

Village-Wide Effects of Agricultural Biotechnology:

The Case of Bt Cotton in India

By Arjunan Subramanian and Matin Qaim

Department of Agricultural Economics and Rural Development

Georg-August-University of Goettingen, 37073 Goettingen, Germany

Key words: Agricultural Biotechnology, Bt cotton, Village-wide effects, Social Accounting Matrix, Asia, India

Corresponding author:

Arjunan Subramanian

Department of Agricultural Economics and Rural Development

Platz der Goettinger Sieben 5

Georg-August-University of Goettingen

37073 Goettingen, Germany

Phone: +49-551 - 39 4806, Fax: +49-551 - 39 4823

E-mail: asubram@uni-goettingen.de

The financial support of the German Research Foundation (DFG) is gratefully acknowledged.

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Summary. – Previous studies on impacts of agricultural biotechnology have mostly focused on direct effects. We suggest an economy-wide framework to analyze income distribution aspects more carefully. For a village in India, a micro social accounting matrix (SAM) is developed and used to simulate the effects of Bt cotton adoption. Overall, the technology is employment generating, although family labor in cotton production is saved. While substantial benefits are observed for small and large farmers, total income effects are bigger for large farm households. This is largely due to differential opportunity incomes of saved family labor. Some research and policy implications are discussed.

Key words – agricultural biotechnology, Bt cotton, village-wide effects, social accounting matrix, Asia, India

1. INTRODUCTION

The introduction and spread of genetically modified (GM) crops is one of the more significant technological changes currently taking place in the world. While the potentials of this technology are still debated, farmers' demand for GM seeds has continued to grow rapidly. In 2006, around 102 million hectares were grown globally with GM crops, with over 40% of this area located in developing countries (James, 2006). One of the most widely adopted GM technologies in developing countries is *Bacillus thuringiensis* (Bt) cotton, which makes the plant resistant to certain insect pests, especially cotton bollworms. Among the beneficial impacts of Bt cotton, significant yield increases and pesticide reductions have been reported for different countries (e.g., Pray, Ma, Huang, & Qiao, 2001; Qaim, 2003; Qaim & de Janvry, 2003; Thirtle, Byers, Ismael, & Piesse, 2003). As the technology is divisible and pest pressure relevant across farm sizes, it is believed to be scale neutral, so that both small and large farms can benefit (Qaim, 2005).

However, most of the impact studies to date have been carried out at the farm level or in a partial equilibrium framework, ignoring more indirect effects on factor markets and household incomes. Such indirect effects can be sizeable, as has been shown, for instance, by Hazell & Ramasamy (1991) in the context of the green revolution. A few studies have been carried out on economy-wide effects of GM crops, building on macro general equilibrium models (e.g., Elbehri & Macdonald, 2004; Huang, Hu, van Meijl, & van Tongeren, 2004; Hareau, Norton, Mills, & Peterson, 2005). While such macro models capture indirect effects, the level of aggregation is generally high, so that aspects of household income generation and distribution at the micro level cannot be evaluated. We are not aware of any studies that have analyzed the economy-wide effects of GM crops at the micro level. Yet this would be important to better understand the broader development implications. Our study is a first step in this direction.

We develop a micro social accounting matrix (SAM) for a typical cotton growing village in India and use a multiplier model to simulate village-wide effects of Bt technology adoption.¹ Bt cotton was commercialized in India in 2002 under the brand name Bollgard I, and since then, adoption rates have been rising rapidly (Qaim, Subramanian, Naik, & Zilberman, 2006). For the analysis, we use a unique data set collected through a village census, complemented by additional representative data from different states of India. Village SAMs have been developed and used previously in different contexts (e.g., Adelman, Taylor, & Vogel, 1988; Subramanian & Sadoulet, 1990; Taylor & Adelman, 1996; Parikh & Thorbecke, 1996). However, most of these SAMs are based on village sample surveys instead of a complete census. We extend previous approaches by capturing all households in the study village and most of their transactions over a period of one year.

Special attention is given to the analysis of Bt cotton employment and labor market impacts and related income effects for farm and non-farm households. Bt cotton is often associated with higher effective yields, so that more labor is used for harvesting. On the other hand, the inbuilt pest resistance leads to lower labor requirements for pest scouting and spraying. Net effects on labor input in cotton production may be positive or negative. In addition, however, the timing and source of labor inputs matter. While in India, cotton harvesting is predominantly carried out by hired female laborers, pest scouting and spraying is often performed by male members of the farm family. When labor time is saved, the household income effect will also depend on how the saved time can be used alternatively, that is, the opportunity income. This can certainly vary by household characteristics. While savings in farmers' management time through GM crop adoption have been recognized in general (e.g., Kirsten, Gouse, & Jenkins, 2002; Naseem & Pray, 2004), opportunity income effects have not yet been integrated into empirical analyses, probably because quantifying them is difficult in a partial equilibrium framework.

The article is organized as follows. Section 2 presents the data base and a summary of the direct farm level effects of Bt cotton in India. Then, in Section 3 we introduce the analytical framework for the analysis of economy-wide effects. At first, we underline the potential role of opportunity income in Bt technology adoption, before the village SAM approach is described. In Section 4, we compute empirical results by decomposing the SAM multipliers and running different adoption experiments. The last section concludes and discusses policy implications.

2. DATA AND DIRECT EFFECTS OF BT COTTON

(a) *Representative data from four states*

Recent farm-level studies on Bt cotton in India show that the technology is pesticide reducing and yield increasing on average across different agro-ecological environments (Bennett, Kambhampati, Morse, & Ismael, 2006; Gandhi & Namboodiri, 2006).² This is in line with results by Qaim et al. (2006), who had carried out a sample survey in 2003 in four major cotton growing states of India, namely Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu. These data are representative for central and southern India. In 2005, we surveyed the same farmers as Qaim et al. (2006) had done previously, but also somewhat increased the overall sample size. Summary results on yield and pesticide effects from these two successive surveys are shown in Table 1. In addition to overall mean values across the four states, results are shown separately for Maharashtra, since this is the state in which our study village for the SAM analysis is located. The difference in effective yields between Bt and conventional cotton is 30-40%, and Bt adopters reduced their insecticide quantities by about 50% on average. Unsurprisingly, reductions are higher for insecticides that farmers use to control bollworms than for insecticides against sucking pests, which are not controlled by the Bt toxin. In spite of higher GM seed prices, Bt adopters also benefit economically. In 2002-03, the mean gross margin difference between Bt and conventional cotton was 2,161 Indian Rupees (Rs.) per acre (US \$48.43), while it was Rs.2,719 in 2004-05. These effects are similar across different farm sizes.

Table 1 approximately here

(b) *Village census*

In addition to the representative data from cotton growers in different states of India, for the SAM analysis, a more detailed census survey was carried out in the village Kanzara, which is located in the state of Maharashtra. Maharashtra is the state with the largest area under cotton in India, and Kanzara is a fairly typical setting for small-scale cotton production in the semi-arid tropics. This village has been the focus of research for several decades.³ Our survey in Kanzara was carried out between March and August 2004. Comprehensive data were collected from all 305 village households. We interviewed the head of each household to record most economic transactions retrospectively for the 12-months period from April 2003 to March 2004. One exception was household food consumption, which was collected through a 30-day recall referring to the month of March 2004.

The survey questionnaire included details on land and other assets owned, area under each crop, revenues and production costs for crop and livestock activities, individual incomes from different off-farm activities, and labor market participation. Moreover, household transactions in consumer and producer durables, financial assets, borrowing, lending, and consumption expenditures on food and non-food were captured. For all transactions, it was exactly recorded from whom households purchased items – including labor – and to whom they sold. These source and destination data are needed to establish tradability and to construct trade flows in the SAM.

There are 203 cotton growing households in the village, out of which 15 cultivated Bt cotton in the 2003-04 growing season.⁴ For the analysis, cotton growing households are categorized into three groups: (i) small farmers holding less than 5 acres of land, (ii) medium farmers holding 5-13 acres, and (iii) large farmers with more than 13

acres. The majority of the village cotton producers are small farmers, who primarily grew conventional cotton in 2003-04; they accounted for only 15% of total village cotton production. In contrast, large farmers constitute the smallest group of cotton producers, yet accounting for the biggest number of Bt adopters and for the largest proportion of total village cotton production (52%).

3. ECONOMY-WIDE FRAMEWORK

In this section, we first highlight the potential role of opportunity income in Bt cotton adoption and then describe the construction of the SAM for Kanzara village, before illustrating how a SAM multiplier model can be used to simulate the impacts of alternative technological choices in cotton production on income distribution.

(a) *The role of opportunity income*

A farmers' decision whether or not to adopt Bt cotton depends on the technology's expected impact on profitability. Previous impact studies have mostly looked at pesticide and yield effects, as well as changes in the cost of seeds and hired labor. However, changes in management time might also matter, as pest control is often carried out by farmers themselves. Hence, the difference in overall profitability between Bt and conventional cotton can be expressed as

$$\Delta\pi = P\Delta Y - \Delta e - \Delta t\gamma, \quad (1)$$

where P is the output price per unit of cotton, ΔY is the change in effective yields, which is expected to be positive, and Δe is the cost change associated with the technology, including pesticide savings, the technology fee charged on seeds, and additional

harvesting costs. Δt is the change in management time, which has to be multiplied by the opportunity income γ , that is, the return on the farmer's own labor employed in alternative activities per unit of time. Most previous studies on Bt crop impacts have implicitly assumed that $\Delta t = 0$. Yet, conventional pest control is particularly management intensive. Given the wide variety of relevant pests, the time spent on regular scouting and the judicious choice of insecticides and timing of sprays are particularly important. Hence, we expect Δt to be negative, which will result in a positive opportunity income effect of Bt cotton adoption, unless $\gamma \leq 0$.

The management-time saving feature of Bt technology can potentially lead to differential impacts by farm size, even if the technology as such is neutral in scale. Given constant Δt per acre across farmers with different scales of production, $\Delta \Pi$ directly depends on farmers' opportunity income. A lower γ entails lower net returns, so that a farmer is less likely to adopt in the long run, even though in the short run higher yields might tempt some farmers to adopt. Due to financial and human capital constraints, the opportunity income might be lower for small than for large farms, although this is an empirical question to which we will return later. In any case, especially when Δe is high, thus eroding the yield advantage, net returns will crucially depend on γ . These results underline that a comprehensive evaluation of the impacts of GM crop adoption requires not only quantification of direct but also of indirect effects associated with spillovers to other markets. For that purpose, an economy-wide framework is essential.

(b) *The village SAM*

A SAM combines diverse data on all aspects of an economy such as production, consumption, savings and investment, income generation and distribution, transfers, external trade, and income flows (e.g., Taylor & Adelman, 1996). It presents these data as a set of consistent accounts in the form of a square matrix. Each row contains receipts accruing to a particular account, and the corresponding column shows how that account's total receipts are spent on or distributed to other accounts. For any account, total receipts and total expenditures must tally, and so each account's row and column totals are the same. A schematic aggregate SAM of Kanzara village is presented in Table 2. While most SAMs have a similar structure in general, our SAM has relatively few commodity-producing activities, but instead provides greater details on services, labor flows, transfers, and income distribution. This is determined by the predominantly agricultural nature of the village and the primary focus of the study on income distribution.

Table 2 approximately here

For each production activity in our SAM, the rows contain payments received by the activity for the commodity that it produces and sales to the commodity account. The corresponding column account breaks up total output into value of intermediates, payments to factors, profits accruing to the owners of the activity, taxes to the village government, maintenance expenses, and taxes to the rest of India. The commodity row account gives the components of total demand such as intermediate use, consumption demand by households and other institutions, investment and maintenance demand, changes in stocks, and village exports to the rest of India. The commodity column accounts show what part of each commodity's total supply comes from each production activity, stocks, and village imports.

The factor accounts show how factor incomes are generated and distributed to households and other institutions. The household and other institution accounts show the sources of each institution's income along the row, and the objects of expenditures in the column. The capital account shows each household group's savings, and the column account breaks up total investment into investments in physical assets within the village and net capital outflows. The rest of India row account shows payments such as transfers, taxes, and interest payments on bank loans made by the village to the rest of India. The column account shows payments received by the village such as transfers, wages received by villagers working outside the village, and payments for sales outside the village.

Table 2 shows that the gross domestic product of the village is about Rs.24.54 million (US \$0.55 million) with imports and exports accounting for Rs.15.56 million and Rs.18.04 million, respectively. The village is a net exporter of commodities, but a net importer of factor services with the village value added at Rs.10.90 million. The village is characterized by extreme openness, with total imports accounting for 71% of village domestic absorption. Only 28% of total crop production within the village is for subsistence purposes. This includes crops like sorghum, black gram, sesame, and maize that are mostly for self-consumption or animal feed. Almost all households sell some part of their agricultural output in the market either within or outside the village. The total village investment is about Rs.2.91 million, with Rs.2.68 million invested within and the rest outside the village.

As indicated above, our SAM builds on a village census survey, which is an improvement over previous approaches. While a few micro SAMs exist (e.g., Adelman et al., 1988; Subramanian & Sadoulet, 1990; Taylor & Adelman, 1996; Parikh & Thorbecke, 1996), most if not all of them are based on sample surveys. Sample surveys in

a village can only capture part of the transactions to the extent that not all households are included, leading to a potential sample bias that causes unbalanced markets. Since a SAM by construction requires both receipts and payments, unbalanced markets and transactions can lead to serious problems. Building on a census survey can reduce these discrepancies, because most economic transactions within the village can be captured and tracked during the survey. Of course, tracking transactions outside the village is often difficult.

(c) The SAM multiplier approach

In this sub-section, we describe how multi-sectoral multiplier models (Adelman & Robinson, 1986) can be used to analyze the gains from adoption of GM crops such as Bt cotton. The SAM provides the basis for a simple linear model formed by dividing each column by its total. This coefficient matrix has the property of yielding, when it multiplies the vector of row sums of the original SAM, the row sum vector itself – a property that can be expressed as a system of linear equations. Since each column of the coefficient matrix sums to unity, it is singular. Hence, this system can be solved by considering some flows as exogenous and the rest as endogenous. Here, production activities, commodities, factors, and institutions are the only accounts that are treated as endogenous, while all the other accounts are exogenous (maintenance, stock, government services, capital, and the rest of India). Given this and the existence of excess capacity, any exogenous increase in cotton demand can be satisfied through a corresponding increase in output without having any effect on prices. Such an increase in either conventional or Bt cotton demand is the exogenous shock we will consider, in order to simulate impacts on value added and household incomes at the village level.

The effects of an additional demand for cotton on total outputs of different production activities and the incomes of various factors and household groups can be estimated through the multiplier process and transmitted through the interdependent SAM system. The SAM multiplier, M_n , derived and illustrated in the appendix, can be decomposed into separate effects as follows:

$$M_n = I + (M_1 - I) + (M_2 - I) M_1 + (M_3 - I) M_2 M_1, \quad (2)$$

where $M_1 = (I - \tilde{A}_n)^{-1}$, $M_2 = (I + A^* + A^{*2})$, and $M_3 = (I - A^{*3})^{-1}$.

The first term on the right-hand side of equation (2) represents the impact of the initial injection (I), which in our case is the exogenous increase in cotton demand. The second is block-diagonal and is the multiplier due to intra-block transactions, for example input-output transactions and flows between institutions. The third term is the net contribution of open-loop multiplier effects; it has identity matrices along the diagonal, and its off-diagonal entries represent cross-effects between different blocks of accounts. The fourth term is the net contribution of closed-loop multiplier effects; it is also block-diagonal and shows the effect of a change originating in one block reinforcing itself through its effect on a chain of blocks looping back to the originating block of accounts (see appendix for further details). To analyze impacts on value added, the model treats returns to capital and other factors separately; returns to capital (profits) are paid directly to households, whereas other factor returns are paid through the factor accounts.

One distinctive feature of the SAM multiplier model presented here is that it incorporates the dual cotton technologies – Bt and conventional – within a single accounting structure, which allows evaluation of both technologies' distributional impacts. As indicated above, we start our simulations with an initial injection in the form

of an exogenous increase in cotton demand. This is done separately for Bt and conventional cotton. For instance, an increase in Bt cotton demand will pull village production factors and resources into Bt cotton production away from conventional cotton and other activities. This is equivalent to an increase in Bt cotton adoption at the village level. Additional Bt cotton production is likely to increase aggregate village income. However, the same also holds true for the alternative simulation of an increase in conventional cotton production. Therefore, to evaluate differential impacts, the results of the simulations for both technological alternatives have to be compared.

4. SIMULATION RESULTS

(a) Decomposition of SAM multipliers

We now empirically analyze the additive decomposition of the SAM multipliers that were theoretically described above. We do this separately for dry and wet cotton, since cultivation details differ between rainfed and irrigated production systems. Kanzara is not supplied by a canal irrigation system, but farmers often drill wells to pump groundwater for crop production purposes. Whenever a cotton plot does not receive any irrigation water, it is counted as dry production, whereas it is counted as wet when some irrigation is used, regardless of the amount of irrigation water applied. In 2003-04, 63% of the total cotton was produced under dry conditions. A single farmer might cultivate both dry and wet cotton plots, depending on his access to well water. And, all three farm size categories are involved in both types of production, although the share of wet cotton is positively correlated with farm size.

Table 3 shows the multiplier decomposition. As the initial injection, an exogenous demand increase of 100 units of cotton is assumed. Since the focus here is on examining

the impact of the injection on income generation and distribution, transfer effects within activities or institutions are ignored. As can be seen, it matters whether the injection occurs in conventional or Bt cotton, that is, the underlying production structure and linkages are not uniform across technologies. Nonetheless, a technological comparison simply based on the multiplier decomposition should be avoided. This is done below within different experiments. The decomposition into open-loop and closed-loop effects shows that, overall, the open-loop effects dominate. This is because the raw cotton that is produced is sold outside the village.

Table 3 approximately here

The “value added” rows show how returns to labor are affected by the injection for different groups of people. Regardless of the underlying technology, hired female laborers benefit over-proportionally, which demonstrates the significant role of female workers in cotton production, especially for harvesting and weeding activities. But also hired male and family laborers are important. The “households” rows show how households are affected by the initial injection. The main beneficiaries are cotton-producing farm households, indicating that farmers on average derive substantial profits from cotton production. But also non-farm households benefit to some extent. While many of the effects are similar for dry and wet cotton, there are also notable differences. For instance, an injection into wet cotton production benefits large farmers more than it does small and medium farms. This is not surprising, given that large farmers usually have better access to irrigation water, that is, they often have more and deeper wells.

(b) *Adoption experiments*

We now use the SAM multipliers within several experiments, in order to analyze how different shocks could affect income distribution within the village. Tables 4 and 5 summarize the results of six experiments, each of which involves an exogenous Rs.100 thousand increase in cotton demand. The three experiments presented in Table 4 are under dry conditions, whereas the other three in Table 5 are under wet conditions. Apart from this difference, the two sets of experiments build on the same assumptions. Experiment 1 examines the potential impact of an increase in conventional cotton production to satisfy the additional demand, while experiments 2 and 3 assume that the additional demand is met through an increase in Bt cotton production. Since all the cotton produced within the village is exported, the Bt experiments reflect the increased adoption of Bt cotton and the technology's differential impact on value added and incomes of cotton growing and non-growing households. All experiments build on the observed production structure in the village. For the Bt cotton simulations, the village data was supplemented by the sample survey data presented in Table 1. In experiment 2, we assume that Bt increases yields and reduces pesticide use by 50%, as actually observed in India. In experiment 3, we change the pesticide parameter and assume that the reduction is 90%.⁵ We use the additional 90% experiment mainly to examine the sensitivity of the welfare results, since pesticide reductions might potentially change over time. In China and Mexico, for instance, pesticide savings of around 80% have been observed among Bt cotton adopters (e.g., Pray et al., 2001; Traxler et al., 2003). Furthermore, stacked Bt gene products (marketed under the brand name Bollgard II) were recently commercialized in India and might further increase the technology's effectiveness. On the other hand, understanding how sensitive the results are with respect to actual pesticide changes also

helps to assess what might happen if farmers would not follow recommended pesticide reductions.

Table 4 approximately here

Table 5 approximately here

Experiment 1 in Table 4 shows that a Rs.100 thousand increase in the demand for dry conventional cotton generates additional employment within the village, thus raising the total value added or wage income by Rs.29.60 thousand (3.7%). The largest increase in absolute terms (column 2 of Table 4) occurs for hired agricultural female laborers. In relative terms (column 3), the largest gains are observed for agricultural family and hired female laborers. As mentioned, harvesting is generally considered a female activity. Household incomes – i.e., combined factor incomes of all members of a household – increase by Rs.58.12 thousand, with the largest increase occurring for medium farmers. In relative terms, the largest gainers are agricultural landless households. This includes salaried households, where at least one member has a permanent employment in agriculture, and non-salaried households, where members work as hired agricultural laborers.

Experiments 2 and 3 for dry Bt cotton show an increase in value added by Rs.31.98 thousand (4.0%) and Rs. 34.72 thousand (4.4%), respectively. This is higher than for conventional cotton, demonstrating that Bt cotton generates more employment, especially for hired female and family male agricultural labor. The aggregation of total wage income shows that females earn much more from Bt cotton than males. The increase in female labor returns is mostly related to the higher yields in Bt cotton that are harvested by hired female laborers. For males, the linkage is different. With reduced pesticide applications in Bt, some of the family male labor involved in scouting and

spraying is saved. This is what we previously referred to as saved management time. Time of family members saved in cotton production is reallocated within the SAM to other household economic activities. This reallocation is proportional to the currently observed allocation to non-cotton activities, including both agricultural and non-agricultural employment.⁶ Hence, a substantial increase in value added reveals that there is a relatively high opportunity income for family male labor on average. As one would expect, the returns to family male labor increase with further reduction in pesticides (experiment 3). For family female labor, the opportunity income effect is less important, because they are less involved in pest control. Moreover, alternative employment opportunities in rural India are worse for women than for men, especially outside the agricultural sector.

The additional gains for households through an increase in dry Bt cotton production are Rs.47.44 thousand and Rs.52.52 thousand under experiments 2 and 3, respectively. This is somewhat lower than the gains observed under conventional cotton in experiment 1. There are also differences in income distribution. While non-cotton-growing households experience lower income gains under dry Bt than under dry conventional cotton, the income gains are higher for some of the cotton farmers. Especially large farm households benefit significantly from dry Bt cotton adoption, much more than their smaller counterparts.⁷ Table 6 shows that the largest share of the income increases for cotton-producing households with Bt technology is due to higher returns to labor. For small and medium farmers, higher returns to labor come from more employment of female household members as hired workers on other farms, as well as higher returns for agricultural family labor in alternative employments. For large farms, hiring out female agricultural labor is rare, so that the increase is almost exclusively from

higher returns for agricultural family male labor employed in alternative activities. The differences in household income increases between farm size categories are primarily determined by differential returns to labor saved in cotton production, that is, different opportunity incomes.

Table 6 approximately here

Figure 1 further supports this result by showing how the three farm size categories contribute to different economic activities within the village. Large farmers receive the highest proportion of the village income from agricultural production and agricultural services (e.g., hiring out machinery), while small farmers are more dominant in village production activities (e.g., construction and small-scale manufacturing). Medium farm households account for the largest share of trade and service activities within the village. The last set of columns in Figure 1 shows that large farmers capture the highest average income share over all activities. Hence, it is plausible that they can obtain a significantly higher opportunity income from saved management time in cotton production through Bt adoption. Of course, our finding of higher income gains for large farmers in an economy-wide framework is not inherent to the technology. Improving rural employment opportunities for small and medium farmers outside the agricultural sector might modify the picture.⁸

Figure 1 approximately here

Table 5 shows that, in wet cotton production, the overall generation of employment is again higher under Bt (experiments 2 and 3) than under conventional cotton (experiment 1). However, especially the returns to hired female labor are lower than in dry cotton production. In terms of overall household incomes, unlike in dry cotton, benefits are significantly higher with Bt than with conventional cotton. In wet

agriculture, also some of the landless households benefit from Bt technology, especially those with salaried workers employed on cotton farms, as these permanent workers are often carrying out irrigation operations. Among the cotton producers, small and large farmers benefit from Bt adoption, albeit large farmers benefit to a greater extent. Again, the household income effects from Bt adoption are largely driven by higher returns to saved family labor (Table 6). Overall, the income effects of Bt technology are somewhat more favorable under wet than under dry conditions. Indeed, almost 80% of the Bt cotton production in Kanzara in 2003-04 took place under irrigated conditions. While the technology is also effective in controlling pests without irrigation, farmers are often hesitant to invest in expensive seeds under more risky rainfed conditions.

Comparison of experiments 2 and 3 under both dry and wet conditions shows that actual pesticide reductions do not alter the general findings, although they influence the magnitude of the overall welfare effects of Bt cotton technology. Interesting to observe is that pesticide reductions mostly affect the welfare of farmers, while hardly changing the outcome for landless rural households. For farm households, higher pesticide reductions lead to higher savings in management time, higher opportunity incomes, and thus slightly higher welfare gains. Accordingly, the returns to family male labor increase. Conversely, lower pesticide reductions reduce the role of opportunity income.

5. CONCLUSIONS AND POLICY IMPLICATIONS

This article has analyzed the economy-wide effects of Bt cotton for rural households in semi-arid India by developing and using a village SAM. Since spillovers to other markets occur, partial equilibrium analysis can be misleading, especially when the focus is on household income distribution. The simulation results demonstrate that labor market

effects in particular should not be ignored. Bt cotton is associated with a substantial overall generation of rural employment. While labor requirements for pest control decrease, more labor is employed for harvesting. This has interesting gender implications. The aggregation of total wage income shows that females earn much more from Bt cotton than males. This is due to the fact that cotton harvesting is largely carried out by hired female laborers, whose employment opportunities and returns to labor improve remarkably. Pest control, on the other hand, is often the responsibility of male family members, so that Bt technology reduces their employment in cotton production. However, the SAM results show that, on average, the saved family labor can be re-employed efficiently in alternative agricultural and non-agricultural activities, so that – also for males – the overall returns to labor increase.

The returns to saved management time in alternative activities are higher for large than for small farmers. This can be explained by the fact that large farmers are often better educated and have better resource endowments, which facilitates access to employment and self-employed activities. In spite of similar benefits from Bt cotton for small farmers in a mere farm-level assessment, different opportunity incomes of saved management time lead to a situation where large farmers benefit much more from Bt adoption in an economy-wide framework. The long-term implications are not entirely clear. Bt cotton adoption has been increasing rapidly in India, and this trend is likely to continue in the future. If the currently observed economic structure persists, large farmers have a bigger incentive to use the technology, so that they might dominate the adoption process. However, the scale effects are not inherent to the technology. Policies directed at increasing rural employment opportunities for small and medium farmers could change the incentive structures and distributional outcomes by enabling them to use the saved

family labor time more profitably in alternative employment. This could include improvements in infrastructure and access to education and financial markets – that is, policies that would also promote overall economic development. Of course, measures that help to lower Bt technology costs for farmers, such as lower seed prices, could also raise the benefits, generating additional incentives to adopt the technology, also among smallholders. Indeed, Bt seed prices in India have been lowered substantially since 2005, and adoption rates continue to increase among large and small farms.

While the conclusions reached here for Bt cotton are specific to the particular village analyzed, the implications and issues raised are also relevant for other regions in semi-arid India and beyond. The SAM approach in general is certainly also applicable to other GM crops, but the empirical results will vary, because technological features and underlying economic structures are not uniform. The economy-wide framework developed and used extends previous, more partial impact studies related to GM crops. Nevertheless, the approach has some drawbacks, too. The behavioral specifications used in the SAM-based multiplier analysis are demand driven and ignore issues of resource allocation, productivity, and factor utilization. Substitution possibilities in consumption and production are also ignored, and prices are assumed to be fixed and exogenous. Neglecting price effects is perhaps more defensible for a small open village economy than for a regional or national economy, but assuming that output is solely determined by demand is clearly unrealistic. These drawbacks can be remedied through a village CGE approach, by embedding optimization behavior in the description of various institutions in the micro SAM, and allowing production and demand functions to be more flexible. This, however, is beyond the scope of this article and remains part of the future research agenda.

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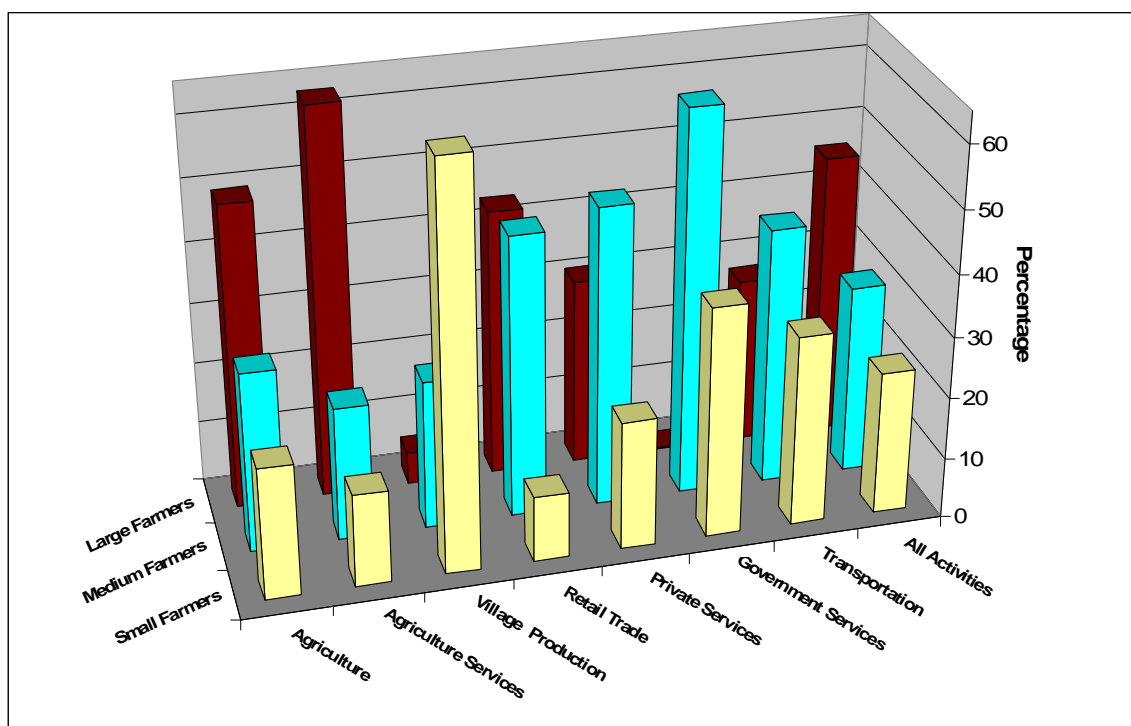
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Note: The columns show income shares of the three farm household categories. For each activity, the shares add up to 100%; the contribution of non-farm households is neglected here.

Figure 1. Contribution of farm households to different economic activities

Data for Figure 1:

Activities	Agriculture	Agricultural Services	Village Production	Retail Trade	Private Services	Government Services	Transportation	All Activities
Small Farmers	21.36	15.08	70.60	10.65	20.87	37.39	30.96	23.25
Medium Farmers	29.19	21.77	24.22	45.73	48.60	62.42	41.87	30.75
Large Farmers	49.45	63.16	5.18	43.62	30.53	0.18	27.17	46.00
All Households	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 1. *Yield and pesticide effects of Bt cotton technology in India*

	Data from Four States ^a			Data from Maharashtra		
	Bt	Conventional	Difference (%)	Bt	Conventional	Difference (%)
<i>Mean values (standard deviations) for 2002-03 growing season</i>						
Yield (kg/acre)	658.82 (393.64)	490.86 (335.88)	+34***	641.02 (305.87)	485.53 (222.22)	+32***
Insecticide quantity (kg/acre)	2.07 (2.65)	4.17 (3.37)	-50***	2.71 (3.36)	5.02 (4.22)	-46***
Of which						
Against bollworm	0.95 (1.83)	2.59 (2.71)	-63***	1.53 (2.62)	3.58 (3.36)	-57***
Against sucking pests	0.99 (1.20)	1.29 (1.21)	-23**	1.14 (1.31)	1.34 (1.32)	-15
Broad spectrum	0.13 (0.43)	0.29 (0.75)	-55**	0.03 (0.15)	0.10 (0.53)	-70
Number of observations	133	301		44	97	
<i>Mean values (standard deviations) for 2004-05 growing season</i>						
Yield (kg/acre)	744.52 (328.55)	548.34 (289.35)	+36***	669.39 (281.15)	481.32 (223.65)	+39***
Insecticide quantity (kg/acre)	2.05 (2.68)	4.19 (10.48)	-51***	0.90 (0.89)	2.22 (1.75)	-59***
Of which						
Against bollworm	0.73 (1.17)	2.31 (9.90)	-68**	0.42 (0.67)	1.40 (1.24)	-70***
Against sucking pests	1.23 (2.39)	1.73 (2.69)	-29**	0.47 (0.42)	0.80 (0.84)	-41***
Broad spectrum	0.10 (0.44)	0.15 (0.63)	-33	0.01 (0.04)	0.01 (0.15)	-0
Number of observations	167	298		49	106	

^a The four states surveyed include Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu.

*, **, *** The difference between Bt and conventional plots is statistically significant at the 10%, 5%, and 1% level, respectively.

Sources: Qaim et al. (2006) for 2002-03 data and authors' own survey for 2004-05 data.

Table 2. *Aggregate village SAM for Kanzara (2003-04 in Rs.)*

	Activities	Commodities	Factors	Households	Village temple	Village government	Capital	Maintenance	Stocks	Rest of India
Activities	-	24,541,240	-	-	-	-	-	-	-	-
Commodities	10,629,354	32,181	-	8,685,950	28,105	10,956	2,316,525	385,618	1,839,491	18,035,150
Factors	7,863,386	-	-	395,862	19,281	14,310	365,657	252,295	-	1,990,001
Households	5,311,468	-	6,646,770	568,154	-	5,190	-	-	-	2,411,335
Village temple	-	-	96,100	41,426	-	-	-	-	-	9,095
Village government	4,939	-	-	22,941	4,656	-	-	-	-	12,568
Capital	-	-	-	2,860,404	52,612	585	-	-	-	-
Maintenance	99,271	-	-	488,997	36,842	12,803	-	-	-	-
Stocks	-	1,829,278	-	10,214	-	-	-	-	-	-
Rest of India	632,822	15,560,633	4,157,922	1,868,969	5,125	1,260	231,418	-	-	-
Total	24,541,240	41,963,332	10,900,792	14,942,917	146,621	45,104	2,913,601	637,913	1,839,491	22,458,149

Table 3. Multiplier decomposition of selected accounts for an initial 100 unit injection into cotton production

	Open-loop effects		Closed-loop effects		Total effects	
	Conventional	Bt	Conventional	Bt	Conventional	Bt
<i>Dry cotton production</i>						
Value added						
Family male (agriculture)	2.38	6.16	0.40	0.39	2.78	6.55
Family male (non-agriculture)	0.38	0.54	0.46	0.74	0.84	1.27
Family female (agriculture)	2.50	0.81	0.08	0.05	2.59	0.86
Hired male (agriculture)	3.90	2.80	0.20	0.10	4.10	2.90
Hired male (non-agriculture)	0.60	0.30	0.30	0.20	0.90	0.50
Hired female (agriculture)	10.40	15.70	0.30	0.40	10.70	16.10
Salaried permanent male workers (agriculture)	1.80	1.90	0.20	0.10	2.00	2.00
Salaried permanent male workers (non-agriculture)	0.80	0.40	0.80	0.50	1.60	0.90
Households						
Agricultural landless salaried	1.70	1.40	0.10	0.10	1.80	1.50
Agricultural landless unsalaried	5.80	4.10	0.40	0.20	6.20	4.30
Non-agricultural landless salaried	0.40	0.30	0.10	0.00	0.50	0.30
Non-agricultural landless unsalaried	2.30	1.70	0.90	0.60	3.20	2.30
Small farmers	8.60	9.10	1.40	2.30	10.00	11.40
Medium farmers	16.50	4.70	2.50	1.50	19.00	6.20
Large farmers	9.20	11.30	2.80	1.60	12.00	12.90
<i>Wet cotton production</i>						
Value added						
Family male (agriculture)	1.69	5.79	0.18	0.26	1.87	6.05
Family male (non-agriculture)	0.30	0.23	0.46	0.31	0.76	0.54
Family female (agriculture)	2.55	0.06	0.05	0.04	2.60	0.10
Hired male (agriculture)	1.50	0.50	0.10	0.10	1.60	0.60
Hired male (non-agriculture)	0.30	0.20	0.20	0.10	0.50	0.30
Hired female (agriculture)	8.20	9.20	0.20	0.30	8.40	9.50
Salaried permanent male workers (agriculture)	0.70	1.70	0.10	0.10	0.80	1.80
Salaried permanent male workers (non-agriculture)	0.40	0.20	0.50	0.40	0.90	0.60
Households						
Agricultural landless salaried	0.90	1.10	0.20	0.20	1.10	1.30
Agricultural landless unsalaried	3.10	2.70	0.40	0.40	3.50	3.10
Non-agricultural landless salaried	0.20	0.20	0.10	0.10	0.30	0.30
Non-agricultural landless unsalaried	1.30	1.30	1.10	1.00	2.40	2.30
Small farmers	8.20	10.00	2.40	2.60	10.60	12.60
Medium farmers	14.10	4.20	2.80	2.60	16.90	6.80
Large farmers	32.60	48.70	3.10	2.80	35.70	51.50

Table 4. Simulation results for different experiments in dry cotton production

	Base value (2003-04)	Experiment 1		Experiment 2		Experiment 3	
		Increase in demand for conventional cotton by Rs.100 thsd.		Increase in demand for Bt cotton by Rs.100 thsd.		Increase in demand for Bt cotton by Rs.100 thsd.	
	(thsd. Rs.)	Change	% Change	Change	% Change	Change	% Change
	1	2	3	4	5	6	7
Value added							
Family male (agriculture)	75.5077	2.984	3.952	4.663	6.176	6.840	9.059
Family male (non-agriculture)	85.8623	1.871	2.179	2.145	2.498	2.264	2.637
Family female (agriculture)	20.3352	2.661	13.086	0.895	4.401	0.958	4.711
Hired male (agriculture)	110.4684	4.297	3.890	3.013	2.727	3.133	2.836
Hired male (non-agriculture)	166.5697	3.197	1.919	2.513	1.509	2.617	1.571
Hired female (agriculture)	119.3322	12.217	10.238	16.381	13.727	16.487	13.816
Permanent male workers (agriculture)	46.9600	0.022	0.047	0.016	0.034	0.019	0.040
Permanent male workers (non-agr.)	161.5156	2.191	1.357	2.213	1.370	2.243	1.389
Sum	793.2043	29.607	3.733	31.989	4.033	34.722	4.377
Households							
Agricultural landless salaried	29.6394	1.942	6.552	1.615	5.449	1.632	5.506
Agricultural landless unsalaried	103.9745	6.448	6.202	4.629	4.452	4.685	4.506
Non-agricultural landless salaried	19.0383	0.538	2.826	0.422	2.217	0.430	2.259
Non-agr. landless unsalaried	108.5235	3.988	3.675	3.075	2.833	3.208	2.956
Small farmers	360.5785	11.976	3.321	11.695	3.243	12.015	3.332
Medium farmers	402.0882	20.225	5.030	8.109	2.017	8.836	2.198
Large farmers	471.9107	13.004	2.756	17.890	3.791	21.715	4.602
Sum	1495.7531	58.121	3.886	47.435	3.171	52.521	3.511

Note: Experiment 2 assumes that pesticide use levels in Bt cotton are reduced by 50%, while in experiment 3 the assumed reduction is 90%.

Table 5. Simulation results for different experiments in wet cotton production

	Base value (2003-04)	Experiment 1		Experiment 2		Experiment 3	
		Increase in demand for conventional cotton by Rs.100 thsd.		Increase in demand for Bt cotton by Rs.100 thsd.		Increase in demand for conventional cotton by Rs.100 thsd.	
	(thsd. Rs.)	Change	% Change	Change	% Change	Change	% Change
	1	2	3	4	5	6	7
Value added							
Family male (agriculture)	75.5077	2.476	3.279	4.599	6.091	6.563	8.692
Family male (non-agriculture)	85.8623	2.467	2.873	2.559	2.980	2.580	3.005
Family female (agriculture)	20.3352	2.721	13.381	0.242	1.190	0.246	1.210
Hired male (agriculture)	110.4684	1.920	1.738	0.909	0.823	0.918	0.831
Hired male (non-agriculture)	166.5697	4.005	2.404	4.409	2.647	4.463	2.679
Hired female (agriculture)	119.3322	9.092	7.619	10.001	8.381	10.035	8.409
Permanent male workers (agriculture)	46.9600	1.214	2.585	2.158	4.595	2.169	4.619
Permanent male workers (non-agr.)	161.5156	2.000	1.238	1.849	1.145	1.865	1.155
Sum	793.2043	26.093	3.290	26.945	3.397	29.063	3.664
Households							
Agricultural landless salaried	29.6394	1.165	3.931	1.409	4.754	1.416	4.777
Agricultural landless unsalaried	103.9745	3.872	3.724	3.578	3.441	3.600	3.462
Non-agricultural landless salaried	19.0383	0.357	1.875	0.368	1.933	0.371	1.949
Non-agr. landless unsalaried	108.5235	3.395	3.128	3.523	3.246	3.574	3.293
Small farmers	360.5785	12.965	3.596	13.395	3.715	13.685	3.795
Medium farmers	402.0882	18.520	4.606	9.138	2.273	9.588	2.385
Large farmers	471.9107	36.968	7.834	54.167	11.478	55.308	11.720
Sum	1495.7531	77.242	5.164	85.578	5.721	87.542	5.853

Note: Experiment 2 assumes that pesticide use levels in Bt cotton are reduced by 50%, while in experiment 3 the assumed reduction is 90%.

Table 6. *Decomposition of household income effects for Bt cotton experiments*

	Experiment 2				Experiment 3			
	Returns to capital		Returns to labor		Returns to capital		Returns to labor	
	Change	% of total effect	Change	% of total effect	Change	% of total effect	Change	% of total effect
	1	2	3	4	5	6	7	8
Dry cotton production								
Agricultural landless salaried	0.059	3.653	1.556	96.347	0.063	3.860	1.568	96.078
Agricultural landless unsalaried	0.148	3.197	4.480	96.781	0.166	3.543	4.519	96.457
Non-agricultural landless salaried	0.015	3.555	0.407	96.445	0.015	3.488	0.414	96.279
Non-agricultural landless unsalaried	0.873	28.390	2.201	71.577	0.931	29.021	2.276	70.948
Small farmers	1.722	14.724	9.972	85.267	1.871	15.572	10.144	84.428
Medium farmers	2.417	29.806	5.692	70.194	3.004	33.997	5.831	65.991
Large farmers	3.966	22.169	13.924	77.831	4.040	18.605	17.675	81.395
Sum	9.200	19.395	38.232	80.599	10.090	19.211	42.427	80.781
Wet cotton production								
Agricultural landless salaried	0.088	6.246	1.321	93.754	0.090	6.356	1.325	93.573
Agricultural landless unsalaried	0.290	8.105	3.288	91.895	0.296	8.222	3.303	91.750
Non-agricultural landless salaried	0.020	5.435	0.348	94.565	0.020	5.391	0.351	94.609
Non-agricultural landless unsalaried	1.193	33.863	2.330	66.137	1.216	34.024	2.358	65.976
Small farmers	5.135	38.335	8.259	61.657	5.360	39.167	8.325	60.833
Medium farmers	3.979	43.543	5.158	56.446	4.375	45.630	5.212	54.360
Large farmers	4.107	7.582	50.059	92.416	4.137	7.480	51.170	92.518
Sum	14.812	17.308	70.763	82.688	15.494	17.699	72.044	82.296

APPENDIX

(a) *Technical details of the SAM multiplier model*

Following Pyatt & Round (1979), the rows and columns of the SAM can be partitioned into endogenous and exogenous, with N representing the matrix of SAM transactions between endogenous accounts, X the matrix of injections from exogenous into endogenous accounts, L the matrix of leakages from endogenous into exogenous accounts, and R the matrix of SAM transaction between exogenous accounts. Let A_n and A_l be the sub-matrix of the average endogenous expenditure propensity and average propensity to leak, respectively. The column sum vectors for the endogenous and exogenous accounts are denoted by y_n and y_x . The row sums of N , X , L , and R are denoted by n , x , l , and r . Since expenditure and receipts must tally for each account, the row and column sum vectors must be the same:

$$y_n = n + x = A_n y_n + x, \quad (\text{A1})$$

$$y_x = l + r = A_l y_n + r. \quad (\text{A2})$$

Provided that $(1 - A_n)^{-1}$ exists, the fixed price multiplier matrix M_n can be written from equation (A1) as,

$$y_n = (1 - A_n)^{-1} x = M_n x. \quad (\text{A3})$$

Some studies have used fixed price multiplier models to impose production constraints in the form of perfectly inelastic supply in some sectors or beyond predetermined output levels (Subramanian & Sadoulet 1990; Parikh & Thorbecke 1996). The resource constraints accommodated by these models generate high shadow prices on the resources whose supply is fixed and guide the scarce resources to their most productive use. These

complex price effects generated by imposing constraints on the production sector cannot be handled in the SAM framework, and they also complicate the interpretation of the results further. Hence, we do not pursue this approach in our multiplier model.

Corresponding to the above partition, the matrix of expenditure propensities is (note that only A_{33} is the marginal expenditure propensity),

$$A_n = \begin{bmatrix} A_{11} & 0 & A_{13} \\ A_{21} & 0 & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \quad (\text{A4})$$

Following Subramanian & Sadoulet (1990), the endogenous accounts are segregated under three blocks, where commodity and activity accounts form one block, factor accounts another, and the rest forms the third. Let \tilde{A}_n be given by,

$$\tilde{A}_n = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \quad (\text{A5})$$

From equation (A3) it follows that for any matrix \tilde{A}_n of the same size as A_n and such that

$(I - \tilde{A}_n)^{-1}$ exists, y_n can be written as,

$$y_n = (A_n - \tilde{A}_n)y_n + \tilde{A}_n y_n + x, \quad \text{or} \quad (\text{A6})$$

$$y_n = A^* y_n + (I - \tilde{A}_n)^{-1} x, \quad (\text{A7})$$

where $A^* = (I - \tilde{A}_n)^{-1}(A_n - \tilde{A}_n)$, so that

$$A^* = \begin{bmatrix} 0 & 0 & (I - A_{11})^{-1} A_{13} \\ A_{21} & 0 & 0 \\ (I - A_{33})^{-1} A_{31} & (I - A_{33})^{-1} A_{32} & 0 \end{bmatrix} \quad (\text{A8})$$

From equation (A8) it can be observed that the pattern of zero and non-zero cells of A^* corresponds to a circular permutation matrix. Accordingly, if y_n is partitioned compatibly

with A_n , then the structure of equation (A7) implies that the partitions of y_n are related to each other as points on a closed loop. In figure A1, these points are shown schematically as the corners of a triangle (y_1 , y_2 , and y_3). Matrix A^* represents the mapping from one partition of y_n to another, as also shown in Figure A1. This can be represented by the following equations:

$$y_1 = (I - A_{11})^{-1} A_{13} y_3 + (I - A_{11})^{-1} x_1, \quad (\text{A9})$$

$$y_2 = A_{21} y_1 + x_2, \quad (\text{A10})$$

$$y_3 = (I - A_{33})^{-1} A_{31} y_1 + (I - A_{33})^{-1} A_{32} y_2 + (I - A_{33})^{-1} x_3, \quad (\text{A11})$$

where $(I - A_{11})^{-1}$ and $(I - A_{33})^{-1}$ are transfer multipliers, and the formulation in the equations represent a closed-loop system, which is the algebraic statement of the circular flow of income from activities to factors to institutions, and then back to activities in the form of consumption demand.

(b) *Simulations*

Equations (A9) to (A11) and Figure A1 show the mechanisms through which the multiplier process operates. The initial injection I , in our case an exogenous increase in cotton demand, generates a rise in cotton output of $(I - A_{11})^{-1} x_1$. This in turn creates additional demand for different factors of production leading to the generation of additional value added $A_{21} y_1$. Apart from labor income, equation (A10) also includes any exogenous factor income received from government and the rest of India. The households receive profit income $(I - A_{33})^{-1} A_{31} y_1$ and labor income $(I - A_{33})^{-1} A_{32} y_2$ based on their resource endowment (A_{31} and A_{32}) and transfer system (A_{33}) as well as income

$(I - A_{33})^{-1} x_3$ based on exogenous transfers from the rest of India. The loop in Figure A1 is closed through the pattern of household expenditures on commodities, which translates into new production and corresponding additional flow of income accruing to production activities given by equation (A9).

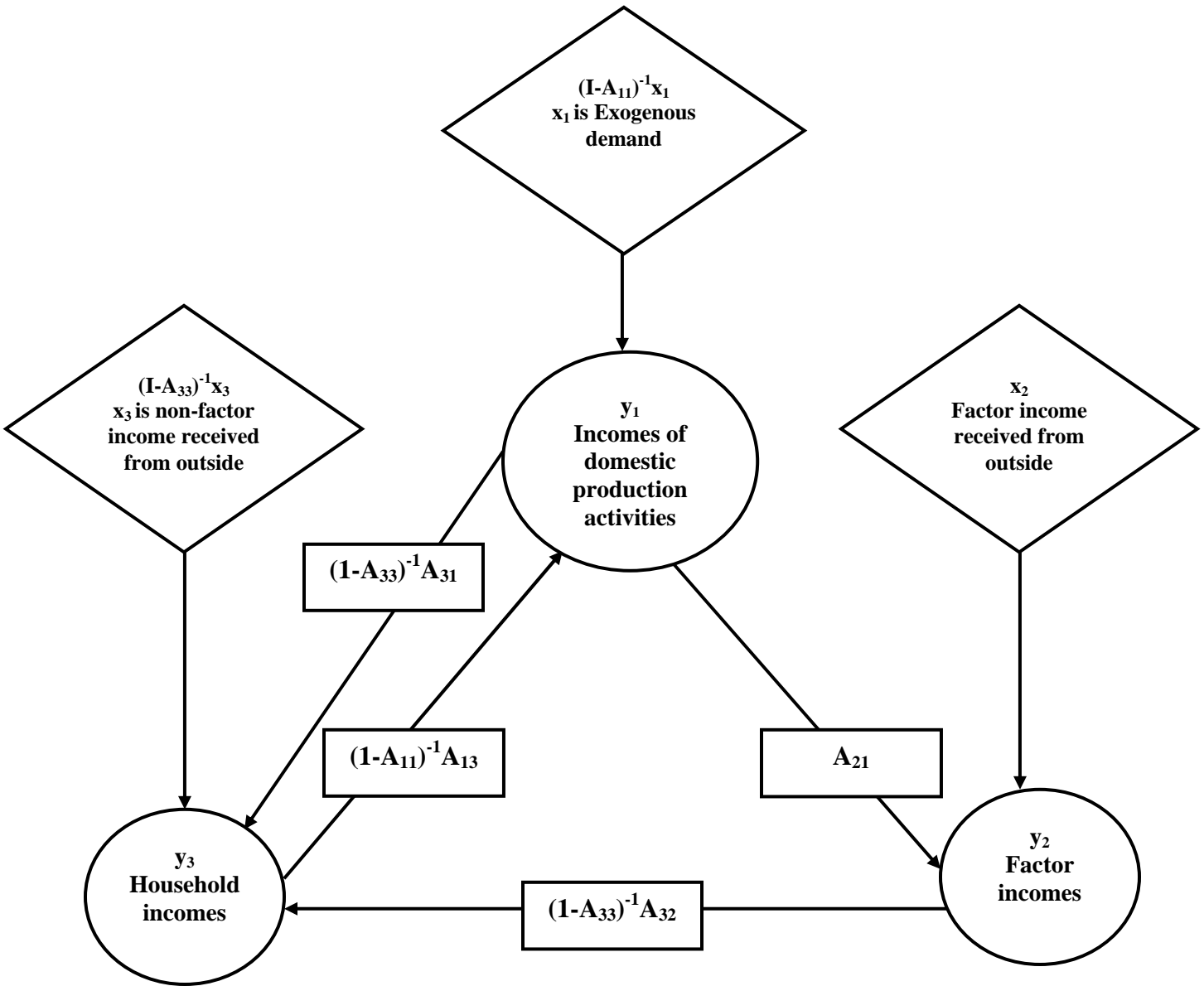


Figure A1. Schematic representation of the multiplier process among endogenous accounts

ENDNOTES

¹ Some spillover effects to other markets could also be captured with a multi-market model, which – in contrast to the SAM approach – would allow price adjustments. However, multi-market models usually remain sectoral, so they cannot capture general equilibrium effects. Moreover, they are usually less suitable to model distribution outcomes across different economic agents. Some of the drawbacks of the SAM multiplier approach can be remedied through village computable general equilibrium (CGE) models, as is further elaborated below. A micro SAM is a first step towards developing such models.

² The study by Bennett et al. (2006) is based on random samples of 787 cotton growers for the years 2002 and 2003 from three different sub-regions of the state of Maharashtra. Gandhi & Namboodiri (2006) surveyed 694 cotton growing farmers in 2004 from four major cotton growing states – Andhra Pradesh, Gujarat, Maharashtra, and Tamil Nadu.

³ Several sample surveys have been carried out in Kanzara by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). See Walker & Ryan (1990) for a detailed discussion.

⁴ This low village adoption rate might surprise. It needs to be stressed, however, that 2003-04 was only the second year of Bt cotton commercialization in India, so that adoption rates are still increasing. In India as a whole, Bt adoption has reached over 40% of the cotton area in 2006.

⁵ In order to re-balance the SAM with the changed pesticide reduction in Bt cotton, all backward and forward linkages associated with pesticide use were taken into account. These adjustment mechanisms depend on the current input use patterns and linkages observed in the village, so that they are consistent with all the other accounts.

⁶ Note that the allocation of the saved family labor to other activities should sensibly be based on the optimization principle, where saved labor is directed towards the most profitable activity undertaken by each household. This, however, cannot be modeled in a SAM, which is a drawback of the approach.

⁷ The lower income gains for medium farmers are driven by the fact that one medium-scale farmer in the village lost his entire Bt crop in 2003-04. Since the result is influenced by a single outlier, it should not be over-interpreted. Yet we had to leave this observation in the data set, since removing the household would have led to an unbalanced SAM.

⁸ As mentioned above, in the SAM framework the reallocation of saved labor is done proportionally to the currently observed allocation to alternative activities. It might well be that increasing cotton incomes lead to increasing demand for locally produced goods and services, so that non-agricultural employment opportunities improve, and relative profitabilities between different activities change. In that case, the SAM results would underestimate the opportunity income, especially for small and medium farmers.