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Relative Profitability, Supply Shifters and Dynamic Output Response: The Indian Foodgrains

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Abstract

The realisation that the wage-goods constraint, if binding, could stall the growth process of a developing country, prompted policy makers to encourage agriculture by various means. The success of public policy depends, however, on how strongly farmers respond to the incentives provided. Using a large panel dataset pertaining to Indian agriculture - spanning the period 1967-68/1999-00, and covering the 6 important food crops cultivated across 16 major states - we provide estimates of area, yield and output elasticities w.r.t price and nonprice factors. We find consistent evidence, that the supply response of food crops is influenced by rainfall, input availability (specifically irrigation, fertilizer and improved seeds), and relative profits, in that order of importance. Our results prompt us to conclude, that all things considered, the preferred policy should be to encourage irrigation, fertilizer use and the use of modern seeds, rather than raise output support/procurement prices period after period.

Keywords: wage-goods, price incentives, supply shifters

JEL Classification: O13

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I. Introduction

One of the more obvious benefits of a dynamic food crops sector is its positive role in easing the wage-goods constraint which, if binding, could bring the entire growth process of a developing country to a pre-mature halt (Harris and Todaro, 1970; Lewis, 1954). A host of policy instruments have been used, therefore, to encourage developing country agriculture. In the Indian context, while both price and nonprice instruments were emphasized in the process, the cornerstone of the policy initiative appears to have been output price support. Thus, the Commission on Agricultural Costs and Prices[1] (CACP), established in 1965, used the instrument of 'incentive prices' backed by government procurement to encourage agricultural performance. While the ambit of the CACP in terms of crop-coverage has widened over time, in the area of foodgrains its efforts have focused almost entirely on Rice and Wheat. The government procurement operations have been more or less restricted to Wheat and Rice, and for all practical purposes there has been no procurement of the important 'coarse grains' (Bajra or pearl millets; Jowar or sorghum; Maize or corn) and pulses (particularly Gram). The reasons for this policy emphasis are probably several - that Rice and Wheat are the overwhelmingly important staples in India, that spreading resources thin (across several crops) may not prove effective, and that consumers prefer the superior grains to the coarse grains, substituting the former for the latter with rising incomes.

Wheat, and to a lesser extent Rice, have performed very well post-1965. Thus, Wheat production grew at the rate of 4.8% p.a. over the period 1967-68/1999-00, whereas Rice production grew at 3.4% p.a. over the same period. By contrast, of the other important foodgrains only Maize (corn) did well, with its production growing at 2.2% p.a. Bajra, Jowar and Gram production, however, was more or less stagnant - growing at a mere 0.3% p.a. in the case of Bajra, and actually declining at -0.02% p.a. and -0.01% p.a. for Gram and Jowar, respectively, over the same period. Excessive dependence on the output price instrument, however, has lead to many problems. Not only has it lead to an imbalanced growth of the foodgrains, it has also tended to institutionalise inflation (as food expenditure constitutes a large proportion of domestic budgets in poor countries), and has resulted in large unsold stocks of grain with the procurement agencies, which recently peaked at over 60 million tons (Government of India, 2003). Inordinate increases in output prices is obviously not the last word on encouraging the performance of the Indian food crops. What are the important factors we must ask, therefore, that lie behind the output responses of the foodgrain crops? Do they respond strongly to output prices in all cases? And/or do they respond strongly to movements in nonprice factors such as the availability of high yielding variety seeds (HYVs), fertilizer, and water (i.e. irrigation and rainfall)? The relative magnitudes of the price and nonprice elasticities of output would help to suggest the appropriate instruments that policy makers may use to encourage their production; although the relative importance of nonprice instruments need not imply that price instruments are ineffective (Nerlove, 1979). Further, one would like to know whether the short-run elasticities of output (both price and nonprice) are significantly smaller then the long-run elasticities? For if so, that would indicate various constraints on farmers' response in the short-run, so that policy could more usefully focus on loosening these constraints than on infusing still more resources into providing price and nonprice incentives. To address these questions[2] we need information on the acreage, yield and output responsiveness of the individual foodgrains, with respect to price and various nonprice factors.

The studies in this area relating to Indian agriculture, however, are mostly dated and use data till the mid-1970s or earlier (Krishna, 1963; Madhavan, 1972; Cummings, 1975; Ray, 1980; Krishna and Roychoudhury, 1980; and Narayana and Parikh, 1981), and/or are very narrow in terms of region or crop coverage (Krishna, 1963; Madhavan, 1972; Krishna and Roychoudhury, 1980; Lahiri and Roy, 1985; Gulati and Sharma, 1990), and/or are technically deficient. With regard to the latter-most, Krishna (1963) and Madhavan (1972) assume naive price expectations, which is not very appealing. Cummings (1975) frequently finds price-expectation and area-adjustment parameters to be larger than 1, and Ray (1980) reports long-run elasticities *smaller* than short-run elasticities; but neither explains the rationale behind the persistent overadjustment in the context of poor, resource-constrained Indian farmers. Krishna and Roychoudhury (1980) curiously define the price variable in their output response functions as the ratio of *lagged* wholesale price to the *current* input price index; and the wheat equation dispenses with a lagged dependent variable term. Lahiri and Roy (1985) report static price expectations and full area adjustment for rice, the former being especially surprising in a period of rising prices. Gulati and Sharma (1990) implicitly assume naive price expectations, and do not correct for autocorrelation. Although Behrman (1968) was amongst the first to introduce risk variables into his analysis of Thai agriculture, none of the Indian studies appear to follow suit (see Just, 1974; Pope, 1982; Pope and Just, 1991; and Chavas and Holt, 1996, for alternative risk specifications). This paper attempts to correct some or all of these deficiencies.

Section II outlines the model used in this study, and the estimation methodology adopted. Section III provides a description of the data used. Section IV presents the estimation results; and, finally, Section V underlines the important conclusions and policy implications.

II. The Model and Methodology

The Economic Model

We hypothesize that the representative farmer determines the desired area under crop i in response to relative expected profit,[3] production risk, and various enabling factors. That is

$$A^d_{it} = \alpha_0 + \alpha_1 \Pi^{re}_{it} + \alpha_2 Z_{it} + \varepsilon_{1it} \quad (1)$$

where, for crop i, A^d_{it} is the desired supply for period t, Π^{re}_{it} is the relative expected profit in period t, Z_{it} is the vector of risk variables and enabling factors (such as price risk, yield risk, rural public investment, irrigation, and rainfall) in period t,[4] and ε_{1it} is the error term such that ε_{1it} ~ (0, $\sigma^2_{\varepsilon_1}$). The relative expected profit is defined as $\Pi^{re}_{it} = \Pi^e_{it}/0.5(\Pi^e_{jt} + \Pi^e_{kt})$, i.e. the expected profit of crop i relative to the average expected profit of the two most important competing crops (j and k).

In a poor developing country (specifically Asian) context, a farmer may not be able to adjust his actual acreage towards the desired level in a single time-period, on account of credit constraints, lack of availability of inputs, the need to diversify production to spread risks etc. In the Nerlovian tradition (Nerlove, 1958) we hypothesize, therefore, that the change in acreage between periods occurs in proportion to the difference between the desired acreage for the current period and the actual acreage in the previous period. That is

$$A_{it} = A_{i(t-1)} + \gamma(A^d_{it} - A_{i(t-1)}) + \varepsilon_{2it} \qquad 0 < \gamma \leq 1 \qquad (2)$$

where, for crop i, A_{it} is the actual acreage in period t, $A_{i(t-1)}$ is the actual acreage in period t-1, A^d_{it} is the desired acreage for period t, and ε_{2it} is the error term such that $\varepsilon_{2it} \sim (0, \sigma^2_{\varepsilon_2})$. The adjustment parameter γ must lie between 0 and 2 for the adjustment to converge over time, but γ > 1 implies persistent overadjustment, and does not appear plausible in a developing country context; so we limit γ to lie between 0 and 1.

The structural form equations (1) and (2) yield the reduced form

$$A_{it} = \theta_0 + \theta_1 A_{i(t-1)} + \theta_2 \Pi^e_{it} + \theta_3 Z_{it} + \nu_{it} \qquad (3)$$

where

$$\theta_0 = \gamma\alpha_0$$
$$\theta_1 = 1 - \gamma$$
$$\theta_2 = \gamma\alpha_1$$
$$\theta_3 = \gamma\alpha_2$$
$$\nu_{it} = \gamma\varepsilon_{1it} + \varepsilon_{2it} \qquad (4)$$

The presence of the lagged dependent variable introduces (first-order) autocorrelation in the error term. But this model, as it stands, is not estimable because of the presence of the unobservable variable Π^e_{it}.

To deal with the above problem, we hypothesize à la Nerlove (Nerlove, 1958), that expectations are updated between periods in proportion to the discrepancy between the actual and expected levels of profits in the previous period. That is

$$\Pi^e_{it} = \Pi^e_{i(t-1)} + \beta(\Pi_{i(t-1)} - \Pi^e_{i(t-1)}) + \varepsilon_{3it} \qquad 0 < \beta \leq 1 \qquad (5)$$

where, for crop i, Π^e_{it} is the profit expectation for period t, $\Pi^e_{i(t-1)}$ is the profit expectation for period t-1, $\Pi_{i(t-1)}$ is the actual profit in period t-1, the expectations parameter β may be constrained to lie between 0 and 1, and ε_{3it} is the error term such that $\varepsilon_{3it} \sim (0, \sigma^2_{\varepsilon_3})$. But as Nerlove (1958) notes, using (5) directly to eliminate the unobservable variable in (3) leads to a parameter identification problem. Therefore, we use (5) *indirectly* to approximate the unobservable variable in (3) as follows (Carvalho, 1972; Nerlove, Grether and Carvalho, 1979;

Narayana and Parikh, 1981; Nerlove and Fornari, 1998; Nerlove and Bessler, 2001). For any crop i, the adaptive profit expectation hypothesis such as the following

$$\Pi^{*}_{it} = \Pi^{*}_{i(t-1)} + \beta'(\Pi_{i(t-1)} - \Pi^{*}_{i(t-1)}) \qquad 0 < \beta \leq 1 \tag{6}$$

may be expressed as an infinite-order AR process as follows

$$\Pi^{*}_{it} = \Sigma^{\infty}_{\tau=0} \; \beta'(1 - \beta')^{\tau} \; \Pi_{i(t-1-\tau)} \tag{7}$$

This can then be rewritten as an ARMA(p,q) process, under conditions of stationarity and invertibility (Judge et.al. 1985), i.e.

$$\Pi^{*}_{it} = b_1\Pi_{i(t-1)} + b_2\Pi_{i(t-2)} + ... + b_p\Pi_{i(t-p)} + \mu_{it} + c_1\mu_{i(t-1)} + ... + c_q\mu_{i(t-q)} \tag{8}$$

where μ_{it} are white noise errors. More generally, if Π_{it} is integrated of order d, we can estimate an ARIMA process of order (p, d, q) as follows

$$\Pi_{it} = b_1\Pi_{i(t-1)} + b_2\Pi_{i(t-2)} + ... + b_p\Pi_{i(t-p)} + \mu_{it} + c_1\mu_{i(t-1)} + ... + c_q\mu_{i(t-q)} \tag{9}$$

and use $\hat{\Pi}_{it}$ in lieu of Π^{*}_{it} for a given crop i.[5] In the literature cited above, (7) is referred to as 'quasi-rational expectations', because price expectations are based on all previous price information. It needs to be emphasized, however, that while (7) may *also* be a representation of quasi-rational expectations, *we use it as a re-expression of the adaptive expectations hypothesis*. In other words, although the adaptive expectations and quasi-rational expectations hypotheses are observationally equivalent when expressed as (7), that does not imply that we are dropping the former expectations formation hypothesis for the latter. Equation (9), then, is merely a practical way of estimating the adaptive expectations hypothesis re-written as (7).

Estimation of (9) requires specification of p, d and q. Allowing d = {0, 1, 2}, p = {1, 2} and q = {1, 2}, we pick the best combination (p, d, q) by considering various stationarity tests, the invertibility criterion, the significance of the ARMA terms, the Schwarz criterion, the Ljung-Box-Pierce test and various error properties. Repeating this process for the two most important competing crops j and k, we estimate $\hat{\Pi}^{re}_{it} = \hat{\Pi}_{it}/0.5(\hat{\Pi}_{jt} + \hat{\Pi}_{kt})$. Substituting $\hat{\Pi}^{re}_{it}$ for the unobservable variable Π^{re}_{it} in (3), we can estimate the reduced form parameters (4). From these estimates we can derive the adjustment parameter γ, and the structural form parameters in (1), for each crop i.

It may be possible to improve the estimates of the profit expectations derived above by allowing for the possibility that the error term in the ARIMA process need not have a constant variance. For if it doesn't, it would be preferable to estimate an ARCH model (Green, 2003). To jump ahead for a moment, conducting tests of ARCH(1) effects we find that the assumption of conditionally homoscedastic errors cannot be rejected for any of the crops in our sample.

The Other Regressors

Having discussed the 'price variable'[6] $\hat{\Pi}_{it}^{me}$, we now briefly discuss the other regressors Z_{it} in our model. One of the most important inputs into agrarian production in the Indian context happens to be water. We represent it by two variables - irrigation and rainfall. The former is defined as the irrigated area under the crop (I_{it}), and the latter is simply the total rainfall (in mm) for that crop, for the current period (R_{it}).[7] A higher irrigated area is expected to have a positive effect on the area planted to that crop, insofar as it implies greater availability of assured water. Similarly, Rainfall is expected to have a positive effect on area allocation, particularly in the case of rainfed crops.

The poor resource base of the Indian farmers, and the fact that even today only about 40% of the cultivated area is irrigated (Government of India, 2003), make for high production risk. Of course, years in which output moves in a certain direction, prices tend to move in the opposite direction, so that our concern is with revenue risk. We represent this by two variables – price risk and yield risk. Price risk is defined as the coefficient of variation of prices over the current and two previous periods (CVP_{it}). In measuring yield risk, however, we must be mindful of the fact, that yield variation is endogenous to the extent that it is influenced by variations in input-use by farmers. Therefore, because yield risk is supposed to reflect that part of yield variation which is *not* within the farmer's control, we proxy it by the coefficient of variation of rainfall over the current and two previous periods (CVR_{it}).[8] The higher the price risk or yield risk associated with the production of a crop, the smaller would we expect the area allocation in favour of that crop to be.

Rural public investment – specifically in the areas of irrigation, soil and water conservation, agricultural research and education, and food storage and warehousing – may also be expected to encourage acreage under a crop insofar as they signify better infrastructure. Given that capital stock figures are non-existent, we compute this variable by using capital expenditure figures. Thus, the rural public investment variable ($\mathbf{PUBINV_{it}}$) is estimated as $[E_t+(1-d)E_{t-1}]/CFD$, where E_t is rural capital expenditure in the current period, E_{t-1} is rural capital expenditure lagged one period, *d* is the annualized rate of depreciation of the capital stock in question, and *CFD* is the capital formation deflator. Although *d* = 0.025 is assumed for the calculations, alternative assumptions about the life of the capital stock do not appear to matter.[9]

Acreage, Yield, and Output Elasticities

Although we have constructed our model in terms of area response (which provides us with the short-run and long-run *area* elasticities), farmers respond to stimuli by adjusting the other inputs into production as well. In situations of land scarcity, the latter response, leading to yield (or output per unit land) increases, is likely to dominate the area response. This, for instance, has been shown to hold for Indian agriculture in the post-1965 period (see Vaidyanathan, 1994; and the citations therein). To capture the full supply response, therefore, we also estimate a yield response model, i.e. with yield ($\mathbf{Y_{it}}$) in place of acreage ($\mathbf{A_{it}}$) in equations (1), (2) and (3)

$$\mathbf{Y^d_{it}} = \alpha'_0 + \alpha'_1 \Pi^{e}_{it} + \alpha'_2 Z_{it} + \epsilon'_{1it} \qquad (1a)$$

$$\mathbf{Y_{it}} = \mathbf{Y_{i(t-1)}} + \gamma'(\mathbf{Y^d_{it}} - \mathbf{Y_{i(t-1)}}) + \epsilon'_{2it} \qquad 0 < \gamma' \leq 2 \qquad (2a)$$

$$\mathbf{Y_{it}} = \theta'_0 + \theta'_1 \mathbf{Y_{i(t-1)}} + \theta'_2 \Pi^{e}_{it} + \theta'_3 Z_{it} + \nu'_{it} \qquad (3a)$$

where all the regressors are as defined above, and we use $\hat{\Pi}^{e}_{it}$ in lieu of Π^{e}_{it} in (3a). It is possible, however, for γ' to exceed 1 on occasion. given the fact that yields are subject to the weather. Of course, for stability it is sufficient that γ' lie between 0 and 2. In contrast to the area response model above, we include two additional regressors in the yield response model. These are the proportion of the cultivated area under high-yielding variety seeds

($\mathbf{AHYV_{it}}$), and the fertilizer input per hectare ($\mathbf{FERT_{it}}$) – for chemical fertilisers and modern seeds are considered to be the most important yield-augmenting inputs after water.[10] The yield response model gives us the short-run and long-run *yield* elasticities. Adding together the area and yield elasticities, we can derive the *output* elasticities.

III. The Data Set and Methodology

The Data Set

The models specified above were estimated for the 6 most important foodgrains in India, for the period 1967–68 to 1999–2000[11]. The food crops are the 'coarse' grains Bajra (pearl millets), Jowar (sorghum), and Maize (corn); the pulses Gram; and the 'superior' grains Rice and Wheat. Unlike previous studies (specifically in the Indian context), instead of using aggregate time series data for these crops, we use panel data, where the cross–section units are the states growing a given crop. This allows for cross–sectional or state–specific variation in the variables, in contrast to all–India data which would reduce such variation by aggregating some variables and averaging others (as in the case of, for example, Gulati and Sharma, 1990, Lahiri and Roy, 1985, and Narayana and Parikh, 1981). Only those states were selected for a given crop which produced at least 3% of the all–India output of that crop for the triennia centred on 1965–66, 1970–71, 1980–81, 1990–91 and 1999–00.[12] For instance, the states of Bihar, Madhya Pradesh, Punjab, Haryana, Rajasthan and Uttar Pradesh each produced at least 3% of the total Wheat output in the triennia mentioned above. Therefore, these six states are taken to constitute the 'Wheat sample' (Appendix 1). Having formed the state samples for the 6 crops in this manner, data for the entire period 1967–68/1999–00 were then used for the estimations. Furthermore, panel estimation allows us to incorporate sources of variation which cannot be incorporated otherwise. Thus, for any given crop, the competing crops need not be the same in each state; as, indeed, was true for some crops. Results based on panel estimation are, therefore, more efficient and representative of the constituent cross–sections.

We prefer to use farm harvest prices for computing the relative profit variable[13] for the different crops, rather than wholesale prices, contrary to the practice in the received literature. Since most Indian farmers have very limited storage facilities, and a large proportion in any case have rather small surpluses to sell, the predominant bulk of the crops are marketed soon after the harvest, and the prices farmers receive are the farm harvest prices. Wholesale prices, on the other hand, are yearly averages of the prices prevailing in the wholesale markets. While these prices tend to be close to farm harvest prices around harvest time, during the rest of the year they can rule substantially higher, and do not necessarily reflect the prices farmers receive.[14]

The data were obtained from various sources in the public domain. For Gram, data on the area under HYVs were not available, and so a proxy was used. To construct the proxy, we note that the National Pulses Development Programme was launched as late as 1986; and subsequently, pulses were brought under the purview of the Technology Mission on Oilseeds in 1990. Given that pulses production probably benefitted from improved seeds only sometime in the 1990s, for Gram we define $\mathbf{AHYV_{it}}$ = 1 for t > 1989, and 0 for the earlier period.

The samples of states for each of the six crops considered are given in Appendix 1. We were forced to drop the state of Madhya Pradesh from the sample of states for the Jowar regressions, because of lack of irrigation data. Although this state is an important producer of Jowar, the other states still accounted for about 94% of the total Jowar production in 1999–00, and close to 85% for the earlier period.[15] The variable definitions are provided in Appendix 2. The data sources drawn upon are reported in Appendix 3; and the means and standard deviations of the variables are reported in Appendix 4.

The Methodology

For estimating the acreage and yield equations (3) and (3a) for a given crop, we pool the panel data using a random effects model. A growing body of literature (Nerlove, 1967, 1971; Maddala, 1971; Nickell, 1981) shows, that this technique is superior to alternative techniques such as fixed effects or OLS estimation, for the latter may imply a significant loss of degrees of freedom and/or completely ignore the information emanating from 'between group' variation. Further, this literature argues, individual (cross-section) effects reflect our ignorance just as much as the normal residuals in the estimating equations and, therefore, there is no reason to treat the former any differently from the latter. An added consideration in our context is the presence of a lagged dependent variable amongst the set of regressors. In such specifications, the above-mentioned literature points out, random effects estimation provides consistent estimators.

Let *s = 1, ..., S* represent the cross-section units (the states), and *t = 1, ..., T* the observations on each cross-section unit. Suppressing the crop index i (because we estimate the same econometric model for each crop), the econometric model that we employ may be stated as

$$y_{st} = \bar{\beta}_1 + \Sigma_{k=2}^{K} \beta_k x_{kst} + \eta_s + e_{st} \qquad s = 1, ..., S; \quad t = 1, ..., T_s \qquad (12)$$

where $\eta_s \sim (0, \sigma^2_\eta)$

$$e_{st} = \rho e_{s(t-1)} + \psi_{st} \qquad |\rho| < 1$$

$$\psi_{st} \sim (0, \sigma^2_\psi)$$

$$E(\eta_s \eta_r) = 0 \qquad s \neq r$$

$$E(\eta_s e_{rt}) = 0 \qquad s \neq r \qquad (13)$$

The dependent variable y_{st} refers to area in equation (3) and yield in equation (3a). Variables x_{kst} denote the set of regressors discussed above. All variables - regressand and regressors - are in (natural) logs. Estimation provides GLS estimates of the reduced form model parameters,[16] which are then used to derive the structural form parameter estimates. These results are presented in Tables 1, 2 and 3, and discussed in the next section. An important assumption of random effects estimation, however, is that η_s is independent of the regressors - an assumption which may not always hold, and which is *not* required for the consistency of fixed effects estimation. Being mindful of this, for comparison purposes we also present the estimation results of fixed effects estimation, in Appendix 5.

IV. Estimation Results

From the estimation results, we find that the hypotheses that changes in area or yield occurred randomly over time are very strongly rejected for all crops – the associated Wald χ^2 values reported in Tables 1 and 2 being very large, with P–values of 0 without exception. The sign and magnitude of the coefficient of the lagged dependent variable (lagged area in the area equation, and lagged yield in the yield equation), which have implications for the dynamic stability of the models, are as per expectation in all cases. In very few cases did a regressor turn out to have the wrong sign *and* was significant.

The Area Response

Considering the area equations first (Table 1), by far the most important variable determining area allocations over time seems to be rainfall. Rainfall has a very strong positive influence on the area planted under the different crops, and the associated long–run elasticities are also the highest (Table 3).[17] Only for Wheat was the associated elasticity much smaller than for the other crops, reflecting the fact that almost the entire area under Wheat has access to assured irrigation in the three most important wheat–growing states of Punjab, Haryana and Uttar Pradesh (Table A4, Appendix 4).[18]

The irrigation variable had the expected positive sign for all crops, but was marginally insignificant in the case of Maize (using a one-tail test). The long–run area elasticities w.r.t irrigation are quite substantial for all crops (except Maize), although not very large with the exception of Rice and Wheat). This result may be better appreciated given the fact, that the coarse grains and pulses are grown under primarily rainfed conditions. Only small percentages of their cultivated areas have access to assured irrigation, and these percentages do not exhibit much variation over time.

The 'price variable', or relative (gross) profits, is mostly positive but is statistically insignificant in the case of Gram and Jowar. Note that this variable does *not* have a negative, significant influence on the area response of the coarse grains, unlike the results reported by Narayana and Parikh (1981). Even excluding Gram and Jowar, however, the associated long-run area elasticities are small, being at most about 0.1.

The risk variables, as also the public investment variable, are consistently insignificant in the case of all crops, barring the lone case of price risk in the Jowar equation. These variables may, therefore, be ignored. The area adjustment coefficient γ (Table 3) ranges between approximately 0.3 and 0.6 for Bajra, Gram, Jowar and Wheat, implying that it takes about two to three years for the 'complete' area response to occur. This is contrary to the results reported by Ray (1980) and Cummings (1975), who found over-adjustment in the short-run - a result we feel is quite implausible given the constraints Indian farmers operate under. An adjustment time of under 3 years for these crops compares quite favourably with the estimate of 2 years reported by Vasavada and Chambers (1986) for U.S. agriculture. The same cannot, however, be said for Maize, for which the adjustment time appears to be several years. The reason for this is the fact, that till recently, Maize was mostly grown by 'small-scale, subsistence oriented farmers' with a poor asset base and lack of access to inputs, which would inhibit their response to stimuli (CIMMYT, 1998). The reason for the slow adjustment of Rice, however, is totally different. The fact that it is already the single most important crop occupying about a fourth of the total cultivated area, makes it difficult to expand its acreage still further given the competing demands for other crops, the need to diversify production as a risk-mitigating measure etc.

The Yield Response

With regard to the yield equations, from Table 2 we find that again rainfall is the most important factor determining variations in yield over time, with the lone exception of Wheat; which, as we noted above, has the greatest access to assured irrigation of all the food crops. The associated long-run yield elasticities are fairly substantial for the coarse grains (Table 3).

The irrigation variable also turns out to be an important factor in determining the crop yields, with the exception of Bajra. While it has a strong positive effect on the yields of Maize, Rice and Wheat, its influence is weak in the case of Gram and Jowar. The long-run yield elasticities of Maize, Rice and Wheat w.r.t irrigation are reasonable and, indeed, even larger than the yield-elasticities w.r.t rainfall.

In addition to water, two other very important yield-enhancing inputs are fertilizer and high-yielding variety seeds. These variables have the expected positive and significant influence on the yields of all the food crops, with this effect being strongly significant in most cases.[19] The associated long-run elasticities are quite substantial in most cases. Although it is difficult to tell which of the two variables is more important for raising yields, perhaps fertilizer use is relatively more important.

The 'price variable' has the expected positive influence on the yields of all crops which, however, is not significant for Bajra and Jowar. This result implies, that after controlling for the use of irrigation, high yielding varieties and fertilizer (inputs that higher expected profits enable), an increase in expected profits still explains part of the variation in crop yields.

The risk variables appear to have a weak, negative effect on the yields of Jowar, Maize and Rice, but are quite insignificant for the other crops. In either case, the associated long-run elasticities are very small and close to zero in all cases. Finally, the rural public investment variable performs very poorly in explaining variations in yield - being insignificant for all crops except Wheat, for which it is mildly significant using a one-tail test.

The Total Output Response

By adding together the area and yield elasticities, we can derive the total output elasticities of the food crops with respect to various regressors. Table 3 shows, first, that the largest output elasticities, with the exception of wheat, are those w.r.t rainfall; a result that differs from the received literature on Indian agriculture, which reports the elasticities of supply w.r.t irrigation to be the largest (for example Gulati and Sharma, 1990; Lahiri and Roy, 1985; and Narayana and Parikh, 1981). These elasticities range from about 0.4 to about 1, being especially large for the coarse grains Bajra and Jowar and the pulses Gram, as one might expect. In other words, rainfall is the single most important factor determining supply response even today. Despite decades of massive irrigation schemes, the food crops continue to be rainfall-dependent. The only exception to this is Wheat, and to a lesser extent, Rice; which merely reflects the fact that the bulk of the irrigation capacity established over the previous decades has been devoted to Wheat and Rice production.

Second, the output elasticities w.r.t irrigation are positive and substantial for all the crops, ranging from a low of about 0.1 for Bajra to a high of about 0.6 for Rice and Wheat. Although, they are relatively small for the coarse grains Bajra, Jowar and Maize, the irrigation elasticities for these crops still compare favourably vis-a-vis the price elasticities of output. Our results for Rice and Wheat differ from those of Gulati and Sharma (1990), and Lahiri and Roy (1985), to the extent that they report irrigation elasticities exceeding unity. Overall, the availability of irrigation turns out to be next in importance to rainfall. It is found to be particularly instrumental in raising yields (as opposed to cultivated area). The importance of rainfall and irrigation taken together implies, that the most important policy variable from the viewpoint of long-run output response, is the water input.[20] Given that rainfall cannot be manipulated, the irrigation variable is the obvious policy choice.[21]

Third, after water (i.e. rainfall and irrigation), the next most important policy variables appear to be fertilizer use and high-yielding variety seeds. All the food crops exhibit a reasonably large positive response to these variables. As one would expect, the fertilizer variable turns out to be the more important of the two in the case of the highly irrigated Rice and Wheat, but not in the case of the primarily rainfed Bajra, Gram, Jowar and Maize.

Fourth, the output elasticities w.r.t the 'price variable' or relative gross profits, are of reasonable magnitude for all but Gram and Jowar. While the 'price' elasticities of output for Gram and Jowar may, therefore, be ignored from the policy viewpoint, for the other crops they may be utilized as policy instruments, as indeed they have been in the case of Rice and Wheat. In general, the price elasticities of output turn out to be substantially smaller than the corresponding irrigation and rainfall elasticities.

Fifth, the output elasticities w.r.t the price risk and yield risk variables are close to zero in virtually all cases and may, hence, be ignored from the policy viewpoint. It appears that any exacerbation in the second moments of the expected revenue distributions in the context of the Green revolution technology, were more than compensated by increases in the expected returns. More specifically, scarce resources need not be allocated to price and yield stabilisation schemes per se, at least *from the production viewpoint*. The insignificance of the public investment variable, however, is somewhat inexplicable, and may have to do with how this variable has been measured. Better data may well change this result.

V. Conclusions

Our study shows that the supply response of the Indian food crops is influenced by the weather (specifically rainfall), input availability (specifically irrigation, fertilizer and improved seeds), and relative profitability, in that order. Our results lead us to opine, that the policy agencies need to concentrate on the increased provision of assured irrigation, fertilizer and improved seeds, if a substantial increase in the long-run output of the food crops is to be achieved. These variables are likely to have a significant positive influence on the output of the food crops. Not only will increased irrigation have a direct positive impact on supply, it will also have an indirect effect insofar as access to irrigation serves to reduce the negative influence of rainfall variation or yield risk (although we found the magnitude of this effect to be very small for all crops, and not worth bothering about of itself).

This prescription does not, however, rule out the importance of the price instrument (quite in consonance with the suggestion of Nerlove, 1979). We cannot conjecture, though, about whether the price instrument is necessarily preferable to the nonprice instruments. This is because the price instrument involves offering 'incentive prices' *for grain purchased by the government*; so that the government agencies would have to reckon with not only the cost of the incentive price scheme for farmers, but also with the cost of disposing off the grain procured (through a public distribution system, for instance). Both operations can be very expensive and inefficient, as the Indian experience amply shows (Ramaswami, 2002).

This is not to imply that similar inefficiencies do not also exist in the case of the nonprice instruments, say the irrigation variable. But how large these costs are, will probably depend upon the manner in which, say, the increased irrigation is secured. At one extreme, an increase in the percentage area irrigated need not involve any large-scale public investment. *Given the extant irrigation infrastructure* (and, hence, the amount of water available for irrigation), an increase in the percentage area irrigated can still be brought about simply by switching to superior irrigation technologies. This could be achieved, for instance, by private investment in sprinkler irrigation (as opposed to the current practice of 'flooding the furrows'), aided by subsidized credit. The inefficiency costs of such schemes could be a lot less than those of entirely government-administered schemes providing producers with 'incentive prices'. In general, then, a choice between the price and nonprice instruments will depend upon the relative costs of a 1% increase in these instruments. We are not aware, however, of any studies which provide such cost comparisons, and are consequently not in a position to judge which of the two sets of instruments is relatively cost-effective in raising output.[22]

Despite this caveat, one cannot disagree with the fact, that incentive prices prove an incentive only to those farmers whose output is actually procured by the agencies; and these are the larger, relatively well-off farmers. Provision of irrigation, fertilizer and modern seeds, on the other hand, is likely to benefit both large and small farmers. Moreover, to the extent that small farmers consume much of what they produce, this would not only raise productivity and production overall, but also reduce poverty directly.

Appendix 1

Sample Crops and the Sample States

Bajra (pearl millets) – Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh

Gram – Bihar, Haryana, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Uttar Pradesh

Jowar (Sorghum) – Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Rajasthan, Tamil Nadu, Uttar Pradesh

Maize (corn) – Andhra Pradesh, Bihar, Gujarat, Himachal Pradesh, Jammu and Kashmir, Karnataka, Madhya Pradesh, Punjab, Uttar Pradesh, Rajasthan,

Rice – Andhra Pradesh, Assam, Bihar, Haryana, Karnataka, Madhya Pradesh, Orissa, Punjab, Tamil Nadu, Uttar Pradesh, West Bengal

Wheat – Bihar, Haryana, Madhya Pradesh, Punjab, Rajasthan, Uttar Pradesh

Appendix 2

Definitions of Variables

A_{it} – Area under crop i in period t ('000 hectares)

Y_{it} – Yield of crop i in period t (tons/hectare)

$A_{i(t-1)}$ – Area under crop i in period t−1 ('000 hectares)

$Y_{i(t-1)}$ – Yield of crop i in period t−1 (tons/hectare)

$\hat{\Pi}^{re}_{it}$ – Estimated Relative gross profit of crop i in period t (number)

CVP_{it} – Coefficient of Variation of (Farm Harvest) Price for crop i in period t (number)

CVR_{it} – Coefficient of Variation of Rainfall for crop i in period t (number)

$AHYV_{it}$ – Area under HYVs as a proportion of the cultivated area for crop i in period t (ratio)

$FERT_{it}$ – Fertiliser consumption (NPK), as a proportion of cultivated area, by crop i in period t (tons/hectare)

$PUBINV_{it}$ – Public investment in agriculture in period t (Rs. million)

I_{it} – Irrigated area as a proportion of cultivated area for crop i in period t (ratio)

R_{it} – Rainfall for crop i in period t (mm)

Appendix 3

Data Sources

A_{it} – Government of India (a)

Y_{it} – Government of India (a)

$\hat{\Pi}^{re}_{it}$ – Computed from data in Government of India (a), (b) and (2001)

CVP_{it} – Computed from data in Government of India (b)

CVR_{it} – Computed from data in India Meteorological Department (2004)

$AHYV_{it}$ – Fertiliser Association of India

$FERT_{it}$ – Fertiliser Association of India

$PUBINV_{it}$ – Reserve Bank of India

I_{it} – Computed from data in Government of India (a), (c) and (d)

R_{it} – India Meteorological Department (2004)

Appendix 4

Table A4 Means and Standard Deviations of Variables 1967–68/1999–00

Variable	Units	Bajra	Gram	Jowar	Maize	Rice	Wheat
Area	'000 hectares	1337.06 (1363.67)	936.10 (727.40)	1848.36 (1756.16)	518.82 (327.55)	3310.98 (1764.75)	3242.15 (2219.82)
Yield	tons/hectare	0.66 (0.30)	0.70 (0.20)	0.67 (0.22)	1.52 (0.66)	1.69 (0.75)	2.03 (0.90)
Relative Profit	ratio	2.17 (3.18)	0.43 (0.42)	3.39 (3.56)	1.30 (0.22)	5.61 (39.39)	2.12 (1.39)
Price risk	number	0.14 (0.10)	0.16 (0.09)	0.13 (0.09)	0.14 (0.09)	0.11 (0.08)	0.11 (0.07)
Yield risk	number	0.20 (0.14)	0.20 (0.15)	0.18 (0.12)	0.21 (0.14)	0.17 (0.13)	0.21 (0.16)
Public Investment	Rs. million	5536.86 (4975.65)	5267.31 (5044.27)	5715.52 (4992.97)	4156.72 (4330.02)	3990.84 (4091.91)	4273.98 (4413.21)
Area under HYVs	ratio	0.4952 (0.33)	na	0.28 (0.31)	0.42 (0.40)	0.53 (0.30)	0.73 (0.29)
Fertiliser	tons/hectare	0.04 (0.09)	0.30 (1.43)	0.02 (0.03)	0.04 (0.05)	0.07 (0.07)	0.05 (0.05)
Irrigated area	ratio	0.08 (0.06)	0.21 (0.23)	0.04 (0.04)	0.24 (0.25)	0.55 (0.32)	0.77 (0.22)
Rainfall	mm	182.55 (146.20)	107.45 (84.36)	427.75 (551.45)	111.37 (95.05)	772.42 (724.35)	387.29 (373.32)

Note: Standard deviations reported in parentheses, below the corresponding means
na – denotes data not available
Rs. – denotes Rupees

Appendix 5

Table A5.1 Random Effects Estimation – GLS Reduced Form Coefficient Estimates: Dependent Variable – Area (A_{it})

Regressors	Bajra	Gram	Jowar	Maize	Rice	Wheat
$A_{i(t-1)}$	0.242 (7.47)	0.406 (13.58)	0.528 (11.42)	0.759 (28.71)	0.677 (25.97)	0.203 (3.54)
$\hat{\Pi}^{me}_{it}$	0.033 (1.69)	−0.005 (−0.70)	0.012 (3.88)	0.013 (2.18)	0.013 (1.27)	0.109 (5.14)
CVP_{it}	0.014 (1.10)	−0.011 (−0.68)	−0.027 (−2.80)	−0.005 (−0.74)	0.001 (0.29)	−0.003 (−0.46)
CVR_{it}	dd	0.017 (1.28)	−0.008 (−0.64)	0.009 (1.20)	−0.004 (−0.82)	−0.006 (−0.85)
$PUBINV_{it}$	−0.019 (−1.42)	−0.008 (−0.58)	0.003 (0.35)	−0.003 (−0.36)	−0.0001 (−0.03)	−0.002 (−0.27)
I_{it}	0.105 (5.68)	0.088 (3.63)	0.106 (5.66)	0.033 (3.74)	0.114 (6.91)	0.197 (7.44)
R_{it}	0.407 (15.24)	0.495 (21.16)	0.270 (11.08)	0.133 (8.08)	0.121 (10.90)	0.097 (5.34)
Intercept	2.939 (13.90)	0.949 (5.89)	1.338 (7.08)	0.778 (6.47)	0.796 (5.34)	2.818 (9.20)
N	264	231	231	330	363	198
Wald χ^2	87.32	385.54	116.71	310.69	712.57	100.16
R^2	0.8498	0.9531	0.9021	0.9440	0.9827	0.9136

Note: All variables are in (natural) logs; Asymptotic t−values are in parentheses
dd – regressor dropped because it had the wrong sign and was significant

Table A5.2 Random Effects Estimation – GLS Reduced Form Coefficient Estimates: Dependent Variable – Yield (Y_{it})

Regressors	Bajra	Gram	Jowar	Maize	Rice	Wheat
$Y_{i(t-1)}$	0.034 (0.73)	0.087 (1.45)	0.076 (1.11)	−0.024 (−0.42)	−0.343 (−7.36)	−0.003 (−0.05)
$\hat{\Pi}^{me}_{it}$	−0.046 (−1.26)	0.002 (0.18)	0.015 (0.18)	0.047 (2.32)	0.096 (3.59)	0.119 (3.57)
CVP_{it}	0.007 (0.31)	−0.014 (−0.66)	−0.034 (−1.52)	−0.060 (−2.51)	−0.018 (−2.04)	0.00001 (0.00)
CVR_{it}	−0.035 (−1.27)	−0.021 (−1.71)	−0.046 (−1.63)	−0.039 (−1.59)	−0.032 (−2.91)	−0.011 (−1.13)
$PUBINV_{it}$	0.021 (0.74)	0.020 (1.06)	0.044 (1.83)	−0.019 (−0.72)	−0.003 (−0.27)	0.018 (2.12)
$AHYV_{it}$	0.121 (4.48)	0.135 (2.93)	0.094 (4.64)	0.074 (2.73)	0.071 (2.08)	0.091 (2.59)
$FERT_{it}$	0.125 (6.37)	0.086 (4.02)	0.046 (2.14)	0.038 (2.61)	0.177 (7.87)	0.170 (4.98)
I_{it}	−0.039 (−1.03)	0.049 (1.53)	−0.003 (−0.06)	0.055 (1.76)	0.130 (2.04)	0.270 (4.41)
R_{it}	0.388 (6.70)	0.204 (7.16)	0.213 (3.56)	0.015 (0.34)	0.112 (5.31)	0.04 (1.81)
Intercept	−2.014 (−5.58)	−1.163 (−6.05)	−1.728 (−5.43)	0.434 (1.58)	0.514 (7.63)	0.642 (5.07)
N	264	231	231	330	363	198
Wald χ^2	19.71	14.84	10.07	9.23	22.72	62.52
R^2	0.0142	0.0319	0.3052	0.3984	0.1636	0.6779

Note: All variables are in (natural) logs; Asymptotic t−values are in parentheses

Table A5.3 Structural Form Estimates

Crop	Area Adj. Coeff. (γ)	Regressors	Structural Form Elasticity Area (A_{it})	Yield (Y_{it})	Elasticity of Output††
Bajra	0.76	$\hat{\Pi}^{ne}_{it}$	0.043	−0.048	−0.005
		CVP_{it}	0.018	0.007	0.025
		CVR_{it}	na	−0.036	na
		$PUBINV_{it}$	−0.026	0.021	−0.004
		$AHYV_{it}$	nr	0.125	0.125
		$FERT_{it}$	nr	0.130	0.130
		I_{it}	0.138	−0.041	0.097
		R_{it}	0.536	0.402	0.939
Gram	0.59	$\hat{\Pi}^{ne}_{it}$	−0.009	0.002	−0.007
		CVP_{it}	−0.018	−0.015	−0.033
		CVR_{it}	0.028	−0.033	−0.004
		$PUBINV_{it}$	−0.013	0.022	0.008
		$AHYV_{it}$	nr	0.148	0.148
		$FERT_{it}$	nr	0.094	0.094
		I_{it}	0.148	0.054	0.202
		R_{it}	0.833	0.224	1.056
Jowar	0.47	$\hat{\Pi}^{ne}_{it}$	0.266	0.017	0.282
		CVP_{it}	−0.056	−0.037	−0.093
		CVR_{it}	−0.016	−0.049	−0.066
		$PUBINV_{it}$	0.007	0.048	0.055
		$AHYV_{it}$	nr	0.102	0.102
		$FERT_{it}$	nr	0.050	0.050
		I_{it}	0.225	−0.003	0.222
		R_{it}	0.572	0.231	0.803
Maize	0.24	$\hat{\Pi}^{ne}_{it}$	0.054	0.046	0.101
		CVP_{it}	−0.022	−0.059	−0.081
		CVR_{it}	0.037	−0.038	−0.001
		$PUBINV_{it}$	−0.012	−0.019	−0.031
		$AHYV_{it}$	nr	0.073	0.073
		$FERT_{it}$	nr	0.037	0.037
		I_{it}	0.138	0.054	0.191
		R_{it}	0.552	0.015	0.567
Rice	0.32	$\hat{\Pi}^{ne}_{it}$	0.042	0.072	0.113
		CVP_{it}	0.004	−0.014	−0.010

		CVR_{it}	−0.012	−0.024	−0.036
		$PUBINV_{it}$	−0.0005	−0.002	−0.003
		$AHYV_{it}$	nr	0.053	0.053
		$FERT_{it}$	nr	0.132	0.132
		I_{it}	0.355	0.097	0.452
		R_{it}	0.376	0.084	0.459
Wheat	0.80	$\hat{\Pi}_{it}^{ne}$	0.137	0.119	0.256
		CVP_{it}	−0.004	0.00001	−0.004
		CVR_{it}	−0.008	−0.011	−0.018
		$PUBINV_{it}$	−0.002	0.018	0.016
		$AHYV_{it}$	nr	0.091	0.091
		$FERT_{it}$	nr	0.170	0.170
		I_{it}	0.246	0.269	0.516
		R_{it}	0.121	0.040	0.161

Note: Elasticities w.r.t the lagged dependent variables are not reported here

†† − Elasticity of output is the sum of the structural form elasticities of area and yield;

nr − denotes 'not relevant' because the corresponding regressor was not included in the relevant equation

na − denotes 'not available' because the corresponding regressor was dropped from the relevant equation

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Table 1 Random Effects Estimation – GLS Reduced Form Coefficient Estimates: Dependent Variable – Area (A_{it})

Regressors	Bajra	Gram	Jowar	Maize	Rice	Wheat
$A_{i(t-1)}$	0.395 (11.83)	0.435 (14.51)	0.700 (17.72)	0.888 (57.87)	0.857 (55.71)	0.662 (16.03)
$\hat{\Pi}^{e}_{it}$	0.072 (3.68)	0.0004 (0.06)	−0.013 (−0.64)	0.010 (1.42)	0.009 (1.69)	0.036 (2.34)
CVP_{it}	0.018 (1.24)	−0.005 (−0.29)	−0.036 (−3.49)	0.001 (0.11)	−0.002 (−0.34)	0.006 (0.71)
CVR_{it}	dd	0.018 (1.28)	0.004 (0.32)	0.002 (0.19)	−0.007 (−1.28)	−0.002 (−0.27)
$PUBINV_{it}$	−0.008 (−0.53)	−0.014 (−0.95)	−0.002 (−0.19)	0.006 (0.68)	0.002 (0.35)	−0.001 (−0.07)
I_{it}	0.080 (4.07)	0.110 (4,87)	0.039 (2.33)	0.008 (1.24)	0.052 (4.78)	0.081 (3.38)
R_{it}	0.397 (13.79)	0.457 (20.14)	0.190 (8.28)	0.037 (3.22)	0.065 (7.30)	0.121 (6.39)
Intercept	1.949 (7.20)	1.296 (6.63)	0.915 (3.88)	0.437 (3.53)	0.320 (3.60)	1.369 (6.47)
N	264	231	231	330	363	198
Wald χ^2	784.51	3330.17	1916.35	4476.05	15569.03	1861.86
R^2	0.9038	0.9621	0.9680	0.9732	0.9913	0.9705

Note: All variables are in (natural) logs; Asymptotic t–values are in parentheses
dd – regressor dropped because it had the wrong sign and was significant

Table 2 Random Effects Estimation – GLS Reduced Form Coefficient Estimates: Dependent Variable – Yield (Y_{it})

Regressors	Bajra	Gram	Jowar	Maize	Rice	Wheat
$Y_{i(t-1)}$	0.117 (2.28)	0.223 (3.62)	0.173 (2.57)	0.096 (1.77)	−0.282 (−5.99)	0.198 (2.99)
$\hat{\Pi}^{e}_{it}$	0.029 (0.91)	0.017 (1.61)	0.016 (0.41)	0.028 (1.39)	0.083 (3.54)	0.050 (1.81)
CVP_{it}	−0.001 (−0.05)	0.004 (0.18)	−0.036 (−1.60)	−0.051 (−2.06)	−0.015 (−1.56)	0.005 (0.42)
CVR_{it}	−0.019 (−0.62)	−0.023 (−1.14)	−0.048 (−1.69)	−0.032 (−1.27)	−0.030 (−2.62)	−0.005 (−0.37)
$PUBINV_{it}$	−0.011 (−0.34)	0.010 (0.47)	0.030 (1.23)	−0.029 (−1.07)	−0.004 (−0.34)	0.014 (1.46)
$AHYV_{it}$	0.098 (3.50)	0.147 (3.04)	0.056 (3.14)	0.084 (3.47)	0.045 (1.89)	0.084 (2.15)
$FERT_{it}$	0.109 (5.00)	0.033 (1.75)	0.054 (2.75)	0.022 (1.54)	0.170 (7.96)	0.136 (3.75)
I_{it}	−0.030 (−0.77)	0.017 (0.55)	0.005 (0.15)	0.066 (2.76)	0.267 (4.72)	0.246 (4.02)
R_{it}	0.161 (3.02)	0.092 (3.51)	0.066 (1.81)	0.043 (1.19)	0.108 (5.20)	0.012 (0.55)
Intercept	−0.683 (−1.75)	−0.718 (−3.11)	−0.803 (−2.58)	0.571 (1.81)	0.615 (3.23)	0.722 (3.08)
N	264	231	231	330	363	198
Wald χ^2	130.55	84.94	110.90	106.70	229.04	589.67
R^2	0.2798	0.2670	0.4928	0.4964	0.4424	0.8380

Note: All variables are in (natural) logs; Asymptotic t–values are in parentheses

Table 3 Structural Form Estimates

Crop	Area Adj. Coeff. (γ)	Regressors	Structural Form Elasticity Area (A_{it})	Structural Form Elasticity Yield (Y_{it})	Elasticity of Output††
Bajra	0.61	$\hat{\Pi}^{ne}_{it}$	0.119	0.033	0.152
		CVP_{it}	0.030	−0.001	0.028
		CVR_{it}	na	−0.021	na
		$PUBINV_{it}$	−0.014	−0.012	−0.026
		$AHYV_{it}$	nr	0.111	0.111
		$FERT_{it}$	nr	0.124	0.124
		I_{it}	0.132	−0.034	0.098
		R_{it}	0.656	0.182	0.838
Gram	0.56	$\hat{\Pi}^{ne}_{it}$	0.001	0.022	0.023
		CVP_{it}	−0.008	0.006	−0.003
		CVR_{it}	0.031	−0.029	0.002
		$PUBINV_{it}$	−0.024	0.013	−0.011
		$AHYV_{it}$	nr	0.189	0.189
		$FERT_{it}$	nr	0.043	0.043
		I_{it}	0.195	0.022	0.216
		R_{it}	0.810	0.119	0.929
Jowar	0.30	$\hat{\Pi}^{ne}_{it}$	−0.043	0.020	−0.024
		CVP_{it}	−0.119	−0.044	−0.162
		CVR_{it}	0.014	−0.059	−0.044
		$PUBINV_{it}$	−0.007	0.037	0.030
		$AHYV_{it}$	nr	0.068	0.068
		$FERT_{it}$	nr	0.066	0.066
		I_{it}	0.129	0.007	0.136
		R_{it}	0.633	0.080	0.713
Maize	0.11	$\hat{\Pi}^{ne}_{it}$	0.089	0.031	0.121
		CVP_{it}	0.008	−0.056	−0.048
		CVR_{it}	0.014	−0.035	−0.021
		$PUBINV_{it}$	0.058	−0.032	0.026
		$AHYV_{it}$	nr	0.093	0.093
		$FERT_{it}$	nr	0.024	0.024
		I_{it}	0.076	0.073	0.149
		R_{it}	0.333	0.048	0.381
Rice	0.14	$\hat{\Pi}^{ne}_{it}$	0.064	0.064	0.128
		CVP_{it}	−0.011	−0.012	−0.022

		CVR_{it}	−0.048	−0.024	−0.072
		$PUBINV_{it}$	0.015	−0.003	0.012
		$AHYV_{it}$	nr	0.035	0.035
		$FERT_{it}$	nr	0.132	0.132
		I_{it}	0.367	0.208	0.575
		R_{it}	0.456	0.084	0.540
Wheat	0.34	$\hat{\Pi}^{e}_{it}$	0.107	0.063	0.170
		CVP_{it}	0.019	0.006	0.025
		CVR_{it}	−0.007	−0.005	−0.012
		$PUBINV_{it}$	−0.002	0.018	0.016
		$AHYV_{it}$	nr	0.104	0.104
		$FERT_{it}$	nr	0.170	0.170
		I_{it}	0.241	0.306	0.547
		R_{it}	0.358	0.015	0.373

Note: Elasticities w.r.t the lagged dependent variables are not reported here

†† − Elasticity of output is the sum of the structural form elasticities of area and yield;

nr − not relevant, because the corresponding regressor was not included in the relevant equation

na − not available, because the corresponding regressor was dropped from the relevant equation

Notes

1. Earlier named the Agricultural Prices Commission (APC).

2. Earlier researchers also used supply response behaviour to address issues of farmer rationality in developing countries. Thus, Krishna (1963) interprets his finding of a positive acreage response to prices, to imply that Indian farmers are, after all, rational. However, this is no longer an issue today, as the new development economics literature has amply demonstrated (see Basu, 1997, for numerous models of credit and interlinkage which substantiate this point).

3. Parikh (1972) considered relative price and relative yield, but not relative profit per se, in his set of regressors. Barten and Vanloot (1996), and Holt (1999) consider absolute, and not relative, profit as the relevant regressor. Narayana and Parikh (1981) consider relative gross profit as the appropriate regressor. See also Rosegrant et.al. (1998) where the theoretical model is set up in terms of profit, but the empirical models include only prices.

4. To employ the profit function approach instead we would require data on (at least) the input prices of improved seeds, irrigation water and fertiliser, which are considered the three most important yield-enhancing inputs in the context of the Green Revolution. Detailed data on neither seed prices nor irrigation water charges, however, are available in the Indian context. Moreover, canal water (which is only one source of irrigation) is provided by public agencies, and its user charges are administered prices which do not reflect the scarcity value of this resource. At one extreme, for instance, political expediency often prompts state administrations to make water (and electricity) available to farmers free of cost! Even these user charges data are not available in the requisite detail. Furthermore, input prices would not vary across crops and states for a given year, negating the advantages of panel estimation.

5. Narayana and Parikh (1981) argue, that given $\Pi_t = \Pi_t^* + \mu_t$ where μ_t is the random component, the Nerlovian expectation specification (7) amounts to placing equal weights on the expected and random components of profits. To remedy this, they prefer specification (8). But not only should the weights on the expected and random components of profits be different, the weight on the

former should exceed that on the latter. There is nothing in specification (8), however, to ensure that – a fact that is borne out by many of the results reported in *their* Table 2 (p. 16; Narayana and Parikh, 1981). Therefore, we prefer to use specification (8) strictly as a statistical approximation.

6. The price variable that we have derived above indicates the return on marketed produce for those who have a surplus. But for small farmers, who don't have much to market, it indicates the opportunity cost of the resources devoted to the production of that crop. If the relative price of the crop declines, implying higher prices for the competing crop(s), a rational farmer would be better off producing more of the latter, selling some (or all) of that output, and using the proceeds to purchase (more of) the subsistence crop in question. Thus, a lower (relative) price for the crop in question would lead to a decline in the area allocated to it, just as it would for the 'large' farmer with a surplus.

7. The irrigation variable is not measured as a proportion of cropped area *in the acreage equation* currently under discussion, as that would introduce a negative bias into the relationship between the regressand (acreage) and the irrigation variable so defined. Thus, an increase in the regressand would imply a smaller percentage area irrigated, downwardly biasing the relationship between acreage and the irrigation variable. However, *in the yield equation* discussed in the following sub-section, the irrigation variable is defined as irrigated area under the crop as a proportion of cropped area. Note that because all variables are taken in logs, the regression coefficient of the ratio will be the same as that of the numerator.

8. We also tried an alternative proxy of yield risk - namely, the absolute deviation of the current period rainfall from 'normal' rainfall (where the meteorological department measures normal rainfall in a given period as the average of the previous thirty years). The results using this alternative definition were, however, no different.

9. We were prevented from considering other relevant regressors such as credit due to the lack of data availability.

10. Another variable that we would like to include in the yield equation is mechanisation. Although some (partial) data on the stock of tractors and diesel pumpsets are available, these are obviously not crop-specific. For that we would require data on the number of machine-hours of labour used per crop, which do not exist.

11. The beginning of the sample period is taken to be 1967-68, because this is considered to be the first 'normal' year after the onset of the Green Revolution in 1965; the first two years 1965-66 and 1966-67 being drought years. However, our results were not found to be sensitive to the choice of beginning year.

12. The only exception was Haryana in the case of Rice. We included this state in the sample even though it consistently accounted for less than 3% of the total Rice production, because Haryana is an important contributor to the central pool of Rice.

13. Since cost of production data were not available for our complete sample period, and were patchy, we were forced to measure expected profits in terms of gross profits.

14. One could derive more accurate estimates of supply response if one had information on which farmers have a surplus, which have a deficit, and which are self-sufficient (Key, Sadoulet and de Janvry, 2000), but we did not have access to household-specific data.

15. The state of Madhya Pradesh was, however, included in the 'Jowar sample' for computing the means and standard deviations of all the variables other than irrigation (see Appendix 4). As explained in the text, this state was omitted only for the Jowar (acreage and yield) regressions.

16. While the disturbances of the area and yield equations for a given crop and, indeed, all crops, may be correlated, this cannot be presently handled in the context of random effects estmation by either the STATA (2003) or the SHAZAM (Whistler et.al., 2001) econometrics packages. This was confirmed in personal communications from the STATA and SHAZAM support staff.

17. The elasticities being referred to here, and in the discussion below, are the long-run (or structural) elasticities, unless specifically stated otherwise.

18. The irrigation variable data in Table A4 (Appendix 4), however, are only indicative for they pertain

to the entire 6 states in the 'wheat sample', and not just to Punjab, Haryana and Uttar Pradesh.

19. In the case of Wheat, the HYV variable actually turned out to be insignificant. A careful analysis of the data revealed, that the proportion area under HYVs was roughly 100% for the most important states of Punjab, Haryana and Uttar Pradesh since the 1970s (since the early-1970s for the first two, and the late-1970s for the latter-most). In other words, it was this lack of variation for the bulk of our sample period which was causing the HYV variable to be insignificant. Given that high-yielding varieties have played a very important role in the case of Wheat during the Green Revolution, we did not want to drop this variable. So we redefined it such that $AHYV_{it}$ = 1 for t > 1979 (i.e. for the 1980s and 1990s), and 0 for the earlier period (i.e. for the 1960s and 1970s).

20. Adding the rainfall and irrigation elasticities of output, though technically feasible, would not be informative because they are measured in different units.

21. As the results for Rice and Wheat show, increased access to assured irrigation reduces the dependence on rainfall.

22. Note that cost estimates in terms of what the Indian government spends on achieving a 1% increase in prices versus a 1% increase in percentage area irrigated, would help but not quite settle the issue. Since private markets for providing irrigation and producer subsidies do not exist, the government expenditure outlays on these instruments would not necessarily reflect the opportunity costs of the resources involved.