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PRODUCTION RISK AND ADVANTAGES OF MIXED FARMING IN THE PAKISTAN PUNJAB

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I. INTRODUCTION

AGRICULTURAL households in developing countries face substantial risk of farm income fluctuations. Farm income is subject to yield and price risk, both of which are significant because of the dependence of farming on weather. Risk considerations are more important for poor farmers because their income is low and formal insurance arrangements are seldom available.[1] Increased income risk is itself a loss of welfare to risk-averse households. It might make modern crop technology less attractive to farmers and delay agricultural development in developing countries. For these reasons, there is a large literature on price and yield variability (Kuchiki 1990; Anderson and Hazell 1989; Thirwall and Bergevin 1985; Newbery and Stiglitz 1981; Johnson 1975).

It should be emphasized here that what matters to risk-averse households when they decide on crop production is the variability of net profit, rather than that of yields or prices per se. Nevertheless, only a few studies have investigated the variability of net profits at the individual farm level, mainly due to the difficulty in obtaining data.[2] Aggregate data on yields and prices are now widely available for developing countries. Experimental yield data have been also accumulated from agricultural research stations (Anderson and Hazell 1989, part 2). On the other hand, reliable data on yield and input at the farm level are not often available as panel data with a time-series dimension.

The scarcity also applies to South Asian agriculture. Some authors have estimated crop income variability in semiarid India using household data collected by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (Walker and Ryan 1990). For Pakistan, however, to the author's knowledge, only a few studies are available, which investigated separably price variability (Byerlee

[1] See, for example, papers reported in "Symposium on Consumption Smoothing in Developing Countries" (*Journal of Economic Perspectives* 9, no. 3 [1995]) for a review of recent literature on risk, household decisions, and rural institutions in developing economies.

[2] In the case of U.S. agriculture, for example, Heifner and Coble (1996) addressed this issue through estimating farm-level yield-price correlations.

and Iqbal 1987; Mohammad 1985) or crop yield variability (Ahmed and Mahmood 1992).

Therefore, the current paper attempts to fill this gap by estimating the variability of net profits at the individual farm level in the case of Pakistan Punjab's agriculture. The empirical model of profit variability in this paper exploits as much information as possible from time-series data of market prices and aggregate yields and panel data of household production with a short-time horizon. These three types of data are more readily available than household panel data with a longer time horizon. Therefore, the methodology used in this paper can be applied easily to other situations as well.

The empirical model is applied to a case of mixed farming in the rice-wheat zone in Pakistan's Punjab, for which the author has shown the importance of livestock as a consumption-smoothing measure under income and price risks (Kurosaki 1995a). The study area is well irrigated and famous for the rapid adoption of high-yielding varieties of wheat in the late 1960s and the early 1970s. Nevertheless, yield risk on individual farms is not negligible. Price risk also affects agricultural households since most of them market their products through private channels. This paper shows that production risk, in terms of the variability of net profits at the farm level, is indeed substantial. A correlation analysis of the net profit variability further shows that profits from green fodder and milk are substantially negatively correlated, which implies that it is advantageous, in terms of risk diversification, to combine fodder production and milk production in one enterprise. Thus, this paper sheds a new light on the advantages of mixed farming in South Asia, where a macroeconomic shift toward livestock products in value-added composition from agriculture was experienced (Kurosaki 1995a, fig. 1).

In the following, Section II gives information on the study area and sample households. Section III proposes an empirical model of profit variability. The model shows that profit variability at the farm level is determined by the variability of the regional average of per-unit revenues and the yield variability that is idiosyncratic to households. Section IV estimates the former using secondary time-series data. Section V estimates the latter using three-year household data. Section VI combines the two sets of estimation results to obtain parameters characterizing net profit variability. The variability of profits and the correlation coefficients among them are discussed. Section VII concludes the paper.

II. STUDY AREA AND SAMPLE HOUSEHOLDS

To investigate the variability of crop profits at the farm level, microeconomic information is necessary. This paper uses the same household data as those in a previous paper (Kurosaki 1995a). Microeconomic data were collected from five villages in the Sheikhupura District, which belongs to the rice-wheat zone of the Punjab, by the Punjab Economic Research Institute (PERI), Lahore. From the data set of ninety-seven household observations conducted each for three years from 1988/89 to 1990/91, this paper uses the subset of fifty-nine households that were surveyed continuously with consistent information for all the three years.

Major grain commodities produced by farmers in the rice-wheat zone are basmati paddy in the *kharif* (monsoon) season and wheat in the *rabi* (dry) season. Wheat is a staple food; basmati rice is a festive food in the local diet, cultivated mainly as a cash crop. In addition to these two grain production activities, most farmers keep livestock animals and allocate a significant proportion of cultivated land to fodder crops used as green fodder. The most popular green fodder crop in *kharif* is *jowar* (sorghum) and that in *rabi* is *berseem* (Egyptian clover). The sum of areas devoted to fodder crops and the dominant grain crops (rice in *kharif* and wheat in *rabi*) amounted to 80 to 90 per cent in the study area. Therefore, this paper analyzes the profit variability of these four major crop activities (basmati paddy, *kharif* fodder, wheat, and *rabi* fodder).

Milk is the most important livestock product sold to markets regularly. Most households keep several cows and she-buffaloes for milk production. The average number of adult she-buffaloes owned by sample households was 1.93 in 1988/89, 1.92 in 1989/90, and 2.80 in 1990/91, and that of adult cows was slightly below one in all the three years. Two adult she-buffaloes in lactation produce milk that is more than sufficient to cover the needs of a household comprising eight people, which is the average household size. Households feed green fodder, dry fodder, and concentrate feeds to livestock animals including draft animals.[3] Among these sources of feed, the expenditure on green fodder (including imputed costs using market prices) accounted for the largest proportion of the total feed cost, approximately 70 per cent. The variability of milk profit is analyzed in this paper in *kharif* and *rabi* seasons separately.

It is important to notice that markets for agricultural produce in the region are well developed so that households need not be self-sufficient in green fodder for their animals or in wheat for their family consumption. Some farmers are close to being self-sufficient in green fodder, some purchase fodder from markets if necessary, and others sell fodder regularly (Table I). Almost all the households sold basmati paddy, the most important cash crop; no household purchased basmati. Wheat was sold by some households and purchased by others. In contrast to cereals, sample households did not participate much in green fodder markets. Only about one-third of the sample households sold surplus fodder and less than 10 per

[3] The importance of draft animals has decreased significantly in the study area due to the development of tractor services market. Since there were no bullock rental transactions among sample households, this paper focuses on the variability of milk profit as a representative livestock activity.

TABLE I

MARKET PARTICIPATION BY SAMPLE HOUSEHOLDS

	Sales		Purchase	
	Number	%	Number	%
Basmati paddy	290	99.7	0	0.0
Kharif fodder	97	33.3	15	5.2
Wheat	182	62.5	28	9.6
Rabi fodder	110	37.8	9	3.1

Source: The author's calculation. The original information was collected by the Punjab Economic Research Institute. See Kurosaki (1995a) for more details.
Note: Numbers show how many households had experience in selling or buying each crop in the study period. In total, 291 observations (97 each in three years) are pooled in this table.

cent purchased deficit fodder, which suggests that smaller landholders prefer to be self-sufficient in green fodder even it may imply that they need to purchase deficit wheat.

The pattern shown in Table I is consistent with the risk-averse behavior of farmers. Market transactions involve price risk. Price risk is especially high for green fodder, a bulky and perishable commodity (Section IV). The fodder price risk has two meanings: it implies *output* price risk when produced fodder is sold to the market; it also implies *input* price risk since fodder is the most important input in milk production.

III. A MODEL OF PROFIT VARIABILITY

By definition, per-acre profit of a crop is the product of its price and yield, minus total production costs per acre. In this paper, it is assumed that market price disturbances are commonly shared by sample households in a village. This assumption is justified for a situation where most farmers participate in market transactions in harvest periods with little price variation, due to, for instance, the government procurement at fixed prices (Kurosaki, forthcoming). Regarding the sources of yield variability, it is assumed that yields at the individual farm level are subject to both common and idiosyncratic disturbances. Idiosyncratic yield shocks are identically and independently distributed across individuals by definition, such as field-specific production problems due to crop destruction by animals or a delay in harvesting.

Therefore, a general model for the *ex post*, realized level of the per-acre profit of crop i on farm h in year t, π_{hit} can be expressed as

$$\pi_{hit} = p_{it}(\varepsilon_t)y_{hit}(Z_{ht}, \varepsilon_t, \eta_{hit}) - w_t \cdot x_{hit}(Z_{ht}), \tag{1}$$

where ε is a vector of common disturbances that affect output price p and per-acre crop yield y_{hi}; η is a vector of idiosyncratic disturbances that affect y_{hi}; and x is an input vector for crop production whose price vector is represented by w. The per-acre crop yield y_{hi} is a realized level, which is different from the desired or planned level of yield that is a solution to household's optimization problem. The vector Z_h denotes household characteristics. A model for per-animal milk profit is defined similarly.[4]

Equation (1) could be interpreted as a reduced-form equation of household production decisions. Structurally, y_{hit} is a function of variable inputs x. In a reduced form, since the optimally chosen x also becomes a function of Z_{ht}, it is not explicitly included in the function of $y_{hit}(..)$. If the theory of duality holds, expression in equation (1) is reduced to a per-acre profit function, which is a function of expected market prices and the vector Z_{ht} consisting of household characteristics of fixed production assets; if the duality theory breaks down, the vector Z_{ht} should include household consumption characteristics as well, and other moments of prices should be also included in the model (Pope 1982; Pope and Just 1991). Because the data covered a three-year period with price variations that were almost collinear with yearly dummies, price variables are not included in the function of $y_{hit}(..)$ when it is estimated in Section V.

In equation (1), variable inputs x are assumed to be chosen once at the beginning of a production cycle, to set aside the sequential aspect of a production process in agriculture. In reality, farmers adjust the use of variable inputs sequentially as the information regarding ε and η is revealed partially and gradually. A formal model of this reality is found, for example, in Fafchamps (1993), who investigated the sequential decisions of labor input under uncertainty and the related issues of precommitment and production flexibility. Unfortunately, this class of dynamic models is too complicated to give practical insights into the needs of this paper to define production risk. Therefore, a simple formula in equation (1) is adopted in this paper and further investigation into this aspect is left for future research.

For the estimation, the yield at the individual farm level in equation (1) is specified further as a multiple of the regional average yield $y_{it}(\varepsilon_t)$ and a household specific multiplier u_{hit}, which is subject to idiosyncratic shocks. Algebraically, it is expressed as

$$y_{hit} = y_{it}(\varepsilon_t)u_{hit}(Z_{ht}, \eta_{hit}). \qquad (2)$$

[4] One difference is that input price vector (w) for milk production is stochastic because the price of the most important input in milk production, green fodder, is unknown at the time of crop planting. On the other hand, w for crop production is assumed to be nonstochastic because the prices of important inputs in crop production such as fertilizer and seeds are known when households decide on crop production plans at the beginning of an agricultural year.

Inserting equation (2), equation (1) becomes

$$\pi_{hit} = Rev_{it}(\varepsilon_t)u_{hit}(Z_{ht}, \eta_{hit}) - w_t \cdot x_{hit}(Z_{ht}), \tag{3}$$

which shows that the part of gross revenues affected by common shocks can be expressed in one term: "per-unit gross revenue in the region" (*Rev*). It also shows that an individual household faces production risk that differs from the variability of *Rev* for three reasons: the existence of inputs, idiosyncratic yields risks, and structural differences in yield levels among households. The variability of *Rev* for each farm activity is estimated in Section IV and the yield multiplier model of $u(..)$ is estimated in Section V.

IV. VARIABILITY OF THE REGIONAL AVERAGE OF GROSS REVENUES

A. *An Empirical Model*

Considering the effects of inflation and technological changes, $p_{it}(\varepsilon_t)$ is log-linearly approximated as

$$\begin{aligned} \ln p_{it} &= \alpha_i + \beta_i t + u_{it}, \\ u_{it} &= \mu_{p_i} u_{i,t-1} + \varepsilon_{p_i t}, \end{aligned} \tag{4a}$$

where t is a time variable measured in years associated with an annual trend rate of β, and μ is an autoregression coefficient for a first order autoregressive (AR(1)) error term.

Given the approximation in equation (4a) and assuming that $y_{it}(\varepsilon_t)$ and $p_{it}(\varepsilon_t)$ are linked through a market demand function, $Rev_{it}(\varepsilon_t)$ can be also approximated similarly as a logarithmic model, which is specified as

$$\begin{aligned} \ln Rev_{it} &= a_i + b_i t + u_{it}, \\ u_{it} &= \mu_{R_i} u_{i,t-1} + \varepsilon_{R_i t}. \end{aligned} \tag{4b}$$

Correction for AR(1) structure is employed for all the commodities so that residuals can be regarded as a white noise process. To control the effects of the information contained in the government support prices, the current support prices of basmati paddy are included in the model for basmati price and revenue. The basmati support prices are usually known to farmers when they decide on their land allocation at the beginning of an agricultural year. Since the wheat support price is not yet announced when farmers choose *kharif* crops, it is not included here.[5]

[5] Obviously the past support prices of wheat may affect expectation on the market price of wheat. The empirical model for wheat price incorporates the effects of past wheat prices in the market, which reflects the information in the support prices until then.

Expected values are approximated as the natural exponential of fitted values defined as

$$\overline{\ln Rev_{it}} = \hat{a}_i + \hat{b}_i t + \hat{\mu}_{R_i}\hat{u}_{i,t-1}, \tag{5}$$

where a hat denotes a regression estimate.

The coefficient of variation (CV) and the correlation coefficients (ρ) of revenues are approximated as

$$CV_{Rev_i} \equiv \frac{\sqrt{\mathrm{Var}(Rev_i)}}{\overline{Rev_i}} \approx \sqrt{\mathrm{Var}(\ln Rev_i)} = \sigma_{R_i},$$
$$\rho_{Rev_i,\,Rev_j} \equiv \frac{\mathrm{Cov}(Rev_i,\, Rev_j)}{\sqrt{\mathrm{Var}(Rev_i)}\sqrt{\mathrm{Var}(Rev_j)}} \approx \frac{\mathrm{Cov}(\ln Rev_i,\, \ln Rev_j)}{\sqrt{\mathrm{Var}(\ln Rev_i)}\sqrt{\mathrm{Var}(\ln Rev_j)}} = \rho(\hat{\varepsilon}_{R_i},\, \hat{\varepsilon}_{R_j}), \tag{6}$$

where σ_{R_i} is a square root of the estimated variance of ε_{R_i} in equation (4b). They are estimated from the residuals adjusted for the autoregression. Similar models for market prices are also estimated from equation (4a) to examine the variability of market prices and their correlation with farm profits. The covariance of prices of consumption commodities and crop profit is an important determinant of crop choices for households who face uncertain food prices and therefore want to obtain price insurance by growing the food crop on their farms (Kurosaki 1995b; Fafchamps 1992).

B. *Data*

Equations (4a) and (4b) were estimated for the period from 1971/72 through 1990/91. The average gross revenues in the region were calculated as the product of annual prices and per-acre yields in the region for each year.

Market price data were obtained from two sources. For the prices of wheat, basmati, and milk, monthly wholesale prices in Sheikhupura were used (Pakistan, Federal Bureau of Statistics, various issues). Sheikhupura is the district headquarters of the villages surveyed. For the prices of green fodder, very few data are available and those in Sheikhupura are not available. Therefore, the prices of green fodder in a nearby market of Faisalabad were used. These data were obtained from the provincial government (Punjab Government, various issues). To represent harvest months, the average price in May and June was used for wheat and *rabi* fodder, and that in December and January for basmati and *kharif* fodder.[6]

Data on crop yields were obtained from a computerized database (Pakistan, Ministry of Food, Agriculture and Co-operatives, 1992). For basmati and wheat yields, data for the Sheikhupura District were used. For fodder yields, there are

6 Since green fodder is marketed continuously before the peak of grain harvest, other months were also examined for fodder prices. However, this adjustment did not change the regression results qualitatively. Therefore, the results based on the months described in the text are reported.

TABLE II

REGRESSION RESULTS OF TIME-SERIES MODEL

A. Regional Average Gross Revenues

	Basmati	*Kharif* Fodder	Wheat	*Rabi* Fodder
Constant	5.870	7.161	4.446	7.679
	(2.61)	(30.2)	(70.6)	(15.5)
Time trend	0.065	0.127	0.092	0.152
	(1.82)	(2.39)	(8.31)	(2.05)
Log of support price, basmati	−0.120			
	(−0.26)			
μ	0.508	0.495	0.370	0.672
	(3.36)	(1.19)	(1.85)	(2.11)
Estimates for σ	0.156	0.365	0.159	0.387
R^2	0.891	0.822	0.930	0.859
Number of observ.	19	10	19	10

B. Market Prices

	Basmati	*Kharif* Fodder	Wheat	*Rabi* Fodder	*Kharif* Milk	*Rabi* Milk
Constant	4.966	2.261	3.984	2.452	4.661	4.704
	(2.43)	(11.4)	(101)	(9.78)	(65.7)	(97.8)
Time trend	0.071	0.119	0.072	0.116	0.085	0.081
	(2.19)	(3.86)	(11.0)	(2.99)	(7.16)	(9.52)
Log of support price, basmati	0.027					
	(0.07)					
μ	0.452	0.403	0.424	0.490	0.496	0.239
	(2.66)	(1.25)	(2.49)	(1.58)	(2.47)	(1.13)
Estimates for σ	0.141	0.353	0.086	0.415	0.140	0.151
R^2	0.930	0.847	0.965	0.816	0.935	0.915
Number of observ.	19	11	19	11	19	19

Source: The author's calculation. See the text for the data source for regression.
Note: Dependent variables are log of gross revenues or log of market prices; absolute values of *t*-statistics are indicated in parentheses; μ is the coefficient of the first-order autoregression in the error term, estimated by the Cochrane-Orcutt method.

very few data. Since those for the Sheikhupura District are not available, fodder yields for the Punjab Province were used. The yield of *kharif* fodder crops is represented by that of *jowar*, and that of *rabi* fodder by that of *berseem*. Data on these fodder yields were estimated from a sample survey mostly conducted in the districts in the vicinity of the sample villages. Therefore, the use of the provincial numbers is justified considering the scarcity of the data.

Data on per-unit yield of milk are not available as a time series. The existing data are simple interpolations of survey results in the livestock census conducted every

TABLE III

CV AND CORRELATION COEFFICIENTS OF PRICES AND GROSS REVENUES

	CV	Correlation Coefficients (ρ) with Gross Revenues					
		K1	K2	R1	R2	Km	Rm
Prices:							
Pr (basmati)	0.141	0.832	–0.394	0.381	0.278		
Wkm (*kharif* fodder)	0.353	–0.428	0.993	–0.304	0.515	0.345	0.507
Pw (wheat)	0.086	0.306	0.223	0.684	0.071		
Wrm (*rabi* fodder)	0.415	0.122	0.599	–0.141	0.962	–0.142	0.029
Pm (milk)	0.146	–0.013	0.576	0.279	0.188		
Gross revenues:							
K1 (basmati)	0.156						
K2 (*kharif* fodder)	0.365	–0.464					
R1 (wheat)	0.159	0.471	–0.309				
R2 (*rabi* fodder)	0.387	0.371	0.503	–0.064			
Km (*kharif* milk)	0.140	0.019	0.443	0.306	0.049		
Rm (*rabi* milk)	0.151	–0.045	0.709	0.251	0.328		

Source: Constructed from the results in Table II.
Note: Only those parameters which are used in constructing Tables VI and VII are listed.

ten years. Therefore, the estimation of milk revenue equations is not attempted and it is assumed that the variability of average milk revenue is due only to price variability.

C. *Estimation Results*

Table II gives the regression results. Coefficient estimates on the time variable for gross revenues and market prices show a deterministic time trend. Revenues from green fodder increased with the annual growth rate of 13 to 15 per cent. These growth rates surpassed corresponding figures for basmati (6.5 per cent) and for wheat (9 per cent). These trend coefficients indicate a pattern similar to that of the coefficients for prices. The similarity suggests that the revenue and the price of a crop tend to move together in the study area. The growth rate of wheat revenue was higher than that of basmati revenue because wheat yield per acre improved during the study period. Basmati yield per acre stagnated during the same period, resulting in the lowest growth rate of its revenue.

Table III shows the estimates of *CV* and ρ constructed from the regression results. The *CV*s of revenues from grain crops (wheat and basmati) are smaller than those of green fodder revenues. As is expected, the price and the regional average revenue of a commodity are highly correlated: parameter ρ is estimated in the range of 0.68 (between wheat price and revenue) to 0.99 (between *kharif* fodder price and revenue). Also, fodder revenues and milk revenues are positively correlated with ρ values of 0.44 in *kharif* and 0.33 in *rabi*. This is expected since the milk price tends to be higher when the price of green fodder, its most important input, is higher.

Information on price variability in Table III confirms that wheat price is the most stable and green fodder price is the most volatile. The government policies of direct procurement at support prices and public issue at fixed prices are one of the reasons for the stability in wheat price (Kurosaki, forthcoming). The *CV*s of green fodder prices are estimated at around 35 per cent in *kharif* and 42 per cent in *rabi*, the highest among the prices listed in the table.

V. VARIABILITY OF YIELD AT THE INDIVIDUAL FARM LEVEL

A. *An Empirical Model*

Yield variability at the individual household level is different from the variability of regional yield for two reasons. First, output yields in individual farms are affected by idiosyncratic risks, which are by definition statistically independent of common risks that affect sample households equally. The existence of the idiosyncratic yield risk results in a more variable individual yield than the average yield. Second, technology is not identical among households in farm production activities. Expected yield and its variability may differ from farmer to farmer due to differences in, for example, land quality, ownership of machinery, and the educational level of the household head.

Incorporating these two aspects, a model of yield multiplier in equation (2) is estimated in the following form:

$$\begin{aligned} y_{hit} &= y_{it}u_{hit}(Z_{ht}, \eta_{hit}) = y_{it}[u_i(Z_{ht}) + \eta_{hit}], \\ u_i(Z_{ht}) &= \beta_i Z_{ht}, \end{aligned} \qquad (7)$$

where β_i is a parameter vector to be estimated.[7]

A convenient aspect of the model in equation (7) is that a square root of the estimated variance of η_{hit} gives an intuitive meaning of the *CV* of yields due to idiosyncratic shocks. If this number is high, it implies that individual yields vary significantly around the average yield in the year. To define y_{it} in a consistent manner, the model is estimated for the subset of sample households that were surveyed continuously.

The household characteristic variables include a dummy variable for tractor ownership (*TRDUMMY*), a dummy variable for tubewell ownership (*TWDUMMY*), the number of family members per acre (*FAMA*), and the years of completed education of the household head (*EDU*). Since these variables are predeter-

[7] Since the specification in equation (7) is ad hoc in nature, other specifications for u_{hit} were also examined such as multiplicative η_{hit}. Since the final results corresponding to Tables VI and VII were very similar, only those based on equation (7) are reported in this paper.

TABLE IV

REGRESSIONS RESULTS OF YIELD MULTIPLIER MODEL

	Multiplier over Average Yield in Each Year				
	Basmati	*Kharif* Fodder	Wheat	*Rabi* Fodder	Statistics of Independent Variables[a]
Constant	0.944	0.924	0.996	1.008	
	(19.9)	(26.0)	(19.9)	(28.4)	
TRDUMMY	–0.072	0.054	0.045	–0.056	0.107
	(1.38)	(1.39)	(0.81)	(1.46)	[0.310]
TWDUMMY	0.042	0.040	–0.056	–0.006	0.695
	(1.09)	(1.38)	(1.39)	(0.22)	[0.462]
FAMA	–0.007	0.032	–0.001	–0.014	1.202
	(0.33)	(2.15)	(0.07)	(0.95)	[0.900]
EDU	0.019	0.001	0.017	0.008	2.288
	(4.26)	(0.44)	(3.78)	(2.60)	[3.576]
Mean of dependent variable	1.000	1.000	1.000	1.000	
Std. dev. of dependent variable	0.217	0.151	0.226	0.154	
Number of observations	177	171	177	176	
R^2	0.111	0.036	0.089	0.049	
Square root of the estimated variance	0.207	0.150	0.218	0.152	

Source: See Table I.
Notes: 1. Continuously surveyed households only.
2. The absolute values of *t*-statistics are indicated in parentheses.
3. Estimated by ordinary least squares.
[a] Means are given first, followed by the standard deviations in brackets.

mined when households decide on land allocation, they are treated as exogenous variables in the estimation. The variables are constructed from the household data described in Section II. To extract full information in the panel data, another model with household dummies was estimated also. This model is expected to correct the bias from unobserved household characteristics by what is known in the panel data analysis as “fixed effects” (Judge et al. 1985, chap. 13). One disadvantage of the model with fixed effects is that coefficients on agricultural machinery dummies become unstable due to their high collinearity with household dummies.

B. *Estimation Results*

Estimation results are given in Table IV for a model without household dummies together with summary statistics of the model variables. Estimation results for a model with household fixed effects are given in Table V.

These tables show that *EDU*, the education level of the household head, raises the yield significantly for most of the crops. Therefore, education is found to im-

TABLE V

REGRESSION RESULTS OF YIELD MULTIPLIER MODEL WITH HOUSEHOLD FIXED EFFECTS

	Multiplier over Average Yield in Each Year			
	Basmati	*Kharif* Fodder	Wheat	*Rabi* Fodder
TRDUMMY	–0.118	0.202	0.155	–0.021
	(1.37)	(2.34)	(1.59)	(0.34)
TWDUMMY	0.118	0.043	–0.098	–0.005
	(2.59)	(0.95)	(1.90)	(0.14)
FAMA	–0.037	0.025	–0.085	–0.037
	(0.73)	(0.49)	(1.47)	(1.00)
EDU	0.194	0.188	0.217	0.190
	(9.20)	(9.07)	(9.12)	(12.5)
Household dummies[a]	(omitted to save space)			
R^2	0.660	0.352	0.600	0.656
Square root of the estimated variance	0.157	0.152	0.177	0.112

Source: See Table I.
Notes: 1. Continuously surveyed households only.
2. The absolute values of *t*-statistics are indicated in parentheses.
3. Estimated by ordinary least squares.
4. See Table IV for the statistics of variables and the number of observations.

[a] Only those household dummies that are not completely collinear with *TRDUMMY*, *TWDUMMY*, and *EDU* are included. The number of those independent dummies is fifty-eight.

prove management efficiency in the farm, as has been emphasized in the literature on human capital (Jamison and Lau 1982; Schultz 1961).

The effects of *TWDUMMY* and *TRDUMMY* are mixed. Although the sign of their coefficients is the same in Tables IV and V, most of them are insignificant. These facts may imply that the existence of active markets for water and tractor services in the study area makes the ownership of these machines a less critical factor in determining crop yields. This does not mean that water markets are perfect. It merely suggests that factor marginal productivities are not likely to differ appreciably among sample households. Another, stronger version of the hypothesis of efficient water markets should require that households' production decisions be separable from their status in tubewell ownership. Kurosaki (1995b) shows that the effect of tubewell ownership is more evident in land allocation decisions. The functioning of these new factor markets deserves further study. At this moment, regression results fulfill the requirements of assessing the importance of idiosyncratic shocks.

C. *Importance of Idiosyncratic Risks*

Overall fit of the regressions presented in Tables IV and V is not good, suggesting that idiosyncratic risk is important in determining yields. Estimates for the coefficient of variation of yields due to idiosyncratic shocks are in the range of 15 to 22 per cent in Table IV and 11 to 18 per cent in Table V.

The importance of idiosyncratic risks is supported further by examining the household data from a different angle. The sample average of annual basmati yield was the highest in the second year (1989/90), followed closely by that in the first year (1988/89); in the third year (1990/91) the harvest was poor (Kurosaki 1995a, table 2). Nevertheless, yield pattern at the individual household level was different from the average pattern. The number of households that experienced a worse yield in the first or second year than in the last year was twenty-two out of fifty-nine, implying that more than one-third of the sample households experienced an adverse idiosyncratic shock in the years of good harvests on average.

Similarly, the average wheat yield in the region was very high in the first year, followed by two bad years (Kurosaki 1995a, table 2). The number of sample households that experienced the highest yield in the second or third year was ten out of fifty-nine. These households experienced a favorable idiosyncratic shock in the years of bad harvests on average.

Therefore, idiosyncratic disturbances are found to be important in determining crop yields at the level of individual farms in the region. In the ICRISAT villages in semiarid India with mostly rain-fed agriculture, the *CV*s of crop yields at the level of individual farms were estimated to range from 31 per cent to 69 per cent (Walker and Ryan 1995, table 8.5). Since Walker and Ryan's numbers reflect the mixture of common and idiosyncratic risks, they are not strictly comparable to the estimates here. But it might be safe to conclude that irrigated agriculture in the Pakistan Punjab is subject to idiosyncratic yield shocks that may be less intense than in the ICRISAT area but are larger than we expect from 100 per cent irrigated agriculture.

VI. VARIABILITY OF NET PROFITS AT THE FARM LEVEL

A. *Adjustments for Input Costs*

A simple model of input costs is adopted for equation (3), in which the costs are assumed to be proportional to expected revenues. Algebraically, the model is now expressed as

$$\pi_{hi} = Rev_i[u_i(Z_h) + \eta_{hi}] - w \cdot x_{hi}(Z_h), \tag{8}$$

where

$E[w \cdot x_{hi}(Z_h)] = c_i E[p_i \cdot y_{hi}] = c_i \cdot u_i(Z_h) E[Rev_i]$,

where c_i is the mean ratio of input costs to revenue.

Other specifications were also examined, but the estimated values of *CV* and ρ did not change appreciably. The model in equation (8) was adopted because a relatively simple calculation can be used to convert average revenue parameters into individual profit parameters.

From equation (8), the parameters associated with individual profit can be expressed as

$$CV_{\pi_{hi}} = \frac{k_i}{1-c_i} CV_{Rev_i}, \quad i = \text{K1, K2, R1, R2, Km, Rm},$$

$$\rho_{\pi_{hi},\pi_{hj}} = \frac{\rho_{Rev_i, Rev_j}}{k_i k_j}, \quad i, j = \text{K1, K2, R1, R2}, \tag{9}$$

$$\rho_{\pi_{hi},\pi_{hk}} = \frac{\rho_{Rev_i, Rev_k} - c_k \dfrac{CV_{w_k}}{CV_{Rev_k}} \rho_{w_k, Rev_i}}{k_i k_k}, \quad i = \text{K1, K2, R1, R2}; \ k = \text{Km, Rm},$$

where

$$k_i = \sqrt{1 + CV_{u_{hi}}^2 \left(1 + \frac{1}{CV_{Rev_i}^2}\right)}, \quad i = \text{K1, K2, R1, R2},$$

$$k_j = \sqrt{1 + CV_{u_{hj}}^2 \left(1 + \frac{1}{CV_{Rev_j}^2}\right) + c_j^2 \cdot \frac{CV_{w_j}^2}{CV_{Rev_j}^2} - 2c_j \cdot \frac{CV_{w_j}}{CV_{Rev_j}} \rho_{w_j, Rev_j}}, \qquad j = \text{Km, Rm},$$

$$CV_{u_{hi}} = \frac{\sqrt{\text{Var}(\eta_{hi})}}{u_i(Z_h)}.$$

Idiosyncratic yield risk affects the CV and ρ of net profits via CV_{uh}, the last term in the above expression. The symbol c_j, which appears in the equation for milk that defines k_j, is the mean ratio of green fodder costs to milk revenues. Crop activities and milk production show different expressions for ρ and k in equation (9), since input prices in crop production are assumed to be nonstochastic whereas those in milk production are stochastic when households select crops to grow. Uncertainty in green fodder price is perceived by farmers both as output price risk and as input price risk.

Crop production costs are defined to include all cash costs, such as the costs of machinery services, hired labor, irrigation, fertilizer, pesticides, and seeds. Milk production cost is defined as the sum of the costs of livestock maintenance, hired labor, green and dry fodder (including the imputed value of fodder produced in the farm), and concentrates.

Based on these definitions, c_i's were calculated for each household for each agricultural activity. On average, *rabi* fodder showed the highest cost ratio at 0.69 because it requires a large amount of hired labor and water. The lowest ratio was 0.22 for *kharif* fodder, which requires less labor and water. The average cost ratios for basmati and wheat were estimated at 0.46 and 0.51, respectively. Milk production was associated with higher cost ratios between 0.62 and 0.67, mostly due to the cost of green fodder.

TABLE VI

CV AND CORRELATION COEFFICIENTS OF PRICES AND NET PROFITS AT THE INDIVIDUAL FARM LEVEL

	CV^a	Multiplier k	Correlation Coefficients (ρ) with Net Profits			
			K1	K2	R1	R2
Prices:						
Pr (basmati)	0.141		0.496	−0.360	0.222	0.256
			(0.022)	(0.002)	(0.010)	(0.001)
Pw (wheat)	0.086		0.182	0.204	0.399	0.065
			(0.008)	(0.001)	(0.017)	(0.000)
Pm (milk)	0.146		−0.008	0.527	0.162	0.174
			(0.000)	(0.002)	(0.007)	(0.001)
Net profits:						
K1 (basmati)	0.488	1.682				
	(0.022)	(0.074)				
K2 (*kharif* fodder)	0.477	1.092	−0.253			
	(0.027)	(0.005)	(0.012)			
R1 (wheat)	0.543	1.719	0.164	−0.165		
	(0.024)	(0.071)	(0.014)	(0.007)		
R2 (*rabi* fodder)	1.234	1.085	0.204	0.424	−0.035	
	(0.091)	(0.005)	(0.010)	(0.003)	(0.002)	
Km (*kharif* milk)	0.631	1.618	0.260	−0.651	0.286	−0.443
	(0.061)	(0.047)	(0.012)	(0.015)	(0.013)	(0.005)
Rm (*rabi* milk)	0.796	1.991	−0.076	−0.146	0.144	−0.611
	(0.027)	(0.021)	(0.003)	(0.005)	(0.006)	(0.005)

Source: Constructed from the results in Tables II, III, and IV. See the text for details.
Notes: 1. Standard deviations are indicated in parentheses.
2. The number of observations is 177 (continuously surveyed households only).
3. Based on regression results in Table IV for a yield multiplier model without household dummies.

[a] *CV* of prices are common to each household in the sample by definition. Therefore, no variation.

B. *Results*

Using regression results in Sections IV and V, parameters characterizing variability and correlation of net profits at the individual farm level are calibrated. Tables VI and VII present the means and standard deviations of the *CV* and ρ coefficients, calculated for each sample observation. Estimates in Table VI are based on a household yield multiplier model without household dummies and those in Table VII on a model with household fixed effects. Two sets of numbers are very similar with the same qualitative implications. The standard deviations are smaller than one-tenth of the mean coefficients in all cases, suggesting a small inter-household variation. Tables VI and VII are different in several aspects from Table III, as follows.

TABLE VII

CV AND CORRELATION COEFFICIENTS OF PRICES AND NET PROFITS AT THE INDIVIDUAL FARM LEVEL (WITH HOUSEHOLD FIXED EFFECTS)

	CV[a]	Multiplier k	Correlation Coefficients (ρ) with Net Profits			
			K1	K2	R1	R2
Prices:						
Pr (basmati)	0.141		0.577	–0.359	0.250	0.265
			(0.048)	(0.006)	(0.024)	(0.003)
Pw (wheat)	0.086		0.212	0.203	0.449	0.068
			(0.018)	(0.003)	(0.043)	(0.001)
Pm (milk)	0.146		–0.009	0.526	0.183	0.180
			(0.001)	(0.008)	(0.018)	(0.002)
Net profits:						
K1 (basmati)	0.421	1.455				
	(0.036)	(0.123)				
K2 (*kharif* fodder)	0.479	1.096	–0.294			
	(0.028)	(0.017)	(0.025)			
R1 (wheat)	0.486	1.538	0.215	–0.185		
	(0.051)	(0.160)	(0.033)	(0.018)		
R2 (*rabi* fodder)	1.194	1.049	0.246	0.437	–0.040	
	(0.089)	(0.013)	(0.022)	(0.007)	(0.004)	
Km (*kharif* milk)	0.629	1.613	0.304	–0.650	0.323	–0.460
	(0.061)	(0.047)	(0.026)	(0.018)	(0.032)	(0.008)
Rm (*rabi* milk)	0.795	1.987	–0.088	–0.145	0.163	–0.633
	(0.027)	(0.021)	(0.007)	(0.006)	(0.016)	(0.009)

Source: Constructed from the results in Tables II, III, and V. See the text for details.
Notes: 1. Standard deviations are indicated in parentheses.
2. The number of observations is 177 (continuously surveyed households only).
3. Based on regression results in Table V for a yield multiplier model with household fixed effects.

[a] *CV* of prices are common to each household in the sample by definition. Therefore, no variation.

First, the *CV*s of individual profits of six farm activities are much greater than those of regional gross revenues. The multipliers k_i or k_j defined in equation (9) are all greater than unity including those on milk profitability. By construction, k_i is greater than unity for crop activities. On the other hand, whether k_j is greater or smaller is indeterminate for milk production. The multiplier in the table is greater than unity for milk production because the effect of an idiosyncratic shock that increases the *CV* outweighs the effects of the positive correlation between fodder price and milk revenue that decreases the *CV*.

Second, the order of the *CV*s of profits among four crop activities shown in Table VI or Table VII is different from that in Table III. The *CV* of *kharif* fodder profit becomes smaller than that of wheat and comparable to that of basmati, the competing crop in *kharif*. On the other hand, the *CV* of *rabi* fodder profit becomes larger than unity, due to the higher input costs required to produce *berseem*, the most important *rabi* fodder crop.

Third, in sharp contrast to Table III, the correlation coefficient between fodder and milk profits in Tables VI and VII takes a negative sign with a large absolute value. The coefficient is estimated at −0.65 in *kharif* and −0.61 in *rabi* (Table VI) or at −0.65 in *kharif* and −0.63 in *rabi* (Table VII), which is in sharp contrast to the changes in the correlation coefficients among crop profits. The difference between the comparable numbers among crop profits in Table III and Tables VI or VII is small, and the sign of the coefficients never changes.

The correlation coefficients between fodder and milk profits at the farm level ($\rho_{\pi_{hi},\pi_{hk}}$) are substantially negative because fodder is the most important input in milk production and fodder price is the most variable. Expression in equation (9) shows that $\rho_{\pi_{hi},\pi_{hk}}$ becomes negative if (i) the cost share of fodder in milk production (c_k) is large, (ii) the *CV* of fodder price (CV_{wk}) is relatively large compared with the *CV* of milk revenue, and (iii) the correlation between fodder price and fodder revenue (ρ_{w_k,Rev_i}) is highly positive. All three conditions are fulfilled in the study area. The negative correlation between fodder and milk profit suggests that it is advantageous to combine fodder and milk production in one farm in terms of risk diversification.

As a final remark, a comparison of these findings with those from the ICRISAT India data is attempted. In semiarid India, mean household crop income variability was estimated to range approximately from 33 per cent to 47 per cent in terms of the coefficient of variation (Walker and Ryan 1991, table 10.6).[8] These figures are mostly smaller than those in Tables VI and VII. Contrary to the expectation that irrigated agriculture should yield more stable income than rain-fed agriculture, this study has found the opposite situation. It is true that crop yields per acre are more stable in irrigated agriculture such as in the rice-wheat zone in Pakistan's Punjab than in semiarid India. Nevertheless, what matters for household decisions is the variability in net profits. In semiarid India, farmers do not apply a large quantity of purchased inputs to crops whose yields are very variable. Furthermore, market prices of those crops are strongly negatively correlated with crop yields. Therefore, profit variability of these crops is not large compared with their yield variability. On the other hand, in irrigated Pakistan, because of higher input costs and lower price-yield correlation, profit variability is much larger than yield variability in terms of the coefficient of variation.

[8] Walker and Ryan estimated these numbers directly from the household panel data, which covered nine years. Therefore, their estimates are not strictly comparable to our estimates, which are estimated indirectly from both time-series data and three-year panel data.

VII. CONCLUSION

This paper has proposed a model of net profit variability at the individual farm level and applied it to Pakistan's agriculture. It has been found that the addition of idiosyncratic yield shocks and adjustment for input costs result in a much larger variability of net profits than implied by the variability of regional average gross revenues. These adjustments have resulted in a seemingly unexpected finding of higher profit variability in irrigated Pakistan than in semiarid India. Therefore, an empirical analysis of production risk based on secondary data of prices and aggregate yields alone would be highly misleading. Such an analysis is likely to underestimate the true production risk faced by farmers. Furthermore, the order of riskiness among crop activities is likely to change after these adjustments. Since the methodology proposed in this paper is relatively simple and requires data which are available in many developing countries, it can be applied to other situations also. For a situation where some inputs (e.g., irrigation water) affect not only the expected yield but also its variance, heteroscedastic production function models in line with Just and Pope's method (1978, 1979) may be incorporated in our model.[9]

Estimation results have also shown that the correlation between green fodder profit and milk profit at the farm level is substantially negative because green fodder is the most important input in milk production and its price is the most volatile. This negative correlation implies that it is advantageous, in terms of risk diversification, to combine fodder production and milk production in one enterprise. This study is the first attempt to quantify this advantage for Pakistan's agriculture.

In the past studies, especially those based on the farming-system approach or mathematical programming (Byerlee and Hussain 1992; Perry 1982; Gotsch et al. 1975), the advantage of combining fodder and milk production in one farm has been analyzed from the viewpoint of saving transaction costs of green fodder. The conclusion in this paper will be reinforced by this traditional argument, namely, when the price differential between selling and buying prices is large, households would find it more advantageous to combine the two activities. On the other hand, the current study shows that this advantage exists even when the price differential is negligible. The author's observations in the study villages suggest that the price differential is not large. It is a common practice for farmers to trade green fodder in villages at the price that equals market selling price minus transportation costs to the market. This way of transactions implies that the buying price in villages is not equivalent to the market price plus transportation costs, which is usually assumed

9 Preliminary application of Just and Pope's method to the fitted residuals of the yield multiplier model in this paper did not reveal significant heteroscedasticity with respect to inputs.

in models with an emphasis on the price differential; on the contrary, selling and buying prices of fodder in villages are approximately equal.

Kurosaki (1995a) has suggested that livestock contribute to households' consumption smoothing and that the rises in the share of the livestock subsector in agricultural value added in Pakistan should have improved welfare positions of poorer households in rural areas. This paper has quantified one of the mechanisms whereby the combination of livestock and crop production is a welfare-improving measure for risk-averse farmers. Findings in this paper have reinforced the claim that a welfare component of diversification strategies of farmers should be considered in formulating agricultural and rural development policies in Pakistan.

Although the crop combination of basmati paddy (cash crop), wheat (staple food), and fodder crops is specific to the study area, basic findings in this paper regarding crop-livestock interactions are relevant for wider geographical areas in South Asia. What is critical is the importance of dairy livestock activities carried out in the backyard of farms as an important source of household income. Therefore, for zones with a similar technology characterized by artificial irrigation and mixed farming, such as those in other irrigated tracts in the Pakistani provinces of Punjab and Sind, and the Indian states of Punjab, Haryana, and Western Uttar Pradesh, the implications derived from this paper can be applied with minor adjustments.

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