Lovell describe the details of this modification.

Empirical research is the stochastic frontier framework often involves estimating firm-level inefficiency and/or the marginal effects on inefficiency given by $\partial h^u(\mathbf{z}_i; \delta^u)/\partial z_i$. Rarely investigated in this framework are the marginal effects on noise, now given by $h^n(\mathbf{z}_i; \delta^n)/\partial z_i$.

Assuming that $f(\mathbf{x}_i;\beta)$, $g(\mathbf{z}_i;\gamma)$, $h^v(\mathbf{z}_i; \delta^v)$, and $h^u(\mathbf{z}_i; \delta^u)$ are all linear, equations (1), (2), and (3) can be written in a straightforward way for latter estimation. In the Just-Pope framework, (1) and (2) become parameterized yield and noise equations, to be estimated with OLS:

(7a)
$$y_i = \beta_0 + \mathrm{b}'\mathbf{x}_i + \varepsilon_i,$$

[3] Kumbhakar and Lovell note that the mode of the distribution can also be used as a point estimator.

(7b) $$\ln(\varepsilon^2_i) = \gamma_0 + \boldsymbol{z_i}' g + \omega_i,$$

where ω_i is a random disturbance with zero mean and constant variance. In the stochastic frontier framework, (1) and (3) become parameterized yield, noise, and inefficiency equations, to be estimated with maximum likelihood techniques:

(8a) $$y_i = \beta_0 + b'\boldsymbol{x}_i + v_i - u_i\ ,$$
(8b) $$\ln(v^2_i) = \delta^v_0 + \boldsymbol{z_i}' d^v + \upsilon_i,$$
(8c) $$\ln(u_i) = \delta^u_0 + \boldsymbol{z_i}' d^u + \mu_i,$$

where υ_i and μ_i are random disturbances with zero mean and constant variances.

Experimental Data

The empirical analysis of noise and inefficiency components centers on two data sets generated by agronomic experiments on cover-crop systems from two separate agricultural experiment stations. One data set, from the West Tennessee Experiment Station in Jackson, TN, contains cotton yield data generated from an experiment where cover crop choice, tillage methods, and nitrogen levels were all varied in a randomized complete block with split-plots and four replications per year. An important characteristic of this data set is that the same plots received the same cover crop, tillage, and nitrogen treatments each year from 1984 to 1997. Because the data can be linked to the physical plot on a yearly basis, the data set could be thought of as a panel.

In the Tennessee cotton experiment, conventionally tilled and no-till cotton were planted after winter wheat, hairy vetch, crimson clover and no winter cover crop alternatives. A burn-down herbicide was used to kill the cover crop before planting cotton in the no tillage plots. Nitrogen was applied at rates equal to 0, 30, 60, and 90 pounds per acre. Two important events complicate analysis of the cotton yield data. First, researchers experienced increasing difficulty with controlling weeds over time, especially in the no-tillage and legume winter cover crops, until new herbicide treatments became available in 1995. And second, while conducting a lime-recommendation study on the same plots, researchers let pH levels deteriorate for several years until 1995, when the plots received lime at the recommended rate. Two weather variables, annual precipitation and growing-degree days, were also collected in the cotton data set. This data set was used previously by Larson *et al*.

The second data set, from Maryland's Coastal Plain, contains no-till corn yield data generated from a similar experiment where cover crop choice and nitrogen levels were varied in a split plot with four replications per year for three years. In this experiment, no-till corn was planted after winter wheat, hairy vetch, crimson clover and no winter cover crop alternatives. Nitrogen was applied at rates equal to 0, 60, 120,and 180 pounds per acre. Unlike the first data set, however, the no-till corn experimental plot area was moved each year. Because of the movement, therefore, this data set cannot be considered a panel. Another important difference was that researchers measured the yield of the cover crop (to measure the potential contribution to soil organic matter and available nitrogen). Weather variables include total precipitation during the early growing season and the number of days during the late growing season between 70° and 80°F. This data set has been used previously by Lichtenberg *et al*. and Chambers *et al*.

For both data sets, yield response was modeled as quadratic in nitrogen so both nitrogen (NIT) and nitrogen squared (NIT^2) were included as elements of $\boldsymbol{x}_i$ for both the cotton and corn cover crop systems. For the cotton-cover crop analysis, additional elements of $\boldsymbol{x}_i$ included a constant, a time trend (Time), and dummy variables for tillage method (D_{NoTill} = 1 for no-till) and the years 1995-1997 (D_{1995+} = 1 for the years 1995-1997), when lime and herbicide management changed. For the corn-cover crop analysis, additional elements of $\boldsymbol{x}_i$ included a constant, the yield of the cover crop (Cover Yld.), and a time trend. Elements of $\boldsymbol{z}_i$ included: a constant and applied nitrogen rate (but not nitrogen squared) for both cotton and corn analysis; cover yield for the corn analysis; two weather variables – total precipitation (PPT) and growing degree days (GDD) for cotton analysis and early precipitation (Precip.) and days between 70 and 80 (Days70-80) for corn analysis; and, finally, a time trend for cotton analysis.

For each cash-crop/cover-crop variation, therefore, the Just-Pope and stochastic frontier models represented by equations (7) and (8) were estimated by OLS and maximum likelihood, respectively. In addition, a stochastic frontier system with random effects was also estimated by maximum likelihood for the cotton/cover-crop variations because of the panel nature of these data. For the stochastic frontier model, the u_i (and the corresponding v_i) were recovered using the formula in (6).

Results

The sheer number of estimation result variations, depending on the model and the cover crop system, makes the reporting and analysis of results difficult. The estimation results are grouped by the particular cash crop/cover crop system and reported in Tables 1a – 1d and 2a – 2d. Tables 1a – 1d present the estimation results for the cotton system with no cover, wheat cover, vetch cover, and crimson clover cover, while Tables 2a – 2d present similar results for the corn systems. In all tables, results for both the Just-Pope model, given by equations (7a) and (7b), and the stochastic frontier models, given by equations (8a), (8b), and (8c), are shown side-by-side. The presentation and discussion of results that follows attempts to highlight instances where the empirical result is sensitive to the modeling framework.

Cotton Systems. For the yield equations in Tables 1a – 1d, the choice of modeling framework rarely alters the sign or significance of estimates of b. Exceptions do occur, however: For cotton grown with a wheat, vetch, and clover covers, Tables 1b, 1c, and 1d, show that coefficients on NIT^2 fail the usual significance test under frontier/panel model. Likewise, coefficients for NIT, D_{NoTill} , and D_{1995+} may sometimes differ in sign and significance for the frontier/panel model. For example, Table 1c shows a substantial discrepancy in estimates for D_{NoTill} based on the frontier/panel model. Unlike with the Just-Pope or frontier/cross section models, D_{NoTill} is highly positive and significant, suggesting that no till methods lead to substantially higher cotton yields. We know of no agronomic reason to explain this result.

The noise equations in Tables 1a – 1d appear more sensitive to the cover system and the choice of modeling framework. For cotton grown with no cover (Table 1a), nitrogen's affect on noise is not significantly different from zero. However, for cotton grown with a cover crop, the tables show limited support for the notion that nitrogen is a noise-increasing (*i.e.*, risk-increasing) input. For example, in cotton grown with a wheat cover (Table 1b), nitrogen has a positive and significant affect on noise. In cotton grown with vetch (Table 1c), only the traditional Just-Pope model reveals nitrogen to have a positive and significant affect on noise. And in cotton grown with clover, only the frontier/panel model finds this result.

Tables 1a – 1d also show very limited support for characterizing no-till as a noise-increasing practice. Specifically, the tables show that only for cotton grown with a vetch or clover cover (both legumes), and only in the frontier/panel model, does the no-till dummy coefficient have a significantly positive estimate.

The effect of the time trend on noise also is sensitive to cover choice and modeling framework. For cotton grown without a cover crop, time's passage increases noise in all three models. For the vetch and clover cover systems, however, time's passage appears to decrease noise in the Just-Pope model, but results are inconclusive in the frontier models. The results, therefore, fail to shed much light on whether a cover crop can add to the system's overall stability over time (by increasing soil quality, for example). The results do suggest, however, that without a cover crop, the cotton system gets noisier over time.

The inefficiency equation results in Tables 1a – 1d suggest, in general, that increases in the two weather variables, growing degree days and precipitation, generally increase the efficiency of the cotton systems. Nitrogen's affect on inefficiency is highly sensitive to cover choice and model choice. (Here, allowing for inefficiency limits the choice to the frontier model, either as a cross section or panel). For the no cover and wheat cover systems (Tables 1a and 1b), the frontier/panel results show that increases in the nitrogen application rate decrease inefficiency. However, for vetch and clover cover systems (Tables 1c and 1d) – the two legume systems, the frontier/panel results show that increases in nitrogen application rates increase inefficiency. These results highlight the fact that, because legume crops can add nitrogen to the soil, higher levels of applied nitrogen may be wasted on the growing cotton. It is noteworthy, however, that this affect that nitrogen has on inefficiency is only readily apparent in the frontier model based on panel data.

For the two frontier models, cross section and panel, Tables 1a – 1d also report the estimate for λ, which indicates the relative contribution of the inefficiency component to the noise component. Table 1a, for instance, shows that the estimate for λ is not significantly different from zero in the cotton system without a cover crop. This result means that the inefficiency component is not significantly different from zero. However, Tables 1b – 1d show there is evidence that the inefficiency component for the wheat, vetch, and clover cover crop systems is significantly different from zero, at least when the cross section model is used. Among the for cotton-cover systems, vetch and clover account for the highest estimates for σ^2_u, the variance parameter for the inefficiency component.

Corn Systems. Tables 2a – 2d present the estimation results for the corn system with no cover, wheat cover, vetch cover, and crimson clover cover. The yield equations show virtually no difference between results for the Just-Pope model and the frontier (cross section) model. One should note that, for both models, estimated coefficients for NIT and NIT^2 (see Table 2c) do not significantly differ from zero when corn is grown with a vetch cover, a crop that adds nitrogen to the soil.

For the noise equation results, Tables 2a – 2d show that very few estimated coefficients are statistically significant, and that their values and significance levels are sensitive to model choice. Using the Just-Pope model, fewer days between 70 and 86 degrees increases noise in the wheat system, and precipitation increases noise in the vetch system. Using the frontier model, nitrogen is found to increase noise in the wheat and vetch systems (Tables 2b and 2c).

None of the regressors in the inefficiency equations are estimated to be significantly different from zero. This statistical insignificance is reinforced by results showing that λ is not significantly different from zero in any of the corn-cover systems. In words, this result means that noise, not inefficiency, dominates the estimated residuals in the corn systems. Among the for corn-cover systems, vetch and wheat account for the highest estimates for σ^2_u, the variance parameter for the inefficiency component.

Parametric Distributions. The estimation results presented above suggest that the choice of the Just-Pope or the stochastic frontier model can dramatically affect the marginal effects of inputs on noise. Plots of the distributions based on estimated values for variance parameters may better serve to highlight some of the "reversals" found in the results. For the cotton-cover systems, Figures 1a, 1b, and 1c, respectively, show the normal distribution for ε in the Just-Pope model, the normal-half normal distribution for ε in the stochastic frontier/cross section model, and the normal distribution for *v* in the frontier/cross section model. Based on the Just-Pope model, the vetch system generates the most dispersed distribution of the noise component and the clover system generates the third-most dispersed distribution. However, with the stochastic frontier model, the vetch and clover systems have the least and second-least dispersed distributions. In other words, the cotton-vetch system moves from being the "noisiest" to the least noisy.

Error distributions for the corn-cover systems, plotted in Figures 2a, 2b, and 2c, echo a similar sensitivity to model choice. The corn-vetch system moves from being the noisiest with the Just-Pope model (Figure 2a) to the second-least noisy with the stochastic frontier model (Figure 2c). Moreover, the corn-no cover system moves from being the second-least noisy system to noisiest.

Conclusions and Implications

This paper develops a general framework for investigating production risk and inefficiency in a stochastic frontier framework. This generality proves important for empirical reasons as the results from the stochastic frontier framework reverse several results obtained from the less general Just-Pope framework. Perhaps most striking is that that the frontier model reorders the relative noisiness of cover-crop regimes associated with both cotton and corn systems. For example, two legume crops (vetch and clover) are shown to generate the least amount of noise, as compared with other cover crops or no cover, only when technical inefficiency is accounted for using the frontier model. Additionally, results from the more general frontier model provide more empirical support than the Just-Pope model for characterizing nitrogen as a noise-increasing input.

These results may help shed light on the current state of cover-crop adoption and utilization by producers. The relatively few empirical investigations on the relative riskiness of cover crops have begun to provide evidence that certain cover crops may reduce yield variability. The present research provides additional weight to these findings. However, the present research goes further to suggest that inefficiencies, apart from pure noise, may be a substantial component of cover crop systems. One general conclusion, therefore, is that future improvements to cash crop/cover crop systems, particularly those featuring vetch, should focus on reducing inefficiency rather than noise.

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Table 1a: Yield, Noise, and Inefficiency Estimation Results for Cotton Following No Cover

	Just-Pope (OLS)		***Frontier/Cross Section***			***Frontier/Panel***		
	Yield	Noise	Yield	Noise	Ineff.	Yield	Noise	Ineff.
Const.	986.85**	4.166**	1055.11**	4.186*	4.732**	1076.98**	5.305**	4.406**
	(35.792)	(1.978)	(5.823)	(1.937)	(22.105)	(24.018)	(2.494)	(24.866)
NIT	4.902**	0.002	4.897**	0.002	0.00002	4.335**	0.003	-0.0004*
	(5.272)	(0.688)	(5.147)	(0.671)	(0.074)	(3.178)	(0.892)	(-1.824)
NIT^2	-0.036**		-0.036**			-0.035**		
	(-3.654)		(-3.624)			(-2.171)		
D_{NoTill}	-89.080**	0.200	-89.194**	0.158	-0.0006	-89.930**	0.883	-0.001
	(-4.998)	(1.045)	(-4.913)	(0.805)	(-0.029)	(-3.257)	(0.456)	(-0.060)
D_{1995+}	458.05**	-1.198**	456.28**	-1.126**	0.081*	457.72**	-1.041**	0.070**
	(14.798)	(-2.946)	(12.866)	(-2.697)	(1.962)	(17.771)	(-2.532)	(2.045)
Time	-56.552**	0.080*	-56.430**	0.072*	-0.007*	-56.729**	0.091**	-0.006*
	(-17.949)	(1.956)	(-17.175)	(1.716)	(-1.686)	(-14.261)	(2.203)	(-1.801)
GDD		0.001**		0.001*	-0.0001*		0.0009	-0.0001*
		(1.970)		(1.861)	(-1.792)		(1.368)	(-1.799)
PPT		0.110**		0.108**	-0.014**		0.085**	-0.012**
		(3.059)		(2.925)	(-3.928)		(2.342)	(-3.945)
F-Test		2.30**		2.02*	2.65**		1.46	3.22**
λ [or λ^2]			0.480			[0.139]		
			(0.347)			(1.150)		
σ^2_v			32391.29			30623.96**		
σ^2_u			7458.68			12319.29		

Table 1b: Yield, Noise, and Inefficiency Estimation Results for Cotton Following Wheat

	Just-Pope (OLS)		***Frontier/Cross Section***			***Frontier/Panel***		
	Yield	Noise	Yield	Noise	Ineff.	Yield	Noise	Ineff.
Const.	957.78**	8.270**	1088.65**	6.581**	5.622**	1080.97**	5.550**	5.149**
	(39.697)	(3.518)	(32.932)	(3.277)	(11.877)	(17.921)	(2.648)	(13.294)
NIT	5.036**	0.007**	5.249**	0.006**	0.0001	4.649*	0.005*	-0.001**
	(6.189)	(2.137)	(6.319)	(2.171)	(0.212)	(1.760)	(1.719)	(2.601)
NIT^2	-0.034**		-0.036**			-0.036		
	(-3.894)		(-4.068)			(-1.266)		
D_{NoTill}	-60.107**	0.031	-60.942**	0.143	-0.005	-61.267	0.118	-0.004
	(-3.854)	(0.144)	(-3.848)	(0.783)	(-0.114)	(-1.312)	(0.617)	(-0.110)
D_{1995+}	364.34**	-0.948**	356.368**	-1.009**	0.119	365.010**	-0.717*	0.113
	(13.451)	(-2.088)	(11.814)	(-2.603)	(1.309)	(20.625)	(-1.771)	(1.506)
Time	-49.200**	0.067	-48.922**	0.047	-0.111	-49.750**	0.033	-0.011
	(-17.845)	(1.470)	(-17.958)	(1.217)	(-1.209)	(-23.336)	(0.818)	(-1.431)
GDD		-0.0006		-0.0001	-0.0002		0.004	-0.0001
		(-0.856)		(-0.207)	(-1.221)		(0.657)	(-1.164)
PPT		0.0132**		0.114**	-0.025**		0.128**	-0.019**
		(3.290)		(3.338)	(-3.049)		(3.580)	(-2.900)
F-Test		4.66**		4.35**	1.67		3.35**	2.62**
λ [or λ^2]			1.307**			[0.7092**]		
			(3.188)			(1.857)		
σ^2_v			16606.73			16890.55		
σ^2_u			28392.11			27439.10		

Table 1c: Yield, Noise, and Inefficiency Estimation Results for Cotton Following Hairy Vetch

	Just-Pope (OLS)		*Frontier/Cross Section*			*Frontier/Panel*		
	Yield	Noise	Yield	Noise	Ineff.	Yield	Noise	Ineff.
Const.	1118.61**	13.225**	1387.02**	7.754**	7.435**	1154.52**	2.130	6.538**
	(36.878)	(5.666)	(40.660)	(3.353)	(10.580)	(15.111)	(1.000)	(13.672)
NIT	0.371	0.006*	0.052	-0.814	-0.198	6.266	-0.002	0.018**
	(0.063)	(1.875)	(0.057)	(-0.273)	(-0.208)	(0.189)	(-0.749)	(27.694)
NIT^2	-0.015		-0.010			0.205		
	(-1.344)		(-1.011)			(0.515)		
D_{NoTill}	-94.763**	0.233	-78.743**	0.299	0.020	2757.41**	1.458**	1.710**
	(-4.833)	(1.098)	(-4.206)	(1.499)	(0.319)	(2.096)	(7.523)	(39.306)
D_{1995+}	444.883**	-0.054	430.457**	-0.384	0.125	473.638**	-0.844**	0.160*
	(13.065)	(-0.121)	(11.416)	(-0.905)	(0.919)	(13.480)	(-2.050)	(1.728)
Time	-50.515**	-0.099**	-54.676**	-0.044	-0.025*	-45.104**	0.034	-0.004
	(-14.574)	(-2.195)	(-15.991)	(-1.040)	(-1.853)	(-14.175)	(0.826)	(-0.470)
GDD		-0.002**		-0.0005	-0.0007**		0.008	-0.0003*
		(-2.089)		(-0.676)	(-3.040)		(1.252)	(-1.818)
PPT		0.032		0.049	-0.025**		0.055	-0.011
		(0.797)		(1.308)	(-2.054)		(1.508)	(-1.338)
F-Test		4.25**		2.40**	1.85*		10.64**	386.66**
λ [or λ^2]			2.866**			155.175		
			(4.167)			(1.250)		
σ^2_v			11022.48			25983.80		
σ^2_u			90532.13			90531.91		

Table 1d: Yield, Noise, and Inefficiency Estimation Results for Cotton Following Crimson Clover

	Just-Pope (OLS)		***Frontier/Cross Section***			***Frontier/Panel***		
	Yield	Noise	Yield	Noise	Ineff.	Yield	Noise	Ineff.
Const.	1033.60**	11.930**	1252.21**	6.721**	6.761**	1445.17	1.984	6.440**
	(38.497)	(5.565)	(46.090)	(2.865)	(10.305)	(0.497)	(1.400)	(21.240)
NIT	0.245	0.002	-0.059	0.001	-0.0001	-2.494	0.005**	0.006**
	(0.271)	(0.762)	(-0.071)	(0.306)	(-0.131)	(-0.125)	(2.439)	(13.635)
NIT^2	-0.004		-0.0001			0.082		
	(-0.413)		(-0.012)			(0.356)		
D_{NoTill}	-21.670	0.174	-18.495	0.054	0.007	2619.02	3.302**	1.864**
	(-1.249)	(0.892)	(-1.173)	(0.252)	(0.121)	(0.581)	(25.623)	(67.609)
D_{1995+}	370.550	0.627	390.987**	-0.008	-0.038	291.645**	-0.089	-0.066
	(12.294)	(1.515)	(14.532)	(-0.017)	(-0.303)	(11.206)	(-0.327)	(-1.129)
Time	-47.693	-0.111**	-50.169	-0.014	-0.008	-47.697**	0.014	0.003
	(-15.545)	(-2.672)	(-19.807)	(-0.317)	(-0.641)	(-17.763)	(0.525)	(0.548)
GDD		-0.0009		-0.00004	-0.0007**		0.329	-0.0002**
		(-1.255)		(-0.060)	(-3.507)		(0.729)	(-2.362)
PPT		-0.007		0.018	0.189*		0.020	0.004
		(-0.192)		(0.449)	(1.694)		(0.809)	(0.791)
F-Test		1.83*		0.14	5.64**		110.56**	795.27**
λ [or λ^2]			2.601**			[112.986]		
			(5.344)			(0.652)		
σ^2_v			9683.81			20201.89		
σ^2_u			65500.42			65149.11		

Table 2a: Yield, Noise, and Inefficiency Estimation Results for Corn Following No Cover

	Just-Pope (OLS)		***Frontier/Cross Section***		
	Yield	Noise	Yield	Noise	Ineff..
Const.	80.667**	-5.810	97.863**	-18.474	-0.230
	(6.613)	(-0.123)	(4.640)	(-0.379)	(-0.030)
NIT	0.526**	0.0002	0.548**	-0.002	-0.00006
	(3.584)	(0.041)	(3.674)	(-0.563)	(-0.086)
NIT^2	-0.001**		-0.001**		
	(-2.067)		(-2.060)		
Time	-5.429		-4.691		
	(-1.147)		(-0.718)		
Days7086		0.248		0.589	0.137
		(0.154)		(0.355)	(0.526)
Precip.		-0.334		-1.000	-0.441
		(-0.081)		(-0.233)	(-0.655)
F-Test		0.56		1.64	1.83
λ			1.130		
			(1.070)		
σ^2_v			446.75		
σ^2_u			570.78		

Table 2b: Yield, Noise, and Inefficiency Estimation Results for Corn Following Wheat

	Just-Pope (OLS)		***Frontier/Cross Section***		
	Yield	Noise	Yield	Noise	Ineff..
Const.	27.282	133.671**	64.203**	20.092	0.509
	(1.373)	(2.662)	(2.440)	(0.412)	(0.046)
NIT	0.758**	-0.005	0.800**	0.008*	0.0003
	(3.784)	(-1.177)	(4.022)	(1.787)	(0.367)
NIT^2	-0.002**		-0.002**		
	(-2.298)		(-2.503)		
Cover Yld.	-0.002	0.0002	0.003	-0.0001	0.00006
	(0.433)	(0.884)	(0.779)	(-0.570)	(1.057)
Time	12.557*		9.375		
	(1.910)		(0.987)		
Days7086		-4.655**		-0.876	0.171
		(2.884)		(-0.527)	(0.456)
Precip.		12.760		3.067	-0.654
		(2.884)		(0.714)	(-0.674)
F-Test		5.62**		3.59**	3.80**
λ			2.279		
			(0.846)		
σ^2_v			419.84		
σ^2_u			2180.48		

Table 2c: Yield, Noise, and Inefficiency Estimation Results for Corn Following Hairy Vetch

	Just-Pope (OLS)		*Frontier/Cross Section*		
	Yield	Noise	Yield	Noise	Ineff..
Const.	89.651**	81.766	146.801**	48.748	13.667
	(4.192)	(1.598)	(3.868)	(1.094)	(0.999)
NIT	0.345	0.005	0.364	0.008**	0.0001
	(1.013)	(1.282)	(0.692)	(2.058)	(0.123)
NIT^2	-0.748		-0.0008		
	(-0.409)		(-0.302)		
Cover Yld.	0.004	0.0002	0.002	0.00004	0.00008
	(0.635)	(0.687)	(0.135)	(0.121)	(0.918)
Time	3.194		3.193		
	(0.331)		(0.186)		
Days7086		-2.831		-1.704	-0.243
		(-1.619)		(-1.119)	(-0.520)
Precip.		7.836*		4.671	0.325
		(1.763)		(1.207)	(0.273)
F-Test		3.57**		2.28*	7.23**
λ			3.887		
			(0.930)		
σ^2_v			297.20		
σ^2_u			4491.35		

Table 2d: Yield, Noise, and Inefficiency Estimation Results for Corn Following Crimson Clover

	Just-Pope (OLS)		***Frontier/Cross Section***		
	Yield	Noise	Yield	Noise	Ineff..
Const.	-52.921**	34.243	-15.036	-10.581	17.042
	(-3.672)	(0.509)	(-1.019)	(-0.158)	(0.712)
NIT	0.380**	-0.004	0.417**	0.005	-0.0001
	(2.185)	(-0.834)	(2.432)	(0.964)	(-0.081)
NIT^2	-0.001		-0.001		
	(-1.108)		(-1.366)		
Cover Yld.	0.030**	-0.0004	0.027**	0.0003	0.0001
	(10.446)	(-0.530)	(8.865)	(0.462)	(0.495)
Time	1.415		2.667		
	(0.301)		(0.646)		
Days7086		-0.850		0.422	-0.444
		(-0.380)		(0.190)	(-0.557)
Precip.		1.979		-1.441	0.985
		(0.369)		(-0.270)	(0.515)
F-Test		1.79		0.48	0.21
λ			5.112		
			(1.075)		
σ^2_v			44.81		
σ^2_u			1170.98		

Figure 1a: Normal Distributions of ε (Just-Pope) for Cotton Systems with No Cover, Wheat, Vetch, and Clover Covers

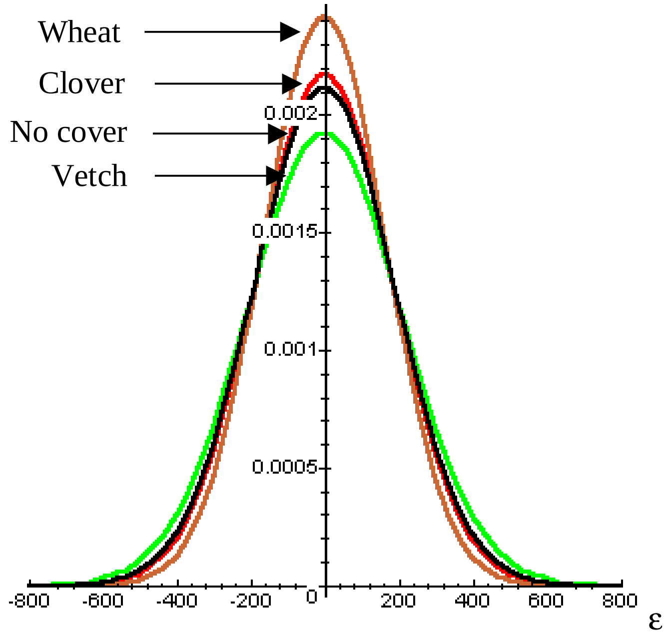

Figure 1b: Normal-Half Normal Distributions of $\varepsilon = v - u$ (cross-section), for Cotton Systems with No Cover, Wheat, Vetch, and Clover Covers

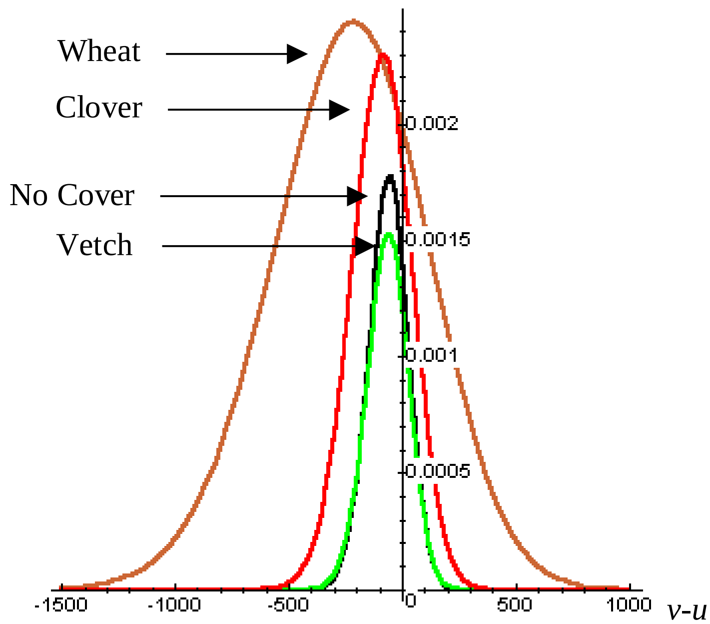

Figure 1c: Normal Distributions of *v* (cross section), for Cotton Systems with No Cover, Wheat, Vetch, and Clover Covers

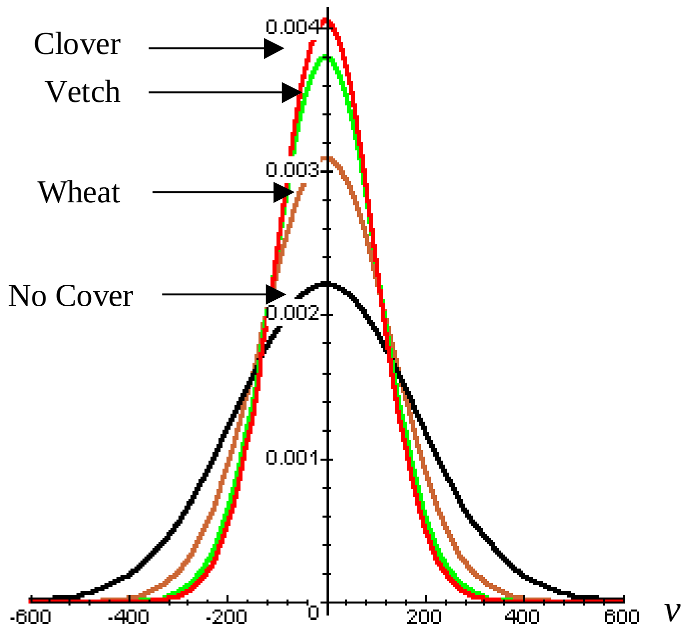

Figure 2a: Normal Distributions of ε (Just-Pope) for Corn Systems with No Cover, Wheat, Vetch, and Clover Covers

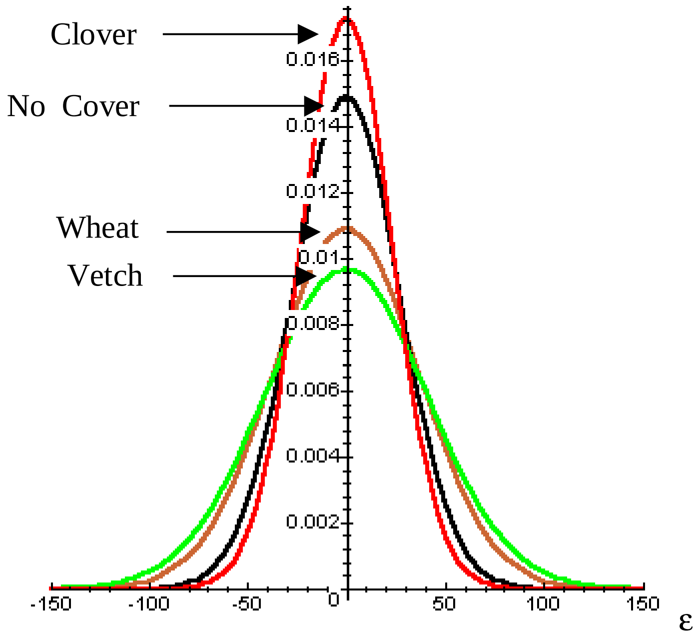

Figure 2b: Normal-Half Normal Distributions of $\varepsilon = v - u$ (cross section), for Corn Systems with No Cover, Wheat, Vetch, and Clover Covers

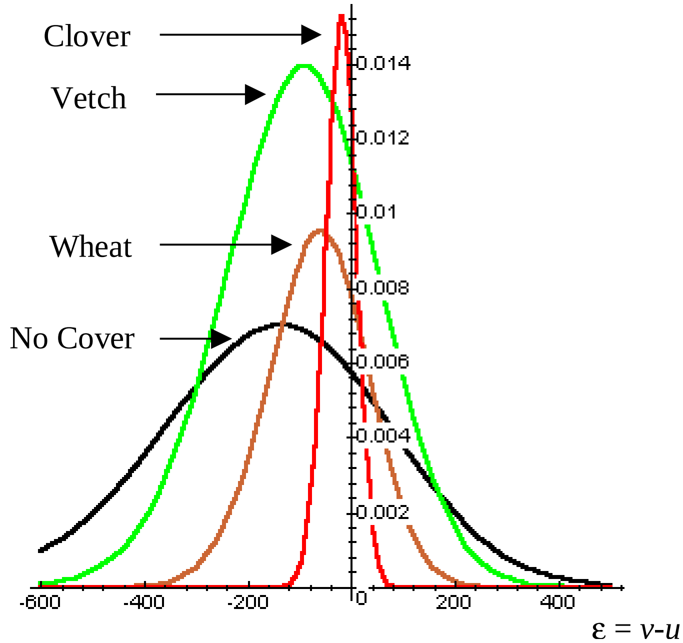

Figure 2c: Normal Distributions of *v* (cross section), for Corn Systems with No Cover, Wheat, Vetch, and Clover Covers