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Market Impacts of Technological Change for Sorghum in Indian Near-Subsistence Agriculture

Jere R. Behrman and K. N. Murty

Evaluating market impacts of technological change for near-subsistence crops like sorghum in semiarid tropical India is complicated because of diversified agriculture, geographically isolated markets, and therefore feedbacks through prices, and producer-demander income links for such products. Dynamic simulations with a multicommodity market model suggest that increased sorghum productivity would have spillover effects on other markets, increase the welfare of sorghum consumers, and probably lower the sorghum price. Contrary to speculations of some experts, the output gain probably would be greater than the pure productivity effect despite the price decline because of induced input allocations favoring sorghum production.

Key words: India, market responses, sorghum, subsistence agriculture, technological change.

The initial successes of the green revolution were the "superior" grains, like wheat and rice, grown primarily in monoculture or near monoculture in irrigated and relatively well-off areas like the Punjab and usually with most of the production traded in geographically well-integrated markets. Emphasis subsequently has shifted to exploration of technological change for near-subsistence products like sorghum and chickpeas that are grown largely in diversified agriculture under rainfed conditions in poorer areas like semiarid tropical peninsular India, often with substantial proportions of the production consumed by the producers themselves and with the marketed surplus sold in geographically isolated markets. In his recent Kellogg Fiftieth Anniversary Lecture, Nerlove observed that the profession has acquired substantial information about the former type of crops, but large lacunae in our knowledge remain for the latter.

Evaluation of the impact of technological innovations on product markets is much more complicated for products like sorghum in India than for the superior grains because such analysis must recognize the added complexities of production, demand, and markets for these crops.[1] The existence of diversified production means that the supply/production side of the market must be modeled to allow substitution among various crops. The geographically isolated product markets mean that output expansion of a particular crop due to a technological innovation may cause the price of that crop to fall, perhaps substantially, which may discourage future output. Feedbacks through product markets, moreover, may cause changes in the prices for other products that also are characterized by geo-

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[1] In this paper emphasis is on product markets. Though important changes also might occur in factor markets, inadequate data preclude incorporation of many of the features of factor markets. However, the sensitivity analysis below includes exploration of the importance of an alternative assumption concerning labor markets.

graphically isolated markets. Likewise, induced shifts in input usage may affect input prices that are determined in isolated markets, with feedback effects on production of all local products. Therefore, the modeling must incorporate the endogenous determination of all of the prices that reflect the isolated nature of the relevant markets. To do so, demand systems must be included that allow for substitution among the major demand categories in response to the relative price changes. The output demand systems also must incorporate endogenous income effects since substantial shares of the production of such crops often are consumed by the producers themselves. For the crop examined in this paper, for example, about three quarters of the production is consumed by the producers.

This paper considers the product market impacts of a hypothetical technological innovation for such a crop: sorghum in semiarid tropical (SAT) India. Sorghum is one of the five mandate crops of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) located near Hyderabad in India. Research at ICRISAT, in Indian research programs like AICRPDA and ICAR, or elsewhere may lead to significant technological improvements in sorghum production. However, some experts have expressed the fear that technological innovation for sorghum in SAT India would depress sorghum prices to such an extent that farmers would shift away from sorghum production enough so that there would be little output gain. The purpose of this paper is to explore this proposition and other related market impacts of technological change for such a crop. The method employed is to simulate the impact of a hypothetical technological change in sorghum production with a market model based on supply and demand systems for SAT Indian agriculture, making explicit assumptions regarding price determination. Sensitivity analysis is undertaken to explore the impact of several critical assumptions that cannot be tested directly because of data inadequacies.

The Model

The approach of this investigation is to specify a model of the relevant SAT Indian agriculture markets and then to use this model to simulate the impacts of a hypothetical improvement in sorghum production. The major components of the model are discussed in turn.

Supply

The basic system output supply-factor demand model for one observation is represented in vector notation as[2]

$$S = f(P^*, X, U) \tag{1}$$

where S is an m-element vector of quantities, including the output supplies of each of the m_s commodities defined below and the input demands for each of m_v variable inputs; P^* is an m_s-element vector of expected prices at the time of production decisions with one element corresponding to each of the first m_s elements of S; X is an m_x-element vector including m_v input prices and the m_n additional nonpurchased or fixed variables such as noted below; U is an m-element vector of stochastic terms to represent unobserved factors, one for each of the elements of S.

An equivalent representation of the ith crop output (or input), which is approximated below, is the growth rate form:

$$\dot{S}_i = \sum_{j=1}^{m_s} E_{S_i P^*_j} \dot{P}^*_j + \sum_{j=1}^{m_x} E_{S_i X_j} \dot{X}_j + E_{S_i U_i} \dot{U}_i \tag{2}$$

where the standard convention is used that a dot above a variable means the rate of change ($\dot{Z} = \partial Z/Z$); E_{YZ} is the elasticity of Y with respect to Z; and subscripts i and j refer to elements in the indicated vector. Equation (2) states that the growth rate of the ith crop's output supply (or input factor demand) is a weighted average of the growth rates of all expected prices ($\dot{P}^*_j$), all of the additional variables ($\dot{X}_j$), and the disturbance ($\dot{U}_i$), with the weights being the respective output (or input) elasticities. The elasticities incorporate the underlying technological and behavioral responses to changes in various expected prices and other variables. In general, the elasticities are not constant but depend on the overall configuration of output supplies and input demand, which in turn depend on the overall configuration of expected prices and other variables.

This study uses the careful supply "system A" estimates for SAT India by Bapna, Binswanger, and Quizon (hereafter BBQ).

[2] This formulation abstracts from possibilities like risk aversion and does not include the impact of higher moments on supply.

These estimates are pooled time-series (1957/58–1973/74) cross-section (73 districts aggregated into thirteen regions in the SAT Indian states of Tamil Nadu, Karnataka, Andhra Pradesh, and Madhya Pradesh) estimates based on underlying normalized profit functions to obtain relation (1), with expected prices represented by a distributed lag in actual prices, and with the disturbance for the ith crop (input) in the tth period having a variance-components structure with regional, time, and residual error components.[3]

In this supply system the number of output commodities (m_s) is six: (*a*) sorghum (almost exclusively a food grain in India), (*b*) superior cereals (wheat and rice), (*c*) other coarse cereals (pearl millet, maize, finger millet, kudon, kutki, and other minor millets), (*d*) pulses (chickpea, pigeonpea, green gram, black gram, horse gram, and other pulses), (*e*) oilseeds (groundnuts, sesamum, castor bean, and linseeds), and (*f*) other crops (sugarcane, cotton, tobacco and chilies). The available data permitted empirical incorporation of only two (m_v) purchased (or purchasable) variable inputs: (*a*) fertilizers (as measured in tons of nutrients N, P_2O_5 and K_2O) and (*b*) labor.[4] Five additional variables (m_a) also were included: (*a*) rainfall, (*b*) road density in length of roads per unit area, (*c*) irrigation as proportion of cropped area, (*d*) market density per unit area, and (*e*) high-yielding varieties as proportion of total cropped area.

Table 1 summarizes the implied price elasticities at the sample means. The simulations to be discussed use these elasticities under the assumption that the elasticities in relation (2) are approximately constant. The elasticities imply some interesting partial-equilibrium features. The own-price elasticities range from 0.16 to 0.87, with that for sorghum equal to 0.43; such values indicate fairly substantial price responsiveness in this relatively poor agricultural area. Several of the cross-crop elasticities also are fairly large with absolute magnitudes on the order of 0.2 to 0.3, which suggests important intrasystem substitution in production.

Demand

The basic demand or expenditure system for one observation can be represented in vector notation as

$$D = g(P^d, Y, V) \tag{3}$$

where D is a n-element vector of quantities demanded for the commodities defined below; P^d is a n-element vector of prices faced by consumers, with one element corresponding to each element of D; Y is total expenditure; and V is a n-element vector of stochastic terms to represent unobserved factors, one for each of the elements of D. An equivalent representation for the ith commodity demand, which is approximated below, is the growth rate form

$$\dot{D}_i = \sum_{j=1}^{n} E_{D_i P_j d} \dot{P}_j^d + E_{D_i Y} \dot{Y} + E_{D_i V_i} \dot{V}_i \tag{4}$$

where the conventions defined for relation (2) apply. Relation (4) states that the growth rate of the demand for the ith commodity is a weighted average of the growth rates of all prices faced by demanders ($\dot{P}_j^d$), of expenditure ($\dot{Y}$), and of the disturbance ($\dot{V}_i$), with the weights being the respective demand elasticities. These elasticities incorporate the underlying behavioral responses and the aggregation across individual households. In general the elasticities are not constant but depend upon the overall configuration of market prices, expenditures, and the distribution of purchasing power.

This study uses demand system estimates for low-income rural Indians from the careful study by Murty and Radhakrishna (hereafter MR). MR utilize the Nasse generalization of the linear expenditure system for relation (3), which allows nonadditivity in the underlying utility function.[5] In order to overcome the linear expenditure effects implied by this model, they subdivide the sample into five real expenditure groups for rural areas and five for urban areas. They allow for cross-equation correlations in the elements of the disturbance vector (V) by using a generalized least-squares estimator. Under these assumptions, MR ob-

[3] The included states account for the following percentages of Indian output and acreage of the major crops considered in this study: wheat (10.8, 17.5), rice (15.6, 14.1), sorghum (36.7, 42.0), other cereals (30.2, 22.4), pulses (24.3, 31.0), oil seeds (37.4, 35.0), and other crops (27.1, 28.2). In regard to the lag structure, after experiments with various alternatives, BBQ adopted a uniform distributed-lag specification for all expected crop prices with a weight of 0.71 on the actual price lagged one year and a weight of 0.29 on the actual price lagged two years.

[4] Labor input data were not available, but the effect of labor market conditions was incorporated by including the daily male wage rates for standard eight-hour days.

[5] To satisfy the convexity conditions MR impose the restrictions that nonfood groups are additively separable, thus reducing this part of the model to a linear expenditure system.

Table 1. Crop Output Supply Elasticities for SAT India

	Output Supply Elasticities for:					
	Sorghum	Superior Cereals	Other Coarse Cereals	Pulses	Oilseeds	Other Crops
Expected prices of:						
Sorghum	.43	02	− 10	19	− 09	− 07
Superior cereals	.05	.30	− 25	11	−.31	− 10
Other coarse cereals	− 08	− 08	38	− 35	10	08
Pulses	.11	.03	−.25	87	02	.05
Oilseeds	− 09	− 13	13	03	21	05
Other crops	− 09	− 05	14	12	06	16

Source: Normalized quadratic profit function estimates, evaluated at point of sample means, for expected prices from Table 5 and for other variables from table 6 in BBQ, after adjustment by an iterative trial and error procedure to assure satisfaction of all convexity conditions

tain maximum likelihood estimates of relation (3) for each of the ten real expenditure groups.

MR estimate these demand systems from a pooled time series of cross-sections from the National Sample Survey Organization (NSSO) for 1950/51 through 1970/71 (rounds 2 through 25). These data permit a hierarchical approach in which systems of demand equations for more aggregate commodities are estimated first, and then these broader aggregates are decomposed into components on a level of aggregation which approximates those used in the supply estimates above (except for the residual sixth category), with n equal to six: (*a*) sorghum, (*b*) superior cereals, (*c*) other coarse cereals, (*d*) pulses, (*e*) edible oils, and (*f*) other items.

This study utilizes the MR estimates for the second lowest expenditure category in the rural sample under the assumption that the elasticities calculated at the sample means for this expenditure group best approximate the elasticities in relation (4) for the commodities of concern for SAT India. Table 2 gives these estimated elasticities, which have several interesting patterns.

First, all of the own-price elasticities are negative, as theory suggests should be the case for normal goods. They range from −.62 for edible oils to −1.92 for sorghum. These values are fairly substantial, particularly for sorghum but are far from negative infinity. Therefore, for those commodities for which SAT markets are not well integrated with other markets, supply shifts cause considerable price adjustments in the opposite direction, *ceteris paribus*. For such cases, if markets are isolated it is critical that both demand and supply be considered in the analysis since the supply relations tell only part of the story.

Second, there are some fairly large cross-price effects, both positive and negative. For this reason using a demand system, instead of individual demand relations, is important for

Table 2. Commodity Demand Elasticities for Rural Indian Low-Expenditure Groups

	Demand Elasticity of					
	Sorghum	Superior Cereals	Other Cereals	Pulses	Edible Oils	Other Commodities
With respect to price of						
Sorghum	−1.92	0.20	0.15	−0.05	−0 08	−0 04
Superior cereals	0.83	−1.20	0 56	−0.19	−0 33	−0 17
Other cereals	0.21	0.19	−1.32	−0.08	−0.14	−0 07
Pulses	−0.01	−0.01	−0.01	−0.92	0.04	0.00
Edible oils	−0.03	−0.02	−0.02	0.04	−0.62	−0.00
Other commodities	−0.09	−0.08	−0.06	−0.03	−0 01	−0.88
With respect to total expenditure	1.01	0.93	0.69	1.24	1.12	1.15

Source: Unpublished work by Murty based on Nasse expenditure system estimates, evaluated at point of sample means, for second lowest rural expenditure group in work summarized in MR.

analysis of various scenarios. For example, a 10% increase in the price of sorghum implies increases of 2% and 1.5%, respectively, in quantities demanded of superior cereals and of other coarse cereals, and decreases of 0 to 1% for edible oils, pulses, and all other commodities.

Third, the expenditure elasticities vary somewhat with those for other coarse cereals (.69) relatively irresponsive, those for superior cereals (.93) and sorghum (1.01) intermediate, and those for the other categories somewhat higher (1.12 to 1.24). Thus, as income and expenditure increase, *ceteris paribus*, there is the well-known shift in expenditure shares away from other coarse cereals and, to a lesser extent, from superior cereals and sorghum to pulses, edible oils, and other commodities.

The Production Equals Absorption Identity

For the ith commodity in SAT agriculture the total supply is SAT production (S_i) plus net imports into SAT (M_i).[6] The total absorption includes demands for current human consumption (D_i), for current livestock consumption (L_i), for seed reserves (R_i), and for changes in inventories held by producers (ΔI_i^p), consumers (ΔI_i^c), market wholesalers and retailers (ΔI_i^m) and public authorities (ΔI_i^g). In addition, there is significant wastage (W_i), including spoilage and loss to insects and other animals. Total supply equals total absorption:

$$(5)\quad S_i + M_i = D_i + L_i + R_i + \Delta I_i^p + \Delta I_i^c + \Delta I_i^m + \Delta I_i^g + W_i.$$

In principle, all of the components of supply and absorption indicated in relation (5) may be responsive to actual and/or expected prices of SAT commodities. If their responses differ, the composition of both supply and demand may change as prices (or expected prices) change.

In practice, unfortunately, data are not available with which to estimate the market responsiveness of most of these components. Therefore, this study assumes for the three crops for which the SAT markets are not well integrated with other markets (i.e., sorghum, other cereals, and pulses)[7] that the sum of net exports, livestock use, seed reserves, producer stock changes, and wastage is proportional to supply:

$$(6)\quad a_i S_i = L_i + R_i + \Delta I_i^p + W_i - M_i.$$

Likewise, for these commodity groups, the sum of other (i.e., nonproducer) inventory changes is assumed to be proportional to demand:

$$(7)\quad b_i D_i = \Delta I_i^c + \Delta I_i^m + \Delta I_i^g$$

Under these assumptions, relation (5) may be rewritten as:

$$(5A)\quad (1 - a_i)S_i = (1 + b_i)D_i$$

$$(5B)\quad S_i = D_i \cdot \alpha_i$$

where

$$\alpha_i = (1 + b_i)/(1 - a_i).$$

Relation (5B) can be utilized with relation (2) substituted in the left side and with relation (4) substituted for the first term in the right side, which ties the production equals absorption identity of relation (5) directly back to the discussion above about supply and demand systems.

At the other extreme are most of the other commodity supplies or demands in the model, in which SAT production or consumption is a small proportion of total Indian quantities and for which markets are relatively well-integrated geographically. In these cases net SAT imports are large and variable compared with SAT production. Therefore prices are assumed to be set in the larger Indian market outside of SAT or by government policies (e.g., fertilizers) with behavior in SAT responding to such prices. The commodities in this category include superior cereals, the other-crop supply category, fertilizer, and other-commodity demand category.

Finally one intermediate case between these extremes is posited. For oilseeds—edible oils SAT production is a fairly large share of the Indian total (about 45% in 1978) and the market is fairly well integrated geographically. In this case, therefore, an intermediate assumption is made between the extremes of prices being determined completely within SAT (as for sorghum, other coarse cereals, and pulses) and prices being determined entirely outside of SAT (as for all remaining categories). The

[6] Net imports, of course, are negative if exports exceed imports.

[7] In these cases, for the most part, net trade between SAT India

intermediate assumption is that the price is an inverse function of SAT quantity produced along a fairly flat price-quantity locus that reflects explicitly the SAT production share and the total Indian demand elasticities and the non-SAT supply elasticity. By differentiation of the identity that SAT plus non-SAT supply equals total Indian demand:

$$(8) \qquad E_{XP} = \frac{D^r}{X} E_D r_P - \frac{S^r}{X} E_S r_P$$

where the superscript r refers to the rest of India and X is exports from SAT to the rest of India.

Supply- and Demand-Price Relations

Prices are determined outside of the model for superior grains, the other-crops supply category, fertilizer, labor, and the other-commodities demand category. For the commodities on the supply side, in addition, there are expected prices (P^*_i) based on actual supply prices (P_i) as indicated in note (3) and prices which consumers pay on the demand side (P_i^d). The prices which consumers pay differ from those which farmers receive due to transportation, marketing, and processing costs (m_i), which differ from crop to crop:

$$(9) \qquad P_i^d = m_i P_i$$

so that

$$(9A) \qquad \dot{P}_i^d = \dot{P}_i + \dot{m}_i.$$

The prices of sorghum, other grains, and pulses also are assumed to adjust within each year to clear approximately the individual markets.

Producer Revenue-Demander Expenditure Linkage

A characteristic which distinguishes SAT Indian near-subsistence agriculture from more commercialized agriculture is that a substantial part of production is consumed by the farmers themselves. This implies an additional link between supply and demand beyond those through market prices since the total expenditure of demanders depends in considerable part on the revenues of producers. To capture this link, total expenditure in the demand system is posited to depend on the weighted sum of the value of SAT production of the six supply commodities[8] in the BBQ supply system $\left(\sum_{i=1}^{6} S_i P_i\right)$ minus expenditures on fertilizer ($S_7 P_7$) plus other net expenditures (Y_o) which are independent of price and quantity movements for the commodities of concern:[8]

$$(10) \qquad Y = c' \left(\sum_{i=1}^{6} S_i P_i - S_7 P_7 \right) + Y_o.$$

The components of Y_o may include some commodity generation and savings activity. But a substantial proportion of SAT economic activity may be related to the value of production of the farm commodities through the impact on related service and transport activities, which implies a value of c' greater than one. On the other hand, the first right-side expression in relation (10) is an overstatement of expenditure from SAT agricultural production to the extent that other nonfertilizer inputs and savings are not deducted from the gross value of production, which implies a value of c' below one, *ceteris paribus*. This study assumes that the net impact of these considerations can be represented at the margin by the following approximation:

$$(10A) \qquad \dot{Y} = c\dot{Z} + \dot{Y}_o$$

where

$$Z = \sum_{i=1}^{6} P_i S_i - P_7 S_7 \text{ and } c = 0.6.^9$$

The Base Simulation

The reference point for the simulations of the next sections is a base simulation in which all endogenous variables are solution values given the actual values for exogenous variables and in which all of the stochastic terms have their expected values of zero. This is a more useful reference point than actual values for the endogenous variables would be because it makes clear the systematic impact of hypothesized changes without confusing effects of stochastic terms.

[8] Note that all production is valued at market prices even though some of it is consumed on the farm without entering the market. The question of whether all or only the marketed portion of production should be valued at market prices underlay a debate between Krishna and Behrman of some years ago regarding indirect measures of the price elasticity of the marketed surplus.

[9] Estimating the empirical value of c is not easy because of possible SAT macroeconomic multiplier effects, etc. The sensitivity of the simulations to different values of c (and therefore c' as

In this base simulation, $\dot{\alpha}_i$ and $\dot{m}_i$ are assumed to be zero in relations (5B) and (9A), respectively. The former assumption is equivalent to assuming that the combined impact of net exports, livestock use, seed reserves, wastage and stock change is constant [i.e., $(1 + b_i)/(1 - a_i)$ is constant] for each crop over time. The latter assumption implies that transportation, marketing and processing costs are constant for each crop over time. These two assumptions are made for the base simulation because inadequate data preclude direct estimates of possible changes over time in α_i and m_i. Below, however, there is consideration of the impact on the basic simulation of technological change in sorghum if these assumptions are modified for this crop.

The base simulation is a ten-year dynamic simulation for 1969–70 through 1978–79 in which, within the simulation period, simulated values of lagged endogenous variables are used instead of actual values. These lagged simulated values are one of the two major mechanisms which link impacts of the hypothetical exogenous change in sorghum technology across periods in a dynamic fashion through the lagged values to which the growth rates in relations (2) and (4) are applied to obtain the levels of endogenous variables for the current simulation period. The other major dynamic mechanism is through the endogenous expected price generation process. The use of a decade simulation period allows substantial time for the dynamic effects of initial exogenous changes to work their way through the system. The use of a long simulation period also permits exploration of whether or not there is error buildup in the model. On the other hand, a decade may be a somewhat long period for the maintained hypothesis of no structural changes other than that posited for sorghum productivity, so most results in this paper also are presented for a shorter period of five or six years.

The first three columns in table 3 give some summary measures of the goodness of fit of the base simulation: mean absolute percentage errors (MAPE) for 1969–73 and for 1969–78 and root mean percentage errors (RMPE) for 1969–78.

The goodness-of-fit statistics for the entire decade in table 3 suggest that the model traces better the actual experience for SAT quantities supplied than for SAT prices (though pulses are an exception to this pattern). This is riod for the relevant commodities.[10] supplies are completely price inelastic, so all of the adjustment to achieve short-run equilibrium must be in prices along the demand curve to the recursively set quantities supplied.

The goodness-of-fit statistics also are relatively high for superior-cereals quantity demanded. They are relatively small for the quantity demanded for the other-items category and total consumer expenditure. The low value for total consumer expenditure is due to a combination of some of the errors in the components of this variable cancelling out in the constructed aggregate (particularly high prices for low quantities supplied and vice versa) and of there being an exogenous component (Y_0) in relation (10). The low error for the other-consumer-demand components reflects the small error in total expenditure in combination with the exogenously fixed value of the other major determinant of this demand variable—the own price (given the small cross-price elasticities for this category in table 2).

The MAPE and RMPE also are relatively large in comparison with those reported in many other studies. This may reflect several factors. First, the dynamic simulation period of a decade is fairly long and there is significant error buildup. This can be seen in that the MAPEs generally are smaller (and often substantially so) for the first five years than for the whole decade (compare columns 1 and 2 in table 3).[11] In other words, as is almost always the case for such models, there is more success in tracing out experience in the short and medium runs than for the longer run. This is particularly the case for the sorghum price.

Though the MAPEs for the first quinquennium are lower than for the decade, they still are relatively large. This may be because of the great volatility of SAT agriculture despite the attempt to incorporate weather conditions in the supply estimates (i.e., U is relatively large in relation 1). To the extent that this is the case, the base simulation just reflects the well-known environmental variability in SAT agriculture and the difficulty of summarizing that dimension of reality in manageable weather indices for econometric estimates.

Another contributing factor may be that the systems estimates do not assume that the

Table 3. Summary Measures of Percentage Errors in Base Simulations and Percentage Deviations from Base Simulations for Simulated Scenario with Improved Sorghum Productivity

	Base Simulations			Productivity Increase in Sorghum Production		
	MAPE		RMPE			
Endogenous Variables	1969–73	1969–78	1969–78	1971	1974	1978
	(1)	(2)	(3)	(4)	(5)	(6)
Output supply						
Sorghum	9.7	8.4	9.9	7.6	26.3	33.1
Superior cereals	5.5	7.5	10.7	0.1	0.0	0.0
Other coarse cereals	10.3	13.4	17.0	-0.4	-0.9	-1.0
Pulses	8.6	17.3	23.7	0.7	2.1	2.1
Oilseeds	9.8	15.8	21.3	-0.4	-0.7	0.6
Other crops	8.3	7.9	8.5	0.3	0.6	0.6
Prices						
Sorghum	5.0	21.4	30.2	-3.4	-10.1	-12.7
Other coarse cereals	14.1	35.2	46.4	-0.0	-0.3	-0.7
Pulses	15.0	10.9	16.8	0.3	-0.3	0.5
Oilseeds-edible oils	16.5	20.5	23.4	0.6	1.8	1.7
Demand quantities						
Superior cereals	16.0	17.9	20.6	-0.6	-2.0	-2.5
Other items	4.4	6.1	9.0	-0.1	-0.3	-0.1
Expenditure	1.5	2.1	2.7	0.2	0.7	0.5

Note: Base simulation, MAPE, and RMPE are defined and discussed in the second section. The scenarios with improved sorghum productivity are defined and discussed in the third section. This table gives percentage deviations from the base simulation for this scenario.

mean error for each endogenous variable is zero over the estimation period (as do ordinary least squares single-equation estimates), so in some cases the base simulated values are systematically too high or too low. To the extent that this possible system feature underlies the relatively large errors, some questions are raised about the stochastic specification of the system estimates and the models may under (over) estimate systematically some endogenous variables. Nevertheless, the model may serve well (and possibly better than single-equation estimates which would trace the sample experience better, but not capture the system features as well) for exploring the impact of hypothesized exogenous changes.

In addition to goodness-of-fit measures based on errors, it is useful to ask how well the model traces turning points in SAT Indian agricultural experience over the simulation decade. Examination of the individual observations (which are not presented because of space limitations) suggests that the summary answer to this question is: fairly well, especially given the great volatility in SAT Indian agriculture. There are some failures, but these tend to be concentrated in the latter half of the simulation period after there is more substantial error buildup. All in all, there is fairly considerable success in identifying turning points.

Basic Simulation of Productivity Increase in Sorghum

For the exploration of the product market impacts of technological improvements in sorghum production, an S-shaped pattern of percentage increases in productivity is assumed because that is the typical pattern of the adoption of innovations in SAT Indian agriculture as in most other agriculture (see Walker and Singh). The exact pattern of assumed annual increases is 0.5%, 1.5%, 3.5%, 4.5%, 5.0%, 4.5%, 3.5%, 1.5%, and 0.5% during 1969–77, respectively. The accumulation of these changes results in an upward shift in productivity of 25% for the ninth year and thereafter.

To simulate the impacts of a T% increase in the productivity of sorghum in any year, the combined impact of what can be considered

tion increases $T\%$ with the same use of inputs. (*b*) Because of the productivity increase in sorghum, there is a reallocation of inputs among all of the crops. If the actual output and input prices were constant, this effect would be equivalent to the impact of a $T\%$ increase in the price of sorghum (including all of the effects through the cross elasticities).[12] (*c*) Because of the resulting expansion of sorghum output and induced changes in other outputs, sorghum and other output prices adjust, with the standard impact on all outputs through the price elasticities. The total impact is the combination of these three effects, with the negative third one partially offsetting the positive first two. Further complications, of course, are introduced by the lag structure in responses due to the price expectation formation process.

The basic simulation explores the impacts of this hypothetical technological improvement in sorghum production by imposing it onto the base simulation of the previous section. Columns 4–6 in table 3 present the resulting impacts as indicated by the percentage deviations induced from the otherwise identical base simulation for 1971, 1974, and 1978 (i.e., years two, six, and ten of the simulation period) because of the sorghum productivity change. The magnitudes of the impacts of the assumed productivity increase in sorghum change over the decade because of the assumed pattern of initially increasing and subsequently decreasing productivity growth. But the general implications are the same over time.

First of all, there is the anticipated negative impact on the sorghum price in order to absorb within SAT India the increased sorghum production. By the sixth year of the simulation the price decline is 10.1% (for a production increase of 26.3%). By the tenth year it is 12.7% (for a production increase of 33.1%). These price declines somewhat discourage sorghum production. Therefore, output does not increase as much as it would were there no induced downward sorghum price movement as would be the case were the SAT Indian sorghum market well integrated into a much larger market.

Second, sorghum output, nevertheless, increases more than sorghum productivity. In the sixth year sorghum output is 26.3% above the base simulation path even though productivity is only 19.5% above the base path. In the tenth year sorghum output is 33.1% above the base simulation path though productivity is 25% above the base path. The larger increases in output than in productivity despite the sorghum price declines reflect that the second effect noted above reinforces the direct pure productivity effect more than the third negative price effect offsets it. This is in sharp contrast to frequent speculations that there might be little output gain due to the output fall in response to the price decline. On the average, sorghum producers receive greater gross revenues since the production increase is much larger than the price decline. But the impact of any productivity improvement is not likely to affect all farms equally because of differences in land quality, water control, management capabilities, etc. Those sorghum farmers who experience little or no sorghum productivity increase, in fact, are worse off because of the lowered sorghum price.

Third, the larger sorghum production and lower sorghum price means that Indian SAT consumers of sorghum are undoubtedly better off due to this productivity change. Since sorghum constitutes a higher share of the budget of poorer individuals (see MR), these benefits accrue relatively more to the poorer members of society.

Fourth, even though the systemic effects are relatively weak for sorghum (in the sense that the cross-price elasticities in tables 1 and 2 are small as compared, for example, to those for superior cereals), there are some impacts on other commodities at least of the magnitude of 1% after several years. Because of the lower sorghum price, for example, pulses substitute somewhat for sorghum, oilseeds, and other crops in production and sorghum substitutes somewhat for superior cereals and other items in consumption—which lowers net imports of superior cereals and increases the net imports and the prices of edible oils. None of these effects is all that large, however.

Sensitivity Analysis of Some Critical Assumptions

The model used in this study incorporates a number of complexities such as the systems nature of supply and demand, varying degrees of market integration between SAT India and

[12] The authors thank H. Binswanger for most useful discussions on how to conduct these simulations, in particular regarding the second effect.

the rest of India, and feedbacks through product prices and expenditure of demanders. Nevertheless, because of data inadequacies, a number of simplifying assumptions are made for the basic simulation of the impacts of technological change in sorghum.

This section explores the sensitivity of the results to modifications in some of these assumptions. Table 4 gives percentage deviations from the base simulation for 1971 and 1974 for six simulations, each of which is identical to the basic simulation with technological change in sorghum productivity discussed in the previous section except for one additional change. The additional change in the first two of these simulations is that α_i for sorghum in relation (5A) is posited to be -2% or $+2\%$ in each year, respectively. That is, the combined effect for sorghum of net exports, livestock use, seed reserves, wastage, and all stock additions changes systematically over the simulation period because of the sorghum productivity change. In the third and fourth of these simulations additional changes are that $\dot{m}_i$ for sorghum in relation (9A) is assumed to be -2% or $+2\%$ in each year, respectively. These changes imply stochastic induced variations in transportation, marketing, and processing costs that separate supply from demand prices. The fifth simulation considers an increase in the wage to a level 2% above the base simulation in each year to be induced by the technological development for sorghum. The sixth simulation hypothesizes that the producer revenue-demand expenditure link in relation (10A) is stronger with ϵ equal to 0.8 instead of 0.6. In all cases the changes are assumed to persist throughout the simulation period in order to provide a fairly strong test of the robustness of the results in table 3.

The changes in these sensitivity simulations from the basic simulation in table 3 are in the directions that one would anticipate. Lesser absorption of sorghum by net exports, livestock use, seed reserves, wastage, and stock changes in the first of these simulations, for example, lowers the expansion of sorghum production (e.g., from a 26.3% increase to a 24.1% increase in the sixth year) and increases the sorghum price decline (from -10.1% to -14.7% in the same year six). The increased transportation-marketing-processing costs in the fourth simulation reduce further sorghum farm prices (from -10.1% to -18.6% in year six), which moderates the expansion in sorghum output (from 26.3% to 22.1% in year six). The increased wages in simulation five reduce slightly the increment in sorghum production (from 26.3% to 25.6% in year six) and the fall in sorghum prices (from -10.1% to

Table 4. Sensitivity Analysis of Simulation of Impact of Improved Productivity for SAT India

Endogenous Variables	Change in Sorghum Net Exports, Livestock Use, Seed Reserves, Wastage, and Stocks in Relation (5A) in Each Year				Change in Sorghum Transportation-Marketing-Processing Costs in Relation (9A) in Each Year				(5) Wage Increased by 2% in Each Year		(6) Stronger Producer Revenue Demander Expenditure Linkage (ϵ) in Relation (10A) is 0.8	
	(1) α for sorghum is -2%		(2) α for sorghum is 2%		(3) $\dot{m}$ for sorghum is -2%		(4) $\dot{m}$ for sorghum is 2%					
	1971	1974	1971	1974	1971	1974	1971	1974	1971	1974	1971	1974
Output supply												
Superior cereals	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	−0.1	0.2	−1.3	1.2
Sorghum	6.8	24.1	8.3	28.6	9.0	30.7	6.1	22.1	6.9	25.6	9.8	28.9
Other coarse cereals	−0.3	−0.8	−0.5	−1.0	0.5	1.1	−0.3	−0.7	−0.7	−1.2	0.7	−0.2
Pulses	0.6	1.6	0.9	2.7	1.1	3.2	0.4	1.2	0.3	1.6	6.7	8.8
Oilseeds	−0.2	0.4	−0.5	1.0	0.6	1.3	0.1	0.1	0.3	0.6	1.8	1.3
Other crops	−0.2	−0.4	−0.4	−0.8	0.4	−1.0	0.1	0.2	−0.4	0.7	0.1	0.6
Farm prices												
Sorghum	−6.1	−14.7	−0.8	−5.4	1.8	−0.9	−8.5	−18.6	−3.2	−9.9	1.3	5.1
Other coarse cereals	−0.5	−1.2	0.4	0.6	0.8	1.4	−0.9	−1.9	0.2	−0.1	5.2	5.7
Pulses	−0.2	−0.1	−0.4	−0.5	−0.5	−0.6	−0.1	0.1	0.1	0.1	7.3	8.6
Oilseeds-edible oils	0.6	1.6	0.6	2.0	0.7	2.2	0.6	1.5	0.5	1.6	7.7	10.2
Demand quantities												
Superior cereals	−1.4	−3.7	0.3	−0.1	1.0	1.6	−2.1	−5.3	−0.5	−1.9	11.3	11.9
Other items	0.3	0.5	−0.4	−1.2	−0.8	−2.0	0.7	1.2	−0.1	−0.3	11.4	12.5
Expenditure	0.0	0.3	0.4	1.1	0.5	1.5	−0.1	−0.1	0.1	0.6	11.0	12.8

−9.9%). The strengthened producer revenue-demander expenditure linkage in simulation six increases sorghum demand and output (from 26.3% to 28.9% in year six) and lessens the decline in sorghum prices (from −10.1% to −5.1% in year six). Of course, for all of these simulations there also are small changes in supplies, demands, and prices for the other products because of the systemic nature of supply and demand.

The magnitudes of the additional changes are quite small for the wage increases and the increased link between producer revenues and demander expenditure, even when such changes persist over a number of years. The magnitudes are larger for the changes in the combined effect of net exports, livestock use, seed reserves, wastage, and stock changes (α_i) for sorghum in simulations one and two and even larger for changes in the transportation-marketing-processing costs ($\dot{m}_i$) in simulations three and four. In simulation three, for example, the persistent reduction in the transportation-marketing-processing costs results in a sorghum farm price decline of about 1% in contrast to a decline of 10% or more after six years in the basic simulation of the previous section.

But the exogenous additional changes explored in this section are quite considerable when maintained over a number of years. It seems unlikely that the basic simulation in table 3 is based on a model that is systematically misspecified by as much as is assumed in table 4. Therefore, with a caveat regarding the first two implications discussed with regard to table 3 (i.e., the fall in sorghum price and a sorghum output increase exceeding the sorghum productivity increase) in the unlikely case that transportation-marketing-processing costs fall persistently as much as in simulation 3 in table 4, the conclusion of this section is that the basic thrust of the results in table 3 seem quite robust to any likely probable degree of misspecification.

Summary

This paper has helped to fill the lacunae that Nerlove noted regarding the market impacts of technological change for near-subsistence products that are grown largely in diversified agriculture in poorer regions with geographically isolated markets and therefore price and income feedbacks by examining the case of sorghum in SAT India. The simulation results seem quite robust to likely orders of magnitude of persistent misspecification in the simulation model. The simulations suggest that adopted technological developments to increase sorghum productivity would have spillover effects on other markets, increase the welfare of Indian SAT consumers of sorghum, and probably lower the sorghum price. In contrast to the speculations of some, however, the sorghum price decline would not be so large as to discourage much sorghum output. To the contrary, output gain would be likely to exceed the pure technological productivity effect because of input reallocations that would more than offset the negative effect on supply of sorghum price declines.

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