Price Uncertainty and Agricultural Productivity

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Abstract: This paper examines the effects of price uncertainty on agricultural productivity. Appelbaum(1991) provided an empirical framework to analyze the effects of uncertainty on firm behavior. We apply the model to the U.S. agricultural sector, using a parametric rather than a nonparametric approach to obtain the measurement of price uncertainty and risk.

Keywords: risk, uncertainty, productivity

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1. Introduction

Appelbaum(1991) provided an empirical framework to analyze the effects of uncertainty on firm's behavior. In particular, they provided a model which can be used to calculate productivity growth for firms facing uncertainty. The model can also by used to decompose total factor productivity into its various components and identify the contributions of price uncertainty and risk aversion to productivity growth. In applying the model to the textile industry, Appelbaum(1991) used a nonparametric method to estimate output price uncertainty. In this paper, we apply the model to the U.S. agricultural sector, using a parametric approach to obtain the measurement of price uncertainty and risk.

2. Model specification.

Consider a production function $y=F(x,t)$, where y is output, x is the vector of inputs, t a time shift variable, and F is a continuous, nondecreasing quasi-concave function. Assume uncertainty enters through output price so that output price is a random variable distributed according to the density function $g(p)$ with $E(p)=\bar{p}$, $Var(p)=\delta_p^2$. Assume farms maximize expected utility of profits $E[U(\pi)]$, where π is the profit given by

$$\pi = pF(x,t)-wx \qquad (1)$$

and $U(.)$ is Von-Neumann-Morgenstern utility function with $U'>0$.
Write the maximization problem as

$$Max\ E[\mathrm{U}(py-C(w,y,t)] \qquad (2)$$

Where $C(w,y,t)$ is the usual cost function. The first order condition yields

$$\bar{p} = \frac{\partial C(w,y,t)}{\partial y} + \theta(y)\,, \qquad (3)$$

where $\theta(y) \equiv -\mathrm{Cov}[U'(\pi),p]/E[U'(\pi)]$, is the marginal risk premium, which is positive, zero, or negative depending on whether the farm is risk averse, risk neutral, or risk loving. Another way to derive this is to define the risk premium , $\gamma(y)$, by the condition

$$E[\mathrm{U}(\pi)]=\mathrm{U}[\mathrm{E}(\pi)-\gamma(y)] \qquad (4)$$

thus the marginal risk premium is

$$\theta(y) = \frac{\partial \gamma(y)}{\partial y} \qquad (5)$$

Using a second order approximation of expected utility we can write:

$$E[\mathrm{U}(\pi)] \approx \mathrm{U}[\mathrm{E}(\pi) - \frac{1}{2} R\, var(\pi)] \tag{6}$$

where R is the measure of absolute risk aversion, which we assume to be constant. Risk premium and the marginal risk premium can be written as

$$\gamma = \frac{1}{2} R\, \mathrm{var}(\pi) = \frac{1}{2} R y^2 \sigma_p^2 \tag{7}$$

$$\theta(\mathrm{y}) = \frac{\partial \gamma}{\partial \mathrm{y}} = \mathrm{Ry}\sigma_\mathrm{p}^2 \tag{8}$$

Output optimality condition can therefore simply written as

$$\bar{\mathrm{p}} = \frac{\partial \mathrm{C}(\mathrm{w}, \mathrm{y}, \mathrm{t})}{\partial \mathrm{y}} + Ry\, \sigma_\mathrm{p}^2 \tag{9}$$

In estimation we need some information about the first and second moments of output price. We assume aggregate demand is given by

$$P=D(Q,I,X,u), \tag{10}$$

where Q is the aggregate output, I is a measure of income to characterize income effect, X is the net export, and u is a random variable with $E(u)=0$. In estimation we assume D is linear in log. Given estimates of $\bar{\mathrm{p}}$ and σ_p^2, we then estimate the model which consists of cost, input demand, and output functions, and further analyze the effects of uncertainty on productivity.

The various productivity measures that we will calculate in this paper include:

(i) growth rate of total cost (*RGTC*);

(ii) growth rate of average cost (*RGAC*);

(iii) growth rate of average cost excluding the effects of changes in factor prices (*RGCE*), which is equivalent to the usual measure of growth rate of total factor productivity.

Differentiating the cost function we obtain the rate of growth of total costs, RGTC, as

$$RGTC \equiv \dot{C} = \mu\, \dot{y} + {}_{i}\; s_i\, \dot{w}_i + \dot{T}\ , \tag{11}$$

where $\mu = \partial \ln C / \partial \ln y$ is the scale elasticity, $\dot{T} \equiv \partial \ln C / \partial t$ is the rate of technical change, and s_i is the input cost share

$$\partial \ln C / \partial \ln w_i = x_i w_i / C \equiv s_i \qquad (12)$$

From (11) and using $\dot{C} = \sum_i s_i(\dot{w}_i + \dot{x}_i)$, we get the percentage shift of the cost function, $\dot{T}$, as

$$-\dot{T} = \mu \dot{y} - \sum_i s_i \dot{x}_i \qquad (13\ )$$

Define the rate of growth of average cost as

$$RGAC \equiv \left(\frac{\dot{C}}{y}\right) = (\mu - 1)\dot{y} + \sum_i s_i \dot{w}_i + \dot{T} \qquad (14)$$

which indicates that average cost may decrease due to technical change, declining input prices, or growth in output (if there is economies of scale, $\mu < 1$).
Define the rate of growth in cost efficiency, *RGCE*, as the rate of growth in average costs, excluding the effects of changes in factor prices,

$$RGCE \equiv \left(\frac{\dot{C}}{y}\right) - \dot{w} = (\mu - 1)\dot{y} + \dot{T}\ , \qquad (15)$$

where $\dot{w} \equiv \sum_i s_i \dot{w}_i$.
Clearly, *RGCE* is equivalent to the usual measure of the rate of growth of total factor productivity, *RGTFP*, which is defined as

$$RGTFP = \dot{y} - \dot{x}\ , \qquad (16)$$

where $\dot{x}$ is the rate of growth of aggregate input, defined by

$$\dot{x} = \sum_i s_i \dot{x}_i\ . \qquad (17\ )$$

Further decompose the output component in RGCE, we obtain

$$\text{RGCE} = \left[\frac{\bar{p}y}{C} - 1\right]\dot{y} + \dot{T} + \dot{B}\ , \qquad (18)$$

where $\overset{\bullet}{B} \equiv -\frac{\theta(y)y}{C}\overset{\bullet}{y} = -\frac{R\sigma_p^2 y^2}{C}\overset{\bullet}{y}$ is the contribution of uncertainty to *RGCE*. If the firm is risk neutral (R=0), or if there is no uncertainty ($\sigma_p^2 = 0$), then uncertainty does not have any effect on productivity.

Finally, as in Appelbaum(1991), we also calculate a measure of *RGCE* under the assumptions of efficient market equilibrium, which is denoted *RGCE**.

Under efficient market equilibrium, the risk premium is just enough to compensate for the existance of risk. This implies that $E(\pi) = \gamma(y)$, where we assume that *U(0)=0*. Using the approximation of expected utility, as in (6), We obtain the market equilibrium condidtion as

$$\bar{p}\, y - C(y) = \frac{1}{2} R\sigma_p^2 y^2 \tag{19}$$

and hence

$$\theta(y) = R\sigma_p^2 y = 2(\bar{p}\, y - C(y)) / y = 2(\bar{p} - AC) \tag{20}$$

where $AC \equiv C(y)/y$ is average cost.

Substitute (20) into (18) we get

$$RGCE = \left(1 - \frac{\bar{p}}{AC}\right)\overset{\bullet}{y} + \overset{\bullet}{T} \tag{21}$$

This measure is calculated in this paper to evaluate the assumption of efficient capital market in this model. The results are compared to the measure obtained from equation (18).

3.Empirical implementation

3.1 Data

We use annual data for the period 1948 through 1994, which come directly from V.Eldon Ball, et al (1991). This data includes indices for output and input price and quantity. Indices for output price and quantity includes livestock and crops, while indices for input price and quantity includes intermediate inputs, labor inputs, and capital inputs. Since we are interested in the aggregated output price and quantity, some method of aggregation is needed. In practice we use Tornqvist index to obtain aggregated output price and quantity indices for both livestock and crops.

In order to obtain $\bar{p}$ and σ_p^2, we also need data on income and net exports in the estimation of aggregate demand equation. We use personal consumption expenditure on nondurable goods to capture income effects. These data come from *Beureau of Economic analysis* time series annual data.

3.2 Econometric specification

Assume a translog cost function

$$LnC=a_0+\sum_i a_i \ln w_i + \frac{1}{2}\sum_i \sum_j a_{ij} \ln w_i w_j +$$
$$\sum_i a_{iy} \ln w_i \ln y + a_y \ln y + \frac{1}{2} \ln y + \frac{1}{2} a_{yy} (\ln y)^2 + \sum_i a_{it} t \ln w_i + a_{yt} t \ln y + a_t t + \frac{1}{2} a_{tt} t^2 ,$$
$$i,j=1,2,3 \qquad (22)$$

where $i,j=1,2,3$ represent the three inputs used in production, i.e., labor, capital, and intermediate goods respectively.
Linear homogeneity in prices and symmetry imply the following parameter restrictions:

$$\sum_i a_i = 1, \quad \sum_i a_{ij} = 0 \quad \forall j, \quad \sum_j a_{ij} = 0 \quad \forall i, \quad \sum_i a_{iy} = 0, \; a_{ij} = a_{ji}, \quad \sum_i a_{it} = 0 \qquad (23)$$

Apply Shephard's Lemma to the translog cost function (22) we obtain the input cost share equations:

$$s_1 = a_1 + a_{11} \ln w_1 + a_{12} \ln w_2 + a_{13} \ln w_3 + a_{1y} \ln y + a_1 t$$
$$s_2 = a_2 + a_{12} \ln w_1 + a_{22} \ln w_2 + a_{23} \ln w_3 + a_{2y} \ln y + a_2 t$$
$$s_3 = a_3 + a_{13} \ln w_1 + a_{23} \ln w_2 + a_{33} \ln w_3 + a_{3y} \ln y + a_3 t \qquad (24)$$

where s_1, s_2 and s_3 are the cost shares of labor, capital and materials respectively. In estimation we drop the last share demand since cost shares sum to one.
Given the cost function (22) we obtain the output optimality condition (9) as

$$\bar{p} = (a_y + a_{1y} \ln w_1 + a_{2y} \ln w_2 + a_{3y} \ln w_3 + a_{yy} \ln y + a_{yt} t) C / y + Ry\sigma_p^2 \qquad (25)$$

In estimation we also assume that technical progress is Hicks neutral thus imposing further restrictions on the parameters:

$$a_{it} = 0 \; \forall i, \; a_{yt} = 0 \qquad (26)$$

In order to estimate this system we must first obtain the first two moments of output price. Specify the aggregate demand equation (10) as log-linear[1] and include one lagged values of each of the independent variables in the equation, we have:

$$\log(P)_t = a_0 + \sum_{i=0}^{1} b_i \log(Q)_{t-i} + \sum_{i=0}^{1} c_i \log(I)_{t-i} + \sum_{i=0}^{1} d_i \log(X)_{t-i} + u_t \qquad (27)$$

where the distribution of u_t is normal with E(u_t)=0, Var(u_t)=σ_t^2.
Our procedure is as follows:
First, we use OLS to estimate the aggregate demand equation (27), and obtain the mean and variance ^{2} of output price. The variance of u_t is obtained by using a weighted average of squared residuals of three lags from the regression, *i.e.,*

$$\sigma_t^2 = 0.6 * \hat{u}_{t-1}^2 + 0.3 * \hat{u}_{t-2}^2 + 0.1 * \hat{u}_{t-3}^2, \qquad (28)$$

where $\hat{u}_t^2$ is the squared residual from the regression of output price equation at time t. After appropriate transformation for the logs, we obtain series of $\bar{p}$ and σ_p^2.

Secondly, using estimates of $\bar{p}$ and σ_p^2, we estimate (22), (24), and (25) using maximum likelihood method, with Hicks neutrality (26) and homogeneity and symmetry assumptions (23) imposed.

3.3 Discussion of results

The parameter estimates are given in table 1.
We checked for monotonicity and concavity in input prices. Monotonicity is satisfied at all data points. Concavity is violated at 13 out of 45 data points.

Estimate of *R* is positive ($\hat{R}$=9.24785) and highly significant. This suggests strong evidence of risk aversion in the agricultural sector. Consequently, we also reject the null hypothesis that marginal risk premium θ is zero, since *R=0* is the condition for the marginal risk premium to be zero at all *t*.

We calculated the estimated values of the risk premium, $\hat{\gamma}(t)$, marginal risk premium, $\hat{\theta}(t)$, and the scale elasticity μ. These results are given in Table 2. The results show that the scale elasticity is less than 1 for all the periods considered.
We also calculated *RGAC*, *RGCE*, their component and contribution of uncertainty to *RGCE,* namely, $\dot{B} \equiv (R\sigma_p^2 y^2 / c)\,\dot{y}$. In calculation, we use the Tornqvist index as a discrete approximation to the corresponding continuous Divisia indices. These measures are reported in Table 3.
Our results show that in most periods average cost has been increasing. Decomposing *RGAC* into effects of technical change, input price changes, and output growth, we can see that the effects of input price changes are stronger than all the other factors. After accounting for this effect, the pattern for *RGCE* shows that total factor productivity improves. Further decomposing *RGCE,* we notice that for most periods, technical change, $(\dot{T})$, has contributed positively to productivity growth, though its contribution is very

small in absolute terms for some periods. Contribution of uncertainty, $\dot{B}$, is very low throughout the period.
We also calculated the rate of growth in productivity, as defined by equation (21), for the case when capital markets are efficient. The figures are given in Table 3 as *RGCE**. The results show that the two models yield somewhat different results.

4. Conclusion

In this paper we utilize an empirical framework to calculate agricultural productivity growth under price uncertainty.
The results show that price uncertainty had a small but significant effect on productivity growth.

Table1. Parameter estimates

Parameter	Estimate	Standard Error	t-statistic
a_{2y}	.054773	.934465E-02	5.86142
a_{1y}	.077518	.010100	7.67543
a_{11}	.065344	.502409E-02	13.0061
a_{12}	-.107869	.690233E-02	-15.6279
a_{22}	.035225	.012234	2.87929
a_2	.884417E-02	.124750E-02	7.08952
a_1	.012137	.875280E-03	13.8662
a_0	-.217242	.079126	-2.74554
a_y	.314337	.723554E-02	43.4435
a_{yy}	-.011484	.021669	-.529944
a_t	.055764	.601392E-02	9.27253
a_{tt}	-.858103E-03	.161328E-03	-5.31900
R	9.24785	1.64640	5.61703

Table2. Marginal risk premium(θ), risk premium (γ), and scale elasticity (μ).

year	θ	γ	μ
1953	0.017317	0.0086613	0.42548
1954	0.011050	0.0054167	0.43471
1955	0.0084750	0.0042489	0.42568
1956	0.010318	0.0051947	0.41188
1957	0.011515	0.0055589	0.38338
1958	0.014209	0.0071731	0.38265
1959	0.013300	0.0069713	0.36835
1960	0.012646	0.0063855	0.36439
1961	0.011675	0.0058567	0.36827
1962	0.012722	0.0063562	0.37164
1963	0.013942	0.0070308	0.37560
1964	0.014725	0.0072944	0.37815
1965	0.020640	0.010106	0.37683
1966	0.027561	0.013609	0.36275
1967	0.030300	0.015266	0.34896
1968	0.036315	0.018505	0.33122
1969	0.040380	0.020096	0.31451
1970	0.045205	0.022159	0.29655
1971	0.047901	0.024615	0.31136
1972	0.044496	0.023039	0.31383
1973	0.041274	0.020877	0.33763
1974	0.15752	0.074702	0.36991
1975	0.20412	0.098873	0.39635
1976	0.13366	0.069639	0.35031
1977	0.097795	0.050813	0.33072
1978	0.090571	0.047168	0.32701
1979	0.10898	0.056928	0.31017
1980	0.21856	0.10840	0.28406
1981	0.20699	0.10557	0.25566
1982	0.18017	0.095262	0.24332
1983	0.17341	0.073487	0.24580
1984	0.17108	0.081890	0.23672
1985	0.13694	0.077944	0.26788
1986	0.15167	0.074050	0.28822
1987	0.16237	0.077359	0.27175
1989	0.21033	0.095595	0.29668
1990	0.23016	0.11140	0.32547
1991	0.23500	0.12702	0.33265
1992	0.25897	0.13002	0.33120
1993	0.27255	0.13872	0.32276
1994	0.29856	0.14193	0.34913

Table 3. Productivity measures and their component

year	$\mu \dot{y}$	$\dot{T}$	$\dot{B}$	$\dot{W}$	*RGCE*	*RGAC*	*RGTC*	*RGCE**
55	-0.00874	-0.02257	0.000246	0.008883	-0.0112	-0.00232	-0.02243	-0.03407
56	0.009573	0.03566	-0.00021	-0.02257	0.022744	0.000177	0.022665	0.049086
57	0.001758	-0.01052	-4.7E-05	0.052019	-0.01303	0.038991	0.043258	-0.00802
58	-0.01612	2.16E-05	0.000466	0.074669	0.02594	0.10061	0.058576	-0.0242
59	0.017097	-0.0207	-0.00061	0.044746	-0.04828	-0.00353	0.041145	0.003989
60	0.01385	0.007763	-0.00047	0.043529	-0.01599	0.027541	0.065141	0.030091
61	-0.0136	0.001146	0.000421	0.026449	0.024865	0.051314	0.013996	-0.02187
62	-0.00244	-0.02135	6.85E-05	0.024429	-0.01716	0.007269	0.000642	-0.02541
63	-0.00149	0.001031	4.28E-05	0.047769	0.003542	0.051311	0.047314	-0.00138
64	0.003494	-0.00168	-0.00011	0.0285	-0.00749	0.021009	0.03031	0.003887
65	-0.00674	-0.01527	0.000207	0.048141	-0.00418	0.043957	0.026133	-0.02606
66	-0.00441	-0.00608	0.000181	0.052643	0.00121	0.053852	0.042147	-0.01287
67	0.003058	-0.00193	-0.00016	0.11167	-0.0073	0.10437	0.1128	0.003085
68	0.007033	-0.01394	-0.0004	0.064174	-0.02706	0.037114	0.057268	-0.00194
69	0.003768	-0.02207	-0.00025	0.081824	-0.02968	0.052146	0.063523	-0.01478
70	-0.00744	0.012295	0.000528	0.078836	0.028507	0.10734	0.083693	-0.00262
71	-0.00449	0.005865	0.000338	0.097635	0.016518	0.11415	0.099009	-0.00404
72	0.014688	-0.02225	-0.00119	-0.01057	-0.05473	-0.0653	-0.01813	0.007434
73	0.002377	0.000119	-0.00017	0.032409	-0.00508	0.027331	0.034905	0.004996
74	-0.00789	0.028685	0.000401	0.1643	0.044162	0.20846	0.1851	0.012798
75	-0.02385	0.016704	0.003656	0.087615	0.057333	0.14495	0.080466	-0.02508
76	0.008392	-0.02336	-0.00162	-0.00654	-0.03614	-0.04268	-0.02151	-0.01149
77	0.025542	0.000472	-0.0033	0.15113	-0.0469	0.10423	0.17714	0.044899
78	-0.00091	-0.01436	8.39E-05	0.093112	-0.01252	0.080591	0.077844	-0.01611
79	0.000749	0.041223	-5.9E-05	0.050929	0.039682	0.090611	0.092901	0.042736
80	0.000935	0.017551	-8E-05	0.14515	0.015471	0.16062	0.16363	0.019625
81	-0.0147	0.024797	0.002183	0.16861	0.061849	0.23046	0.17871	-0.01138
82	0.00712	-0.02711	-0.00101	0.14278	-0.04784	0.094944	0.12279	-0.00739
83	0.008773	-0.03332	-0.0011	0.09805	-0.06061	0.037446	0.0735	-0.00729
84	-0.05439	0.021226	0.005485	-0.02045	0.18811	0.16766	-0.05361	-0.14064
85	0.028828	-0.03167	-0.00315	0.067136	-0.12463	-0.05749	0.06429	0.057628
86	0.046399	-0.07561	-0.00486	-0.1009	-0.20242	-0.30332	-0.13011	0.046898
87	-0.04421	0.004453	0.00471	-0.10089	0.11364	0.012752	-0.14065	-0.09963
88	-0.00666	-0.01152	0.000765	0.044666	0.006317	0.050983	0.026486	-0.02822
89	-0.01397	0.015617	0.001836	-0.01164	0.048737	0.037096	-0.01	-0.01493
90	0.020461	-0.03774	-0.00275	0.054591	-0.08015	-0.02556	0.037312	0.001542
91	0.036731	-0.026	-0.00522	0.043408	-0.09969	-0.05628	0.054139	0.041427
92	-0.02444	0.035443	0.003536	-0.00091	0.084794	0.083884	0.010094	-0.00955
93	0.004411	-0.02373	-0.00069	0.030797	-0.03298	-0.00219	0.011481	-0.01521
94	-0.02384	0.0208	0.003522	0.005352	0.065236	0.070588	0.002317	-0.02057

Note:

1. We choose log-linear specification in the aggregate demand equation after comparison with linear form. Results suggest that log-linear specification performs better.
2. Log-linear specification in the demand equation implies that the output price is distributed as lognormal. So the formula used to obtain the mean and variance of output price is:

   For log(p)~n(μ, σ^2),

   E(p)=$e^{\mu+\sigma^2/2}$,

   Var(p)=$e^{2(\mu+\sigma^2)} - e^{2\mu+\sigma^2}$.

References:

1. Appelbaum, E. (1991) "Uncertainty and the Measurement of Productivity", *Journal of Productivity Analysis*. 2., pp 157-170.

2. Eldon Ball, V. et. al, (1997) "Agricultural Productivity revisited", *American Journal of Agricultural Economics.* 79., pp 1045-1063.