Dynamic Output Response Revisited: The Indian Cash Crops

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Abstract

Diverse instruments have been used to encourage developing agriculture. In the process, billions of dollars have been spent on providing incentives to peasants. Given scarce resources, an important concern has been the issue of what policy instruments to emphasize. In this regard, useful policy information can be gleaned from the role of expected profits (revenue and input prices), assets (irrigation and infrastructure), and relevant risks, in evoking peasant response. Using panel data for the period 1967-68/1999-00 pertaining to 7 major Indian cash crops cultivated across 14 major states, we find strong evidence of a differential producer response in the post-liberalization phase, although the important variables per se are much the same. Our results suggest that the preferred policy ought to emphasize availability of irrigation, affordable fertilizer, and rural infrastructure, rather than incessant increases in output prices.

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1. Introduction

That agriculture has a key role to play in development was well-recognized by the early development theorists, but it also remains a very contemporary issue (World Bank 2007). One of the more obvious benefits of a dynamic agriculture would be 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 (Timmer 2002; Harris and Todaro 1970). In the Indian context, tens of billions of rupees are spent annually by government agencies, to foster agricultural growth (Gulati and Narayanan 2003). Yet, agricultural performance has not been particularly stellar. Hence the renewed need to understand the phenomenon of supply response, and the influence that recent liberalization policies may have had.

The success of public policy in promoting agricultural production depends, inter alia, on the producers' response to variations in expected profit (gross revenue and input prices), the assets base (particularly irrigation and infrastructure), and relevant risks. If these responses are not large enough, obviously other proximate determinants of output response may have to be considered. Measuring the elasticities with respect to expected profit, irrigation and infrastructure should inform policy choices (Rosegrant, Kasryno and Perez, 1998; Ray, 1980). Important also is to compare short-run elasticities of acreage/output with respect to both profit and assets to the long-run elasticities. A large difference may indicate various constraints on the producers' response in the short-run; so that policy could be more effective by removing these constraints rather than fiddling with the various ultimate (price and non-price) determinants influencing output response. Unsurprisingly, therefore, there has been a continuing debate in India on various aspects of these policies, particularly on which proximate determinants policy makers ought to aim their instruments, given scarce resources.

We observe, however, that even the relatively recent studies in this area in the Indian context are mostly dated, using data till only the mid-1970s or earlier (Narayana and Parikh, 1981; Ray, 1980; Krishna and Roychoudhury, 1980), and/or very narrow in terms of state or crop coverage (Gulati and Sharma, 1990; Lahiri and Roy, 1985; Krishna and Roychoudhury, 1980), and/or methodologically unsatisfactory. Gulati and Sharma (1990) implicitly assume naïve price expectations for their sample of farmers, and Ray (1980) reports long-run elasticities *smaller* than short-run elasticities, but does not explain the rationale for this persistent over-adjustment in the context of resource-constrained farmers.

This paper addresses some of these limitations with more disaggregated and more recent data, and a variation in the standard Nerlove-type methodology. The analysis focuses on 7 Indian cash crops – Groundnuts, Rapeseed/Mustard, Sesamum, Cotton, Jute, Sugarcane, and Tobacco – which are included in the list of mandate crops of the Commission on Agricultural Costs and Prices (CACP), the nodal agency at the helm of agricultural price policy in India. Panel data for the period 1967-68 to 1999-2000 are used for estimation, the cross-section units being the different states growing a given crop; which differs markedly from the extant studies in the Indian context, that use aggregate time series data (Gulati and Sharma, 1990; Lahiri and Roy, 1985; and Narayana and Parikh, 1981). This state level disaggregation enables us to consider sources of variation that would not be possible otherwise as the competing crops need not be the same in each state for any given crop. Furthermore, we use farm harvest price data for the different crops rather than the most commonly used wholesale prices; because although the two tend to be close to each other around harvest, the latter tend to be considerably higher at other times and do not reflect the prices farmers receive. Methodologically, our specification employs quasi-rational expectations *as a re-expression of the adaptive expectations hypothesis* (differing subtly from the motivation behind Narayana and Parikh, 1981, as explained below). Finally, we explore the effect of the economic liberalisation of the late-1980s (Chand, 2002). Employing a specification that allows for two different regressions corresponding to the pre-reform and post-reform periods, we strongly reject that they are the same. Thus, liberalization appears to have significantly affected the output response of our sample of crops.

It is worth clarifying, that although we focus on supply response rather than marketed surplus response, the difference between the two is insignificant given that self-consumption of cash crops by producers is very small. Section 2 outlines the model used in this study, and the estimation methodology adopted. Section 3 provides a description of the data used. Section 4 presents the estimation results; and, finally, Section 5 underlines the important conclusions and policy implications.

2. The Model and Methodology used in this Study

The Economic Model

It may be argued that the representative agent, the farmer, determines the desired or long-run area under crop i in response to relative expected profit,[1] production risk, and various enabling factors. We may specify this relationship as

$$A_{it}^{d} = \alpha_0 + \alpha_1 \Pi_{it}^{re} + \alpha_2 Z_{it} + \varepsilon_{1it} \tag{1}$$

where, for crop i, A_{it}^{d} is the desired supply for period t, Π_{it}^{re} 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 infrastructure, fertilizer price, improved seeds, irrigation, and rainfall) in period t,[2] and ε_{1it} is the error term such that $\varepsilon_{1it} \sim (0, \sigma_{\varepsilon_1}^{2})$. The relative expected profit is defined as $\Pi_{it}^{re} = \Pi_{it}^{e}/0.5(\Pi_{jt}^{e} + \Pi_{kt}^{e})$, i.e. the expected profit of the crop i relative to the average expected profit of the two most important competing crops (j and k).

In a developing country (particularly Asian) context, adjusting the actual acreage towards the desired level may not be possible in a single time-period. Farmer response may be constrained by very small acreages combined with the need to diversify production to spread risks, credit constraints, lack of availability of inputs etc. To allow for this possibility we hypothesize 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.[3] This may be expressed as

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

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_{it}^{d} is the desired acreage for period t, and ε_{2it} represents the random shocks such that $\varepsilon_{2it} \sim (0, \sigma_{\varepsilon_2}^{2})$. The adjustment parameter γ must lie between 0 and 2 for the adjustment to converge over time, but because $\gamma > 1$ implies persistent over-adjustment, it is desirable that it lie between 0 and 1.

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

$$A_{it} = \theta_0 + \theta_1 A_{i(t\text{-}1)} + \theta_2 \Pi_{it}^{re} + \theta_3 Z_{it} + v_{it} \tag{3}$$

$$\text{where } \theta_0 = \gamma\alpha_0;\ \theta_1 = 1\text{–}\gamma;\ \theta_2 = \gamma\alpha_1;\ \theta_3 = \gamma\alpha_2;\ v_{it} = \gamma\varepsilon_{1it} + \varepsilon_{2it} \tag{4}$$

This model, however, is not estimable because of the unobservable variable Π_{it}^{re}. To circumvent this problem, we adopt the following approach.

The Profit Variable

We approximate the expected profit underlying the unobservable variable in (3) as follows (Nerlove and Bessler 2001, Narayana and Parikh 1981). For any crop *i*, the adaptive profit expectation hypothesis

$$\Pi_{it}^{e} = \Pi_{i(t-1)}^{e} + \beta' (\Pi_{i(t\text{-}1)} - \Pi_{i(t-1)}^{e}) \qquad 0 < \beta' \leq 1 \tag{5}$$

may be expressed as an infinite-order AR process

$$\Pi_{it}^{e} = \Sigma_{\tau=0}^{\infty}\ \beta' (1- \beta')^{\tau}\, \Pi_{i(t\text{-}1\text{-}\tau)}\ . \tag{6}$$

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

$$\Pi_{it}^{e} = b_1\Pi_{i(t\text{-}1)} + b_2\Pi_{i(t\text{-}2)} + \ldots + b_p\Pi_{i(t\text{-}p)} + \mu_{it} + c_1\mu_{i(t\text{-}1)} + \ldots + c_q\mu_{i(t\text{-}q)}\ , \tag{7}$$

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

$$\Pi_{it} = b_1\Pi_{i(t\text{-}1)} + b_2\Pi_{i(t\text{-}2)} + \ldots + b_p\Pi_{i(t\text{-}p)} + \mu_{it} + c_1\mu_{i(t\text{-}1)} + \ldots + c_q\mu_{i(t\text{-}q)} \tag{8}$$

i.e. by regressing actual profits on the right hand side variables in (7), and using the estimated values of the dependent variable or $\hat{\Pi}_{it}$ in lieu of expected profit Π_{it}^{e} for a given crop *i*.[4] In the literature (6) is referred to as 'quasi-rational expectations'. We would like to emphasize, however, that while (6) may be a representation of quasi-rational expectations (insofar as profit expectations are based on profits in the previous periods), *we use it as a re-expression of the adaptive expectations hypothesis*. In other words, while we recognize that the adaptive expectations and quasi-rational expectations hypotheses are observationally equivalent when expressed as (6), that need not imply dropping the former expectations formation hypothesis in favour of the latter. Equations (7) and (8) are, then, merely practical ways of estimating the adaptive expectations hypothesis re-written as (6).

Estimation of (8), however, requires specification of p, d and q. Allowing $d = \{0, 1, 2\}$, $p = \{1, 2\}$ and $q = \{1, 2\}$, we choose 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. This allows us to estimate the expected profits of crop i ($\hat{\Pi}_{it}$).[5] Repeating this process for the two most important competing crops j and k (which gives us estimates $\hat{\Pi}_{jt}$ and $\hat{\Pi}_{kt}$), we then estimate the relative expected profitability of i as $\hat{\Pi}_{it}^{re} = \hat{\Pi}_{it}/0.5(\hat{\Pi}_{jt} + \hat{\Pi}_{kt})$. Substituting $\hat{\Pi}_{it}^{re}$ for Π_{it}^{re} in (3) allows us to estimate the reduced form parameters (4) which, in turn, provide estimates of the adjustment parameter 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, however, that the assumption of conditionally homoskedastic errors cannot be rejected for any of the crops in our sample.

The Other Regressors

Having discussed the expected profit variable $\hat{\Pi}_{it}^{re}$, we now briefly discuss the other regressors Z_{it} in our model. One of the most important inputs into agrarian production in hot and dry climates is water. We capture this in terms of two variables – the total irrigated area (I_t),[6] and the average monthly sowing period rainfall for the current period (R_t^s).[7] (We do not use crop-specific irrigated area because that is a decision variable of the peasant and, hence, endogenous.) A higher irrigated area is likely to have a positive effect on the area planted to most crop, insofar as it implies a greater availability of (assured) water. Such a response, however, is not necessarily true of dryland crops which perform relatively better in dryland conditions. Tobacco cultivation, for instance, appears to thrive on unirrigated land, and its yields decline with irrigation. Similarly, although rainfall is expected to have a positive effect on area allocation, particularly in the case of rain-fed agriculture, higher rainfall may lead to a shift in cropping patterns towards water-intensive crops.

The poor resource base of the majority of Indian farmers, particularly the fact that even today only about 40% of the cultivated area is irrigated (Government of India, 2003), makes 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 (CVP_{it}) is defined as the coefficient of variation of price differentials from the trend over the three previous periods, where the trend is first estimated for the entire sample period. 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 the rainfall deviations from the 'long period average' rainfall over the three previous periods (CVR_t), where the ‘long period average’ is computed by the meteorological department as the average rainfall of the previous thirty years.[8] It is useful to note that we found the covariance between the rainfall and price risk measures to be virtually zero for four of our sample crops, and small for the other three; which implies that these measures are an adequate representation of revenue risk.[9] The higher the price risk or yield risk[10] associated with the production of a crop, the smaller would we expect the area allocation in favour of that crop to be.

Rural infrastructure – specifically in the areas of food storage and warehousing, agricultural research and extension, rural roads etc. – may also be expected to encourage acreage under a crop. Given that capital stock figures are non-existent, studies tend to use some measure based on capital *expenditure* figures; as do, for instance, Rosegrant, Kasryno and Perez (1998). Following them, we first converted data on annual rural capital expenditure into infrastructure stocks s_t using the formula $s_t = rce_t + (1-\delta)s_{t-1}$, where rce_t denotes annual rural capital expenditure, and δ denotes the annual depreciation rate (taken to be equal to 0.025).[11] These estimates were then deflated by the gross capital formation deflator for the primary sector, to derive the proxy for the infrastructure variable ($INFRA_t$).

Two other variables of interest in the context of the green revolution technology are fertilizer price ($FERTPR_t$), and the availability of high-yielding variety seeds. The former is defined as the ratio of the fertilizer price index to an index of other agricultural inputs.[12] Higher fertilizer price, by raising the cost of cultivation, may dampen the area response of a crop; farmers would attempt to substitute cheaper inputs for the relatively expensive ones to the extent possible, but beyond a point, would have to reign in production, especially for crops which are fertilizer-intensive. In other words, there would a change in cropping pattern. As regards the improved seeds variable, data on the area under high-yielding varieties were never collected for our sample of crops, making it impossible to capture the effect of this variable per se.[13]

Finally, the period since the late-1980s has been marked by gradual economic liberalization which saw the freeing up of input and output markets, and very significant changes in the international trade regime (Chand, 2002). It is quite possible that these changes may have significantly altered the response of crops to the various regressors discussed above. Of course, the reforms may have had a 'level effect' and/or a 'slope effect'. To allow for both possibilities, we define the post-1986 dummy variable as $P86D_{it} = 1$ for $t > 1986$, and 0 for the earlier years, and include in our set of regressors both this dummy variable as well as its interactions with the other regressors mentioned above.[14]

Acreage, Yield, and Output Elasticities

Although we have set out our model in terms of area response (leading to the derivation of the short-run and long-run *area* elasticities), farmers respond to various stimuli not just by adjusting area, but also by adjusting the other inputs into production (such as water, fertilizer, etc.). Indeed, in land-scarce countries such as India the latter response, leading to yield (or output per unit land) increases, is likely to dominate the area response (as is borne out by numerous studies, e.g. Vaidyanathan, 1994). To capture the full supply response, therefore, we also estimate a yield response model, i.e. with yield (Y_{it}) in place of acreage (A_{it}) in equations (1), (2) and (3)

$$Y_{it}^{d} = \alpha_0' + \alpha_1' \, \Pi_{it}^{re} + \alpha_2' \, Z_{it} + \varepsilon_{1it}' \tag{1a}$$

$$Y_{it} = Y_{i(t-1)} + \gamma' (Y_{it}^{d} - Y_{i(t-1)}) + \varepsilon_{2it}' \qquad 0 < \gamma' \leq 1 \tag{2a}$$

$$Y_{it} = \theta_0' + \theta_1' \, Y_{i(t-1)} + \theta_2' \, \Pi_{it}^{re} + \theta_3' \, Z_{it} + \nu_{it}' \tag{3a}$$

where all the regressors are as defined above (except rainfall which is now defined as the average monthly 'growth period' or crop season rainfall R_t^g), and we use $\hat{\Pi}_{it}^{re}$ in lieu of Π_{it}^{re} (as we did for the acreage model above). It is possible, however, for γ' to exceed 1 on occasion, insofar as yield is subject to the weather and not totally within the farmer's control. Of course, for stability it is sufficient that γ' lie between 0 and 2. 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.

3. The Data Set and Methodology

The Data Set

This study focuses on 7 cash crops – the oilseeds Groundnuts, Rapeseed/Mustard, and Sesamum; and the commercial crops Cotton, Jute, Sugarcane,[15] and Tobacco – that figure prominently in the agricultural price policy in India (see, for example, Rao, 2001). Although the CACP's mandate also includes two other oilseeds, Sunflower and Nigerseed, these are currently quite unimportant in terms of percentage area and output. Annual data for the period 1967-68 to 1999-2000 are used for estimation (since 1967-68 is considered the first normal year after the onset of the green revolution in 1965, the previous two years 1965-66 and 1966-67 being drought years).[16]

The two most important competing crops are defined on the basis of detailed state-wise information on the sowing, harvesting and peak marketing seasons of various crops, and the substitutable crops in the different states. This information is obtained from Government of India (2001); see also Narayana and Parikh (1981).[17] This allows for cross-sectional or state-specific variation in the regressors used, as compared to all-India data which would reduce such variation by aggregating some variables and averaging others (as, for example, in Gulati and Sharma, 1990; Lahiri and Roy, 1985; and Narayana and Parikh, 1981). Furthermore, for any given crop, the competing crops need not be the same in each state and, in fact, this was our experience for some crops. All these advantages of panel estimation increase the efficiency of the sample estimates, and render the results more representative of the constituent cross-sections.

As regards the price data used, we use farm harvest prices for computing the (expected) profits[18] for the different crops rather than the more commonly used wholesale prices. Since most Indian farmers have very limited storage facilities 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.[19] All the data were available from various sources in the public domain.[20] We observe variations across states, time and crops for all variables, except infrastructure, irrigation, rainfall, yield risk (proxied by rainfall risk), and fertilizer price, that vary across states and time, but not crops.

None of the sample cash crops performed spectacularly during the sample period 1967-68/99-00. Only the production of Rapeseed/Mustard increased at a substantial 2.3% per annum. The production of Cotton and Sugarcane grew at a more modest 1.3% p.a.; and the production of Jute, Tobacco, Groundnuts and Sesamum grew at the disappointing rates of 1% p.a., 0.8% p.a., 0.6% p.a. and 0.6% p.a., respectively. Given that these are cash crops, and are cultivated for the express purpose of the revenue they earn, the subsequent sections attempt to determine the possible instruments that may be employed to encourage their production. Meanwhile the means, standard deviations, and units of the (untransformed) variables to be used in the analysis, for each of the crops, are reported in Table 1.

The Methodology

For estimating the acreage and yield equations (3) and (3a) (with $\hat{\Pi}_{it}^{re}$ in place of Π_{it}^{re}) for a given crop, we pool the panel data using an error components model. Let $s = 1, \ldots, S$ represent the states and t the time. Suppressing the crop index i (because we estimate the same econometric model for each crop), we have

$$y_{st} = \delta\, y_{s,t-1} + x'_{st}\,\beta + \mu_s + e_{st} \qquad s = 1, \ldots, S; \quad t = 1, \ldots, T \qquad (12)$$

where $\mu_s \sim (0, \sigma_\mu^2)$; $E(\mu_s\mu_r) = E(e_s e_r) = 0$, for $s \neq r$; $E(\mu_s e_{rt}) = 0$, for $s \neq r$. The dependent variable y_{st} refers to area in equation (3) and yield in equation (3a). Variables x_{st} denote the set of regressors discussed above. All variables are in natural logs (except the post-1986 dummy).

We first difference the above model to get

$$y_{st} - y_{s,t-1} = \delta\,(y_{s,t-1} - y_{s,t-2}) + (x'_{st} - x'_{st-1})\,\beta + (e_{st} - e_{s,t-1}) \qquad (13)$$

and then use the Arellano and Bond (1991) one-step, robust estimator. This estimation provides consistent estimates of the reduced form model parameters.[21] Using these results, the structural form estimates are easily derivable. The estimation results are presented in Tables 2, 3 and 4, and discussed in the following section.

4. Estimation Results

For the area as well as the yield equations (Tables 2 and 3), the hypotheses that changes in area or yield occurred randomly over time were very strongly rejected in the case of all crops – the associated Wald χ^2 statistics reported in the tables mostly turn out to be large with p-values of 0 or close to 0. 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 expectations in all cases. Based on the Arellano-Bond tests, we cannot reject the null hypothesis of no second-order autocorrelation in the residuals.[22] In the case of the area equations, the hypothesis that the pre-reform and post-reform regressions are the same (i.e. the post-reform dummy and the interactions are all zero), is rejected for all the sample crops. This indicates that the post-liberalization response of area to various factors was significantly different from the pre-reform response. Area appears to be less responsive to revenue changes than in the pre-reform period, whereas it continues to be strongly responsive to irrigation and/or rainfall for most crops. In the case of the yield equations as well, the hypothesis that the pre-reform and post-reform regressions are the same, is rejected for all the crops. We find that yield too became less responsive to changes in the revenue variable for most crops, but remained strongly responsive to water availability (irrigation and/or rainfall) for almost all the crops. Overall, it appears that the policy variables of interest might be more the availability of fixed factors than the profitability of the crops. We examine these results in detail below.

The Area Response

Considering the area equations first (Table 2), rainfall has a strong positive influence on the area planted under the different crops, and the associated long-run elasticities are quite substantial, with the exception of Tobacco. Thus, the post-reform elasticities range from about 0.06 for Rapeseed/Mustard, 0.09 for Cotton and Sugarcane, 0.12 for Groundnuts, 0.21 for Jute, to about 0.53 for Sesamum (Table 4).[23] In fact, rainfall appears to be the most important variable determining area allocations over time, insofar as this regressor has relatively higher *t*-values for most of the crops, and is the only variable that is consistently strongly significant for these crops. Although the rainfall variable turns out to be inexplicably negative significant for Sugarcane, note that it is economically insignificant, the associated 95% confidence interval being (–0.04, –0.01). This is understandable given the fact that almost 92% of the area under Sugarcane in the post-reform period was irrigated, markedly reducing its dependence on rainfall. We also find, that the post-reform rainfall elasticities are substantially higher than the pre-reform elasticities for Jute (0.21 versus 0.16) and Sesamum (0.53 versus 0.39). The reverse is true for Rapeseed/Mustard (0.06 versus 0.38), Cotton (0.09 versus 0.15), and Tobacco (0.00 versus 0.06); whereas for the other crops the two are not very different. Given that the *crop-specific* percentage area irrigated was, on average, higher in the post-reform period for all the sample crops,[24] this factor cannot be invoked to explain the differential area response to rainfall of some crops. An alternative plausible explanation might be, that Jute and Sesamum cultivation expanded to relatively inferior soils, increasing the sensitivity of area to rainfall; whereas

Rapeseed/Mustard, Cotton and Tobacco cultivation expanded to similar (or better) quality soils, so that greater access to irrigation served to reduce area sensitivity to rainfall variations.

The irrigation variable turned out to have a positive and significant effect in the case of Jute, Sugarcane and Tobacco only, with 95% confidence intervals of (0.12, 0.25), (0.04, 0.45) and (0.16, 0.54) respectively, and was statistically insignificant for the area under other crops. In terms of economic significance, however, this variable appears to be important for Groundnuts, Rapeseed/Mustard, Sesamum and Cotton as well, the 95% confidence intervals for this coefficient being (–0.04, 0.39), (–0.22, 0.39), (–0.26, 0.21), (–0.16, 0.10), respectively. The long-run post-reform area elasticities with respect to irrigation were, on average, substantial – ranging from a low of about 0.25 for Rapeseed/Mustard and Jute, 0.30 for Cotton, –0.41 for Sesamum (implying a shift out of this crop with increasing availability of irrigation), 0.44 for Groundnuts, 0.57 for Tobacco, to a high of 0.78 for Sugarcane. Further, there is not much difference between the post-reform and pre-reform elasticities in the case of Jute and Tobacco, while those for Rapeseed/Mustard and Sugarcane are lower in the post-reform period indicating high percentage areas irrigated, and the post-reform elasticities for Groundnuts and Sesamum are much higher possibly indicating expansion to relatively inferior soils.

The relative gross profits variable[25] is found to be positive significant in the case of all crops but Groundnuts and Jute, although only weakly so for Cotton. The associated long-run post-reform area elasticities are mostly quite small, ranging from near zero to about 0.10, with the exception of Cotton and Sugarcane for which they are about 0.26 and 0.45, respectively. Again, only for Sugarcane (0.45 versus 0.27) is the post-reform area elasticity larger than the pre-reform area elasticity; for all other crops the post-reform elasticities with respect to the profits variable are substantially smaller.

The fertilizer price variable is statistically significant only for Jute and Tobacco, but appears to be economically significant for most other crops as well – the 95% confidence intervals being (–0.39 to 0.08) for Groundnuts, (–0.19 to 0.08) for Rapeseed/Mustard, (–0.39 to 0.13) for Sesamum, and (–0.15 to 0.11) for Cotton. While the post-reform elasticities were substantially smaller than their pre-reform magnitudes for Groundnuts (–0.00 versus –0.19) and Tobacco (–0.16 versus –0.93), they were substantially larger for Sesamum (–0.84 versus –0.42) and Jute (–0.81 versus –0.33), being about the same for Rapeseed/Mustard (–0.21). The risk variables (price risk and yield risk) do not show much consistency in terms of statistical significance or coefficient signs. More importantly, however, both are *economically* insignificant for all the sample crops, in that they are associated with 95% confidence intervals that lie very close to 0. Thus, the 95% confidence intervals for the price risk coefficient are (–0.07, 0.00) for Groundnuts, (–0.06, 0.04) for Rapeseed/Mustard, (–0.12, –0.01) for Sesamum, (–0.01, 0.01) for Cotton, (0.03, 0.05) for Jute, (–0.01, 0.03) for Sugarcane, and (–0.04, 0.05) for Tobacco. The 95% confidence intervals for the yield risk coefficient are of similar magnitude. The post-reform response of area to risk is, however, substantially larger. With respect to price risk, the area elasticities are –0.16 post-reform compared to –0.04 pre-reform for Rapeseed/Mustard, 0.07 versus 0.00 for Cotton, 0.08 versus 0.04 for Sugarcane, and 0.10 versus 0.01 for Tobacco. Similarly, with respect to yield risk, the area elasticities are 0.11 post reform versus 0.08 pre-reform for Sesamum, –0.11 versus 0.07 for Cotton, and –0.08 versus –0.00 for Jute.. In other words, for six of our seven sample crops, variations in revenue risk evoked a markedly larger area response in the post-reform period. This might well be the result of increased openness of the economy post-reform.

The infrastructure variable has a positive and statistically significant influence on area allocations for three of the seven crops – Rapeseed/Mustard, Sesamum and Cotton; though for Groundnuts, Jute and Sugarcane the influence of this variable could be large as well, as indicated by the 95% confidence intervals (–0.07, 0.24), (–0.06, 0.11) and (–0.09, 0.13), respectively. This squares up with the evidence in the literature about the importance of rural infrastructure for agricultural development (see, for instance, Pinstrup-Andersen and Shimokawa 2006, for a detailed review). Amongst these crops, the post-reform elasticities are rather small in the case of Sesamum and Sugarcane, and modest for Jute (0.10), but are substantial for Groundnuts (0.20), Rapeseed/Mustard (0.63), and Cotton (0.40). Further, there does not appear to be a consistent pattern in the relative magnitudes of the post-reform versus pre-reform strengths of area response to variations in infrastructure over time.

The area adjustment coefficient γ (Table 4) ranges from about 0.25 for Sugarcane to about 0.83 for Jute and Groundnuts, averaging approximately 0.49; which implies, that for these crops it would take about four years for the 'complete' area response to occur. This is contrary to the results reported by Ray (1980), who found the short-run elasticities to *exceed* the long-run elasticities (i.e. $\gamma > 1$) – a result we feel is quite implausible given the resource constraints Indian farmers operate under. Our results for the Indian annual cash crops, understandably, compare poorly with the estimate of 2 years reported by Vasavada and Chambers (1986) for U.S. agriculture.

A similar value of γ for two different crops need not result from the same set of factors. Thus, for Sugarcane, a γ value of about 0.25 is probably the result of the fact that it is already the second largest crop in India in terms of area cultivated. Given the competing demands for other crops, the need for crop-diversification as a risk-coping measure etc., further area allocation in favour of Sugarcane tends to be (relatively) muted. A roughly similar γ value of 0.31 for Sesamum, on the other hand, has more to do with the fact that till recently it was grown by small-scale, subsistence-oriented farmers with not much access to land and non-land inputs.[26]

The Yield Response

Coming to the yield equations (Table 3), although none of the variables consistently stand out in terms of statistical significance, from the long-run elasticities in Table 4 we note that the post-reform yield elasticities with respect to irrigation are positive and large for Groundnuts (0.28), and Tobacco (0.52), and positive although small for Sugarcane (0.07). Further, they are negative and substantial for Cotton (–0.22) and Jute (–0.21), implying perhaps a shift onto relatively inferior land with increasing irrigation. Rainfall, too, has a large positive effect in the case of Groundnuts (0.84), Sesamum (1.35), Cotton (0.37) and Jute (0.54), and a small positive effect in the case of Tobacco (0.07). Thus, water availability appears to be relatively the most important variable for the yield response of all our sample crops.

Of the other variables, the relative profits variable is positive significant for five of the seven crops – Rapeseed/Mustard, Tobacco, Jute, Cotton and Sugarcane – albeit using a one-tail test for the last two. The associated post-reform long-term elasticities, however, are close to zero with the exception of Cotton (0.22), Tobacco (0.10), and Sesamum (0.09). The fertilizer price, infrastructure and risk variables do not exhibit any consistent patterns and do not stand out in explaining variations in yield.

The Total Output Response

Putting the area and yield responses together, we obtain the total output responses of the different crops to the regressors used. Of particular interest are the long-run elasticities of output of the crops, and we attempt to discern any patterns that may emerge from the elasticity estimates. From Table 4 we find, first, that the consistently prominent output elasticities are those with respect to rainfall. The post-reform output elasticities are very substantial for Sesamum (1.88), Groundnuts (0.95), Jute (0.75), and Cotton (0.46); and are small only for Tobacco, Rapeseed/Mustard and Sugarcane, ranging less than 0.10. The small elasticity for Sugarcane merely reflects the fact that it is already the second largest crop in India in terms of area cultivated, with limited scope for further expansion; and virtually 92% of its area has access to assured irrigation, with limited scope for yield enhancement due to higher rainfall. A similar situation obtains for Rapeseed/Mustard which is the second-largest oilseed crop in terms of area cultivated, and has access to assured irrigation for more than half this area. Further, these elasticities are substantially higher for the oilseeds than for the commercial crops, reflecting the fact that oilseeds cultivation is mostly rainfed, whereas much larger percentages of the area under the commercial crops has recourse to assured irrigation. Taken together with the results discussed in the previous sections, we know that this influence of rainfall acts chiefly through larger area allocations. Interestingly, the output elasticities with respect to rainfall are higher in the post-reform than in the pre-reform period in most cases, perhaps reflecting the shift to relatively infertile land in the case of some crops as we suggested above.

Second, the output elasticities with respect to the irrigation variable are relatively large and positive for all the crops except Sesamum, ranging from a low of 0.04 for Jute post-reform to about 1.09 for Tobacco post-reform. Although the post-reform elasticities are substantially larger than the pre-reform magnitudes in the case of Groundnuts and Tobacco, they are significantly lower for Rapeseed/Mustard, Sesamum, Jute and Sugarcane; so that there doesn't appear to have been any consistent strengthening or weakening of output response to irrigation over time.

Third, the post-reform output elasticities with respect to relative gross profits are, on average, smaller for the oilseeds than for the cash crops. Thus, they are very small for Groundnuts (0.01) and Rapeseed/Mustard (0.03), although substantial for Sesamum (0.20); but are consistently substantial for Cotton (0.48), Jute (0.17) and Sugarcane (0.33). This picture accords well with that in the pre-reform period, insofar as the pre-reform output elasticities with respect to the profits variable were also quite substantial for the cash crops, although more variable for the oilseeds. These results are quite consistent with the fact that profitability is a major motivation in the cultivation of the latter.

Fourth, the post-reform output elasticities with respect to the risk variables appear to be relatively larger for the cash crops, indicating that revenue risk may have become an important issue for these crops in the post-liberalization period. Ceteris paribus, higher risk appears to hinder cultivation of these crops, and limits their output. By implication, risk mitigating measures are likely to prove beneficial for the output of these crops.

Fifth, the post- and pre-reform output elasticities with respect to fertilizer price do not show much consistency, being negative and substantial in some cases, positive and substantial in others, and almost zero in some. Thus, it is not clear whether higher fertilizer price, by raising the cost of cultivation, appears to induce area allocation away from the relatively fertilizer-intensive crops, thereby reducing their output.

Finally, the post-reform output elasticities with respect to the infrastructure variable are large and positive for Rapeseed/Mustard (0.83), Cotton (0.26) and Jute (0.45), which is consistent with our earlier result that better infrastructure resulted in an increase in area-cultivated of these crops. For Groundnuts, Sesamum and Tobacco, however, improvements in rural infrastructure appear to induce a shift of these crops into relatively inferior land as we observed in the previous sub-section, lowering yields and output.

5. Conclusions and Policy Implications

From the above analysis it is apparent, that the supply response of Indian agriculture is influenced to a relatively greater extent by the weather, input availability and assets, than by expected profits. Rainfall appears to be the single most important factor determining area response, and an important factor determining the yield response of some crops, even today. In other words, even after decades of massive irrigation projects, Indian agriculture continues to be weather-dependent. A second important factor appears to be the availability of irrigation. Taken together with the previous result, it is apparent that the most important policy variable from the viewpoint of long-run output response is the water input. Given that rainfall cannot be manipulated, availability of irrigation is the obvious one that policy can impinge upon. This, probably, also has a bearing on the influence of the risk variables, whose elasticities we found to be much larger in the post-reform period.

At this point, one may well ask 'If water is the scarce resource, is there scope for expanding irrigated area without diverting it from alternative (e.g. urban/industrial) uses?'[27] The answer to that question is: Yes, indeed. Note that currently the predominant mode of irrigation in India is 'flooding the furrows'. As is well known, this is subject to very high evapo-transpiration and run-off losses (as much as 80% in some cases), and only a small proportion of the water gets actually used. If, instead, the farmers were to switch to sprinkler and drip irrigation wherever feasible (and the government could play a big role here), a much larger area could have access to assured irrigation, *given the same amount of water*.[28]

In addition to water, it appears that the affordability of fertilizer, and the availability of rural infrastructure are also significant in determining variations in output, although to a much lesser extent. These observations do not, however, imply that the profit variable is necessarily unimportant as a determinant. In fact, expected profitability may be a major factor in motivating the production of cash crops such as Cotton, Jute, Sugarcane and Sesamum..

These results lead us to opine, that the authorities need to concentrate on the increased provision of assured irrigation, as also affordable fertilizer and rural infrastructure, instead of placing over-riding emphasis on the profit variable, if a substantial increase in the long-run output of the sample crops is to be achieved. Not only will increased irrigation have a direct positive impact on supply, it will also have an indirect impact insofar as access to irrigation serves to reduce yield risk.

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Table 1
Means and Standard Deviations of Variables 1967-68/99-00

Variable (Units)	Groundnuts	Rapeseed	Sesamum	Cotton	Jute	Sugarcane	Tobacco
A_{it} ('000 hectares)	1366.9	652.5	226.9	858.7	243.9	387.5	86.9
	(505.0)	(715.2)	(155.9)	(749.2)	(183.9)	(505.1)	(68.6)
Y_{it} (tons/hectare)	0.900	0.685	0.260	1.334	7.873	68.040	1.502
	(0.37)	(0.29)	(0.18)	(1.04)	(2.06)	(21.67)	(1.34)
$\hat{\Pi}^{re}_{it}$ (ratio)	10.5	0.84	0.48	0.30	0.59	26.93	0.38
	(6.39)	(1.39)	0.76	(0.31)	(0.34)	(35.73)	(0.35)
CVP_{it} (unit-free)	0.13	0.13	0.11	0.15	0.21	0.22	0.20
	(0.09)	(0.08)	(0.08)	(0.12)	(0.22)	(0.39)	(0.12)
CVR_t (unit-free)	0.18	0.22	0.18	0.20	0.14	0.19	0.20
	(0.12)	(0.18)	(0.14)	(0.13)	(0.07)	(0.16)	(0.19)
$INFRA_t$ (Rs. million)	24539	25090	30641	25532	16159	33811	28138
	(16548)	(21462)	(23381)	(19999)	(10849)	(26357)	(35730)
$FERTPR_t$ (ratio)	0.933	0.933	0.933	0.933	0.933	0.933	0.933
	(0.279)	(0.279)	(0.278)	(0.279)	(0.279)	(0.278)	(0.279)
I_t ('000 hectares)	3127	4411	4110	3578	2070	4967	5396
	(1199)	(4153)	(3396)	(1572)	(1392)	(3585)	(4555)
R^s_t (mm/month)	3546.2	1157.5	4503.0	3969.3	1163.2	1225.9	4022.9
	(2291.4)	(853.1)	(3075.4)	(4308.1)	(519.6)	(2061.4)	(1427.2)
R^g_t (mm/month)	3253.0	675.3	4129.7	2862.7	1925.1	2563.4	4058.7
	(2233.8)	(476.9)	(2466.5)	(2355.4)	(670.6)	(2029.1)	(2303.4)
N	132	198	297	297	99	231	132

Note: Standard deviations reported in parentheses, below the corresponding means; Rs. denotes Rupees; Although variables Yield Risk, Infrastructure, Fertilizer Price, Irrigated Area, and (Sowing and Growth) Rainfall do not vary across crops, their summary statistics differ across crops because the state coverage is different for each crop.

Table 2
Arellano-Bond Dynamic Panel Data Estimates: Area Equation

Variable	Groundnuts	Rapeseed	Sesamum	Cotton	Jute	Sugarcane	Tobacco
$A_{i(t-1)}$	0.178	0.743^{***}	0.687^{***}	0.622^{***}	0.166^{***}	0.748^{***}	0.406^{***}
	(0.157)	(0.084)	(0.033)	(0.064)	(0.027)	(0.075)	(0.042)
$\hat{\Pi}_{it}^{re}$	–0.063	0.092^{***}	0.079^{***}	0.118^{*}	0.088	0.068^{***}	0.053^{***}
	(0.069)	(0.025)	(0.014)	(0.070)	(0.072)	(0.024)	(0.011)
CVP_{it}	-0.036^{**}	–0.010	-0.064^{**}	0.0002	0.041^{***}	0.010	0.006
	(0.018)	(0.025)	(0.028)	(0.006)	(0.007)	(0.009)	(0.024)
CVR_t	0.022	0.069	0.026	0.025	–0.003	0.021^{*}	–0.023
	(0.016)	(0.044)	(0.023)	(0.016)	(0.019)	(0.011)	(0.043)
$FERTPR_t$	–0.158	–0.055	–0.133	–0.021	-0.277^{**}	0.045	-0.555^{**}
	(0.120)	(0.071)	(0.132)	(0.065)	(0.134)	(0.036)	(0.248)
$INFRA_t$	0.086	0.257^{***}	0.160^{***}	0.097^{**}	0.023	0.020	-0.242^{**}
	(0.081)	(0.029)	(0.051)	(0.047)	(0.045)	(0.055)	(0.113)
I_t	0.174	0.085	–0.026	–0.032	0.183^{***}	0.248^{**}	0.353^{***}
	(0.108)	(0.154)	(0.118)	(0.067)	(0.032)	(0.104)	(0.097)
R_t^s	0.091^{**}	0.099^{***}	0.121^{***}	0.057^{***}	0.135^{***}	-0.024^{***}	0.037
	(0.039)	(0.021)	(0.033)	(0.011)	(0.039)	(0.006)	(0.045)
$P86D_{it}$	-2.370^{***}	1.622^{***}	2.210^{***}	–1.398	–1.582	0.364	-1.345^{**}
	(0.438)	(0.510)	(0.357)	(0.991)	(1.117)	(0.702)	(0.598)
$\hat{\Pi}_{it}^{re} * P86D_{it}$	0.062	-0.085^{***}	-0.042^{***}	–0.020	–0.027	0.045^{*}	–0.067
	(0.062)	(0.029)	(0.011)	(0.020)	(0.119)	(0.027)	(0.056)
$CVP_{it}*P86D_{it}$	0.034	–0.030	0.074^{**}	0.025	–0.016	0.011	0.054
	(0.033)	(0.023)	(0.031)	(0.017)	(0.023)	(0.015)	(0.056)
CVR_t*P86D_{it}	-0.102^{*}	-0.087^{**}	0.009	-0.066^{***}	–0.022	-0.033^{*}	–0.001
	(0.060)	(0.036)	(0.033)	(0.019)	(0.041)	(0.017)	(0.044)
$FERTPR_t*P86D_{it}$	0.159	0.001	–0.131	0.056	-0.401^{***}	0.016	0.460^{**}
	(0.179)	(0.036)	(0.329)	(0.119)	(0.093)	(0.021)	(0.202)
$INFRA_t*P86D_{it}$	0.076	–0.096	-0.144^{*}	0.054^{*}	0.064	–0.026	0.182^{***}
	(0.108)	(0.084)	(0.085)	(0.031)	(0.058)	(0.046)	(0.025)
I_t*P86D_{it}	0.186^{***}	–0.023	-0.102^{**}	0.147	0.026	–0.050	–0.013
	(0.062)	(0.085)	(0.042)	(0.115)	(0.103)	(0.035)	(0.049)
$R_t^s*P86D_{it}$	0.005	-0.084^{**}	0.044	-0.024^{**}	0.043	0.046^{***}	–0.038
	(0.091)	(0.036)	(0.053)	(0.010)	(0.111)	(0.013)	(0.076)
Intercept	-0.018^{**}	-0.015^{**}	-0.017^{**}	-0.015^{***}	-0.002^{**}	–0.004	0.017
	(0.008)	(0.007)	(0.007)	(0.005)	(0.001)	(0.006)	(0.017)
N	120	186	279	279	93	199	124
Wald $\div^2$ ($\hat{a}_k$=0)	32.05	120.65	264.69	5.14E+09	4.54	2.15E+09	12.10
p-value (P86D and interactions=0)	0.000	0.000	0.000	0.000	0.005	0.000	0.000
p-value (interactions=0)	0.441	0.011	0.000	0.000	0.908	0.000	0.000
AB z-value (p-value)	1.52 (0.130)	–1.41 (0.158)	1.04 (0.299)	–0.59 (0.557)	–0.34 (0.738)	0.26 (0.796)	–1.10 (0.270)

Note: All variables, except the dummy, are in natural logs; Standard errors are reported in parentheses below the corresponding coefficient estimates. 'AB z-value' refers to the Arellano-Bond test for no autocorrelation of second order. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels

Table 3

Arellano-Bond Dynamic Panel Data Estimates: Yield Equation

Variable	Groundnuts	Rapeseed	Sesamum	Cotton	Jute	Sugarcane	Tobacco
$Y_{i(t-1)}$	–0.238***	0.102	0.230***	0.152	–0.022	0.433***	0.277***
	(0.051)	(0.141)	(0.055)	(0.150)	(0.067)	(0.088)	(0.060)
$\hat{\Pi}_{it}^{re}$	–0.012	0.125***	0.080	0.125	0.069*	0.027	0.094***
	(0.082)	(0.035)	(0.069)	(0.089)	(0.035)	(0.018)	(0.020)
CVP_{it}	–0.025	–0.043**	–0.035	0.020	0.010	–0.012**	–0.004
	(0.016)	(0.020)	(0.059)	(0.017)	(0.013)	(0.005)	(0.020)
CVR_t	–0.067*	0.039*	0.053	0.02	–0.013	0.0002	–0.008
	(0.040)	(0.023)	(0.075)	(0.030)	(0.020)	(0.007)	(0.011)
$FERTPR_t$	0.130	0.230***	0.466*	0.027	–0.020	–0.025	0.185**
	(0.126)	(0.075)	(0.248)	(0.078)	(0.196)	(0.021)	(0.091)
$INFRA_t$	–0.260*	0.172***	0.071	0.103	–0.133	–0.041	0.098**
	(0.148)	(0.045)	(0.192)	(0.099)	(0.129)	(0.044)	(0.043)
I_t	–0.358*	0.009	–0.278	0.012	–0.047	0.092	–0.202***
	(0.191)	(0.093)	(0.271)	(0.112)	(0.150)	(0.067)	(0.045)
R_t^g	0.710***	–0.034	0.793***	0.056	–0.098**	0.051	–0.018
	(0.209)	(0.032)	(0.141)	(0.087)	(0.047)	(0.036)	(0.040)
$P86D_{it}$	–1.909***	–0.267	–0.117	2.192**	–9.164*	0.838	–2.923***
	(0.682)	(0.462)	(1.888)	(0.962)	(5.508)	(0.636)	(0.418)
$\hat{\Pi}_{it}^{re} * P86D_{it}$	0.031	–0.124***	–0.013	0.060	–0.033	–0.060*	–0.068**
	(0.082)	(0.031)	(0.045)	(0.043)	(0.040)	(0.036)	(0.032)
$CVP_{it}*P86D_{it}$	0.048	–0.034	0.125	0.021	–0.306**	0.027	0.025
	(0.045)	(0.036)	(0.129)	(0.046)	(0.143)	(0.019)	(0.023)
CVR_t*P86D_{it}	0.161**	0.061*	–0.071	0.001	–0.242	0.008	–0.055***
	(0.073)	(0.033)	(0.093)	(0.070)	(0.148)	(0.013)	(0.014)
$FERTPR_t*P86D_{it}$	0.573*	–0.212*	0.170	0.056	1.069	0.026	–0.070
	(0.304)	(0.128)	(0.608)	(0.148)	(0.970)	(0.020)	(0.180)
$INFRA_t*P86D_{it}$	–0.567***	0.014	–0.351	–0.220**	0.485	0.058**	–0.250***
	(0.173)	(0.052)	(0.215)	(0.092)	(0.417)	(0.027)	(0.036)
I_t*P86D_{it}	0.707***	–0.008	0.276**	–0.198	–0.164	–0.053	0.579***
	(0.063)	(0.030)	(0.140)	(0.122)	(0.172)	(0.044)	(0.034)
$R^g_t*P86D_{it}$	0.326**	0.023	0.247	0.255***	0.650**	–0.098**	0.070***
	(0.153)	(0.032)	(0.186)	(0.070)	(0.317)	(0.047)	(0.016)
Intercept	0.037***	0.007**	0.011	0.013	0.027***	0.005**	0.014*
	(0.010)	(0.003)	(0.018)	(0.009)	(0.006)	(0.002)	(0.008)
N	120	186	279	279	93	217	124
Wald ÷^{2} (â$_k$=0)	108.04	42.47	176.31	11.6	4.44	166.56	91.64
p-value (P86D and interactions=0)	0.000	0.000	0.000	0.000	0.030	0.000	0.000
p-value (interactions=0)	0.000	0.000	0.000	0.000	0.542	0.000	0.000
AB z-value (p-value)	1.55 (0.120)	1.58 (0.114)	–1.37 (0.170)	–0.13 (0.900)	0.00 (0.999)	0.29 (0.774)	0.11 (0.914)

Note: All variables, except the dummy, are in natural logs; Standard errors are reported in parentheses below the corresponding coefficient estimates. ‘AB z-value’ refers to the Arellano-Bond test for no autocorrelation of second order. ***, **, and * indicate statistical significance at the 1%, 5% and 10% levels

Table 4

Structural Form Elasticities – Pre-Reform / Post-Reform

Crop	Area Adj. Coeff. (ã)	Regressor	Area Elasticity	Yield Elasticity	Elasticity of Output*	Crop	Area Adj. Coeff. (ã)	Regressor	Area Elasticity	Yield Elasticity	Elasticity of Output*
Groundnuts	0.82	$\hat{\Pi}^{re}_{it}$	–0.08 / –0.00	–0.01 / 0.02	–0.09 / 0.01	Jute	0.83	$\hat{\Pi}^{re}_{it}$	0.11 / 0.07	0.07 / 0.10	0.17 / 0.17
		CVP_{it}	–0.04 / –0.00	–0.02 / 0.02	–0.06 / 0.02			CVP_{it}	0.05 / 0.03	0.01 / –0.29	0.06 / –0.26
		CVR_t	0.03 / –0.10	–0.05 / 0.08	–0.03 / –0.02			CVR_t	–0.00 / –0.03	–0.01 / –0.25	–0.02 / –0.28
		$INFRA_t$	0.10 / 0.20	–0.21 / –0.67	–0.11 / –0.47			$INFRA_t$	0.03 / 0.10	–0.13 / 0.34	–0.10 / 0.45
		$FERTPR_t$	–0.19 / 0.00	0.11 / 0.57	–0.09 / 0.57			$FERTPR_t$	–0.33 / –0.81	–0.02 / 1.03	–0.35 / 0.21
		I_t	0.21 / 0.44	–0.29 / 0.28	–0.08 / 0.72			I_t	0.22 / 0.25	–0.05 / –0.21	0.17 / 0.04
		R^s_t/R^g_t	0.11 / 0.12	0.57 / 0.84	0.68 / 0.95			R^s_t/R^g_t	0.16 / 0.21	–0.10 / 0.54	0.07 / 0.75
Rapeseed	0.26	$\hat{\Pi}^{re}_{it}$	0.36 / 0.03	0.14 / 0.00	0.50 / 0.03	Sugarcane	0.25	$\hat{\Pi}^{re}_{it}$	0.27 / 0.45	0.05 / –0.06	0.32 / 0.39
		CVP_{it}	–0.04 / –0.16	–0.05 / –0.01	–0.09 / –0.17			CVP_{it}	0.04 / 0.08	–0.02 / 0.03	0.02 / 0.11
		CVR_t	0.27 / –0.07	–0.04 / 0.03	0.22 / –0.04			CVR_t	0.08 / –0.05	0.00 / 0.01	0.08 / –0.03
		$INFRA_t$	1.00 / 0.63	0.19 / 0.21	1.19 / 0.83			$INFRA_t$	0.08 / –0.03	–0.07 / 0.03	0.01 / 0.00
		$FERTPR_t$	–0.21 / –0.21	0.26 / 0.02	0.04 / –0.19			$FERTPR_t$	0.18 / 0.24	–0.04 / –0.00	0.14 / 0.24
		I_t	0.33 / 0.24	0.01 / 0.00	0.34 / 0.24			I_t	0.98 / 0.78	0.16 / 0.07	1.14 / 0.85
		R^s_t/R^g_t	0.38 / 0.06	–0.04 / –0.01	0.35 / 0.05			R^s_t/R^g_t	–0.09 / 0.09	0.09 / –0.08	–0.00 / 0.00
Sesamum	0.31	$\hat{\Pi}^{re}_{it}$	0.25 / 0.12	0.10 / 0.09	0.36 / 0.20	Tobacco	0.59	$\hat{\Pi}^{re}_{it}$	0.09 / –0.02	0.13 / 0.04	0.22 / 0.01
		CVP_{it}	–0.20 / 0.03	–0.05 / 0.12	–0.25 / 0.15			CVP_{it}	0.01 / 0.10	–0.01 / 0.03	0.00 / 0.13
		CVR_t	0.08 / 0.11	0.07 / –0.02	0.15 / 0.09			CVR_t	–0.04 / –0.04	–0.01 / –0.09	–0.05 / –0.13
		$INFRA_t$	0.51 / 0.05	0.09 / –0.36	0.60 / –0.32			$INFRA_t$	–0.41 / –0.10	0.14 / –0.21	–0.27 / –0.31
		$FERTPR_t$	–0.42 / –0.84	0.61 / 0.83	0.18 / –0.02			$FERTPR_t$	–0.93 / –0.16	0.26 / 0.16	–0.68 / –0.00
		I_t	–0.08 / –0.41	–0.36 / –0.00	–0.44 / –0.41			I_t	0.59 / 0.57	–0.28 / 0.52	0.32 / 1.09
		R^s_t/R^g_t	0.39 / 0.53	1.03 / 1.35	1.42 / 1.88			R^s_t/R^g_t	0.06 / 0.00	–0.02 / 0.07	0.04 / 0.07
Cotton	0.38	$\hat{\Pi}^{re}_{it}$	0.31 / 0.26	0.15 / 0.22	0.46 / 0.48						
		CVP_{it}	0.00 / 0.07	0.02 / 0.05	0.02 / 0.12						
		CVR_t	0.07 / –0.11	0.02 / 0.03	0.09 / –0.08						
		$INFRA_t$	0.26 / 0.40	0.12 / –0.14	0.38 / 0.26						
		$FERTPR_t$	–0.06 / 0.09	0.03 / 0.10	–0.02 / 0.19						
		I_t	–0.08 / 0.30	0.01 / –0.22	–0.07 / 0.08						
		R^s_t/R^g_t	0.15 / 0.09	0.07 / 0.37	0.22 / 0.46						

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[*] Elasticity of output is the sum of the structural form elasticities of area and yield; some numbers do not add up due to rounding errors. Numbers before the slash (/) are pre-reform elasticities, those after the slash are post-reform elasticities. Regarding rainfall, area elasticity is with respect to R^s_t, yield elasticity is with respect to R^g_t, and output elasticity is their sum.

Endnotes

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[1] Holt (1999) and Barten and Vanloot (1996) consider absolute, and not relative, profit as the relevant 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. Narayana and Parikh (1981) consider relative gross profit as the appropriate regressor. Parikh (1972) considered relative price and relative yield, but not relative profit per se, in his set of regressors.

[2] The profit function approach would require data on several input prices. Data on neither seed prices nor irrigation water charges, however, are available in the Indian context. Further, 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. Even these user charges data are virtually non-existent. Moreover, depending on political expediency, some state administrations make water (and electricity) available to farmers free of cost!

[3] See Nerlove and Bessler (2001), and the references therein.

[4] Narayana and Parikh (1981) argue that given $\Pi_t = \Pi_t^e + \mu_t$ where μ_t is the random component, the Nerlovian expectation specification (6) amounts to placing equal weights on the expected and random components of profits. To remedy this, they prefer specification (7). It stands to reason, however, that 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. But there is nothing in specification (7) per se to ensure that – a fact that is borne out by many of the results reported in their Table 2 (Narayana and Parikh 1981: p. 16). Therefore, we prefer to use specification (7) strictly as a statistical approximation.

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[5] In an attempt to influence acreage decisions, the Indian authorities announce incentive prices *before* the sowing season. Given this information, the farmers may be thought of as forming profit expectations before the sowing season. Their expectations would not, then, depend upon 'current period' values of the Z-variables. To the extent, however, that incentive prices have tended to be announced after the sowing decisions (Acharya and Chaudhri, 2001), this may be taken to be a simplifying assumption.

[6] The irrigation variable is not measured as a proportion of cropped area, 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.

[7] See Lahiri and Roy (1985) for alternative specifications of the rainfall variable.

[8] We are grateful to one of the referees for clarifying our understanding of these risk measures. Let P_{it} be the price of crop *i* in year *t*. Fitting an exponential trend, we derive $\hat{P}_{it}$, and thence $DP_{it} = P_{it} - \hat{P}_{it}$ ('*D'* for the deviation). We measure CVP_{it} as the standard deviation of ($DP_{i,t-1}$, $DP_{i,t-2}$, $DP_{i,t-3}$) divided by the mean of ($\hat{P}_{i,t-1}, \hat{P}_{i,t-2}, \hat{P}_{i,t-3}$).

Similarly, let R_t be the actual rainfall in year *t*, and $\overline{R}_t$ the long-term average rainfall in year *t* (i.e. the average for the previous 30 years). Derive $DR_t = R_t - \overline{R}_t$ ('*D*' for the deviation). We measure CVR_t as the standard deviation of (DR_{t-1}, DR_{t-2}, DR_{t-3}) divided by the mean of ($\overline{R}_{t-1}, \overline{R}_{t-2}, \overline{R}_{t-3}$).

[9] The correlation between DP_{it} and DR_t (see footnote above for their definitions) is –0.087 for

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Groundnuts, 0.023 for Rapeseed/Mustard, –0.063 for Sesamum, 0.159 for Cotton, 0.175 for Jute, 0.037 for Sugarcane, and 0.106 for Tobacco.

[10] See Chavas and Holt (1996), Pope and Just (1991), Pope (1982), Just (1974), and Behrman (1968), for alternative risk specifications.

[11] The results appeared robust to different values for the depreciation rate.

[12] These were diesel, lubricants, electricity, tractors, implements, and insecticides/pesticides.

[13] The Technology Mission on Oilseeds was established in 1986, so that the oilseeds benefited from improved seeds only by 1987 at the earliest. Of the other crops, improved varieties for Cotton and Jute began to be released from the mid-1980s onwards. For Sugarcane and Tobacco, however, a similar assessment becomes difficult in the face of lack of data regarding the year of release of the improved varieties.

Two other regressors of interest are credit and mechanization, but appropriate data on these were not available. Data on these variables were neither crop-specific, nor available for our entire sample period. Moreover, data on the latter only pertained to the aggregate stock of tractors, whereas what we require are data on the number of machine-hours of labor used.

[14] The results were found to be qualitatively robust to small changes in the choice of 1986 as the demarcation year (as against 1985 and 1987, for instance).

[15] Although Sugarcane planted earlier in the year will yield a harvest later *during the same year*, admittedly its maturation cycle differs somewhat from the crops it competes with. This makes comparisons that much more difficult. We cannot, however, address this issue without very detailed data regarding the multiple cropping possibilities during the period that sugarcane takes

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to mature; data that we did not have access to, and an exercise that is beyond the scope of this paper.

[16] It would be ideal, of course, if data on all the variables were available to us by season, but this was not the case.

[17] Many crops, other than the 7 crops studied here, were considered when deciding on the possible competing crops. Testing whether our results are sensitive to the choice of competing crops does not appear practical, for there is no obvious 'alternative' set of competing crops. Nor is it feasible to try out all other possible competing crop combinations (if only on data grounds).

[18] Cost of production data were not available for the entire sample period (nor even for all the sample crops), and were in any case patchy. More specifically, it was not always possible to fill in the missing values by utilizing data from neighboring states with similar conditions, simply because data for the neighboring states was also not available for those years. Further, from the available data we found that the cost figures for the same crop in the same year tended to be very different even in adjoining states, leave alone non-contiguous states; so that it would be sheer bravado to fill in the missing values in some states by the cost of cultivation figures in other states for which data might be available. Finally, for most crops in our sample, cost of cultivation data are missing for many of the states growing those crops, and for one crop (Tobacco) cost data are not available for any state! Therefore, we could compute only (expected) gross revenue, which we used to proxy (expected) profits. Of course, given that production costs are not constant across states and over time, the ‘expected profits’ variables in our analysis ought to be interpreted as ‘expected revenues’.

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[19] The issue of which farmers have a surplus, which a deficit, and which are self-sufficient in the crop in question (Key, Sadoulet and de Janvry, 2000), is not relevant here because one is dealing with cash (and not food) crops. Besides, we do not have access to household-specific data.

[20] A_{it}, Y_{it} – Government of India (a); $\hat{\Pi}_{it}^{re}$ – computed from data in Government of India (a), (b) and (2001); CVP_{it} – computed from data in Government of India (b); CVR_t – computed from data in India Meteorological Department (2004); $FERTPR_t$ – Fertiliser Association of India; $INFRA_t$ – Reserve Bank of India; I_t – computed from data in Government of India (a), (c) and (d); R^s_t /R^g_t– Indian Institute of Tropical Meteorology (online).

[21] While the disturbances in 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 Arellano-Bond estimation by the STATA (Stata Corporation, 2003) econometrics package. This was confirmed in personal communication by the STATA support team.

[22] Only in the case of the Groundnuts and Sugarcane area equations, and the Groundnuts yield equation did we need to add extra lagged dependent variable terms to take care of some autocorrelation.

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

[24] Crop-specific irrigation data were not available for Jute.

[25] We may talk of a change in profitability (as a policy instrument), brought about by ceteris paribus changes in prices. Further, this change in price may, by affecting profitability, cause a change in yields, which would be picked up by the yield equation. A change in yield, on the

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other hand, is not a policy instrument in the same manner.

[26] A formal regression analysis of the relationship between the area adjustment coefficient and its determinants is not possible, however, because of the lack of a time series on the coefficient *by crop*.

[27] Needless to say, the overall strategy would also have to contend with difficult issues such as public investment in irrigation projects, implications of groundwater use, and even maintenance of traditional systems (such as tank irrigation).

[28] A more complete statement about the benefits of such a switch would, of course, consider various effects – higher yields from lower moisture-stress and continuous growth; lower water and labor costs; more optimal and convenient fertilizer application; slower growth of weeds from application directly to the roots; lower incidence of chemical poisoning (implying better health and lower mortality) from not having to fertilize manually; lesser chemical poisoning of the soil and underground water; healthier crops, which may fetch a higher price; shorter maturation period and higher possibility of multiple cropping; slower lowering of the water table; and greater availability of water for alternative uses. Of course, à posteriori, one would have to consider whether these benefits are large enough to compensate for the expense of these technologies.