

The impact of Bt cotton on poor households in rural India

Arjunan Subramanian¹, Matin Qaim¹

Several recent studies have analyzed the impacts of genetically modified (GM) crops on farm productivity in developing countries¹⁻³. Many of these studies focused on insect-resistant *Bacillus thuringiensis* (Bt) crops, especially Bt cotton, because this technology has been adopted already by millions of small-scale farmers around the world⁴. On average, farmers growing Bt cotton benefit from insecticide savings, higher effective yields through reduced crop losses, and net revenue gains, in spite of higher seed prices⁵⁻¹⁰. There are also studies that have analyzed the economic effects of Bt cotton and other GM crops from a macro perspective, using general equilibrium models¹¹⁻¹³. However, no study to date has analyzed wider socioeconomic outcomes at the micro level, which is probably also the reason for the ongoing controversy surrounding the poverty and rural development implications of GM crops in developing countries^{14,15}. Here we show that Bt cotton entails positive direct and indirect welfare effects in rural India. Using a microeconomic modeling approach and comprehensive household survey data, we found that the technology

¹ Department of Agricultural Economics and Rural Development, Georg-August-University of Goettingen, 37073 Goettingen, Germany.

increases aggregate employment with interesting gender implications. Furthermore, it increases household incomes, including for poor and vulnerable farmers. Our results demonstrate that Bt cotton contributes to poverty reduction and rural development.

In India, cotton is mainly grown on relatively small farms with less than 10 acres¹⁶. Bt cotton was officially commercialized for the first time in 2002, and since then adoption rates have been increasing rapidly: in 2007, already 66% of the total Indian cotton area was under Bt technology. Plot level data that we collected over several years from randomly selected cotton producers in four states confirms the direct effects of the technology reported in previous studies^{8,17,18} (Table 1). Between 2002 and 2007, per-acre net revenues were on average 2000-3000 Indian Rupees (Rs.) (US \$45-67) higher on Bt than on conventional cotton plots.

In order to analyze the broader socioeconomic effects, we selected one village where we collected much more comprehensive data on household characteristics and interactions across various markets. The study village, Kanzara, is located in Akola district of Maharashtra, the state with the largest area under cotton in India. Kanzara can be considered a typical setting for smallholder cotton production in the semi-arid tropics¹⁹. Interviews with all village households and institutions were conducted in 2004, capturing all household economic activities and transactions for the 12-months period

between April 2003 and March 2004. Of the total 305 village households, 102 are landless; the other 203 own land suitable for agricultural production. The average farm size of land-owning households in the village is 4.7 acres. All farm households cultivate at least some cotton, mostly next to a number of food and fodder crops for subsistence consumption and for sale. Fifteen farmers had adopted Bt cotton in 2003-04, which was only the second season after technology commercialization.

For the analysis, we classified households according to their consumption expenditures, using the local rural poverty line of 10.62 Rs. per day²⁰. This corresponds to US \$1.15 in terms of purchasing power parity (PPP), which is close to the \$1.08 a day figure used by the World Bank to classify extreme poverty at the international level²¹. Forty-eight percent of the village households fall below this poverty line. A second threshold of 21.24 Rs. per day (\$2.30 PPP) was used to classify vulnerable households. According to this definition, 38% of the village households are vulnerable, that is, they fall in-between the Rs. 10.62-21.24 range.

Based on this data, we developed a social accounting matrix (SAM) for Kanzara, which represents the flows of all economic transactions that take place within the village economy (Methods). In 2003-04, the gross domestic product of the village was about Rs. 24.54 million (US \$0.55 million). Village SAMs have been developed and used previously in different contexts²²⁻²⁴. Yet, our SAM is distinct in two respects. First, unlike previous SAMs, which are all based on sample surveys, our SAM builds on a village

census. Since a SAM by construction requires both receipts and payments of all transactions, availability of census data reduces the problem of unbalanced markets and thus of biased results. Second, our SAM explicitly considers Bt and conventional cotton as two different activities, which allows us to evaluate both technologies' distributional impacts.

However, the SAM as such is a static representation of the village economy and does not allow making statements about income distribution effects of individual activities like Bt cotton. This requires a SAM multiplier model, which we refined (Methods and Supplementary Fig. 1) and used for different simulations. In particular, we ran two simulation experiments, both considering an expansion in the village cotton area by 10 acres. The first experiment assumes that the additional 10 acres would be cultivated with Bt cotton. Fig. 1 demonstrates that this would generate more employment; aggregate returns to labor would rise by Rs. 39 thousand. Especially the employment of hired female laborers would increase. In the manual cotton production systems, hired women workers carry out most of the sowing, weeding, and harvesting operations, while men are mostly responsible for tillage, irrigation, and pest control. But also returns to non-agricultural labor would increase through employment effects in other village sectors that are linked to cotton production, such as transportation, trade, and other services.

Aggregate household incomes would increase by Rs. 106 thousand (Fig. 2). This is the result of changes in the returns to the factors of production labor, capital, and land

employed within the village. In addition, multiplier effects through spillovers to outside-village markets and feedbacks are included. These are particularly important for a cash crop like cotton. For instance, higher cotton production and rising incomes within the village induce growth also in outside village sectors, which again leads to new employment and investment opportunities, including for village households. Fig. 2 demonstrates that most of the aggregate income effects resulting from an increase in Bt cotton production would be captured by farm households, although landless village households would also benefit to some extent.

Yet, employment and income gains would also result from an increase in conventional cotton production. Therefore, the second simulation experiment assumes that the additional 10 acres would be cultivated with conventional cotton. The effects on employment and household incomes are similar to those in the Bt experiment (Figs. 1 and 2), as one would expect given that both alternatives involve an increase in village cotton production. Nonetheless, there are also noteworthy differences, and these differences are particularly relevant for the comparative evaluation of both technological choices.

Overall, changes in the returns to labor are higher in the Bt scenario (Fig. 1), demonstrating that Bt cotton generates more employment than conventional cotton in the local economy. The difference is especially notable for hired female agricultural laborers, which is due to significantly higher yields to be harvested in Bt cotton. For male members of the farm families, returns to labor are also higher in Bt than in conventional

cotton, although this is largely driven by indirect effects. With reduced insecticide applications in Bt, some of the family male labor involved in pest scouting and spraying is saved, which means less employment in Bt cotton as a direct effect. However, the simulations show that this family labor saved in cotton production can be reallocated to other agricultural and non-agricultural activities, such that the overall returns to labor increase. Apparently, use of family male labor in cotton is associated with a significant opportunity income. Most of this opportunity income is realized in self-employed activities (i.e., own agricultural and non-agricultural businesses). In contrast, the returns to hired male agricultural labor are lower in Bt than in conventional cotton, suggesting that there are fewer alternative employment opportunities for this category of workers.

Total household incomes are 82% higher under Bt than under conventional cotton (Fig. 2). This implies a remarkable gain in overall economic welfare through Bt technology adoption at the village level. For landless households, the effects are relatively small. Especially the poorer landless households derive most of their income from employment as hired agricultural laborers, and the higher employment of female workers in Bt cotton is almost offset by the lower employment of male workers. However, all types of farm households – including those below the poverty line – benefit considerably more from Bt than from conventional cotton. Strikingly, vulnerable farm households are the main beneficiaries with income gains in a magnitude of 134%.

Beyond the direct impacts on cotton profits, labor market effects are an important component of the income changes caused by Bt technology. For poor and vulnerable farmers, higher returns to labor are due to more employment of female household members as hired workers on other farms, as well as higher returns to agricultural family labor in alternative employments. For rich farmers, hiring out female labor is rare, so that the increase is almost exclusively from higher returns to family male labor employed in alternative activities. Thus, the observed differences in household income increases between different types of farmers can largely be explained by different opportunity incomes. Poor farm households are dominant in non-agricultural village production activities such as construction and small-scale manufacturing (Fig. 3), where positive spillover effects through Bt cotton adoption are relatively weak. Spillovers are more felt by vulnerable farm households, who receive a higher proportion of the village income from agricultural production and non-agricultural services, and for rich farm households, who account for the largest share of agricultural services (e.g., hiring out machinery) and retail trade within the village.

While the exact findings presented here are specific to the study village, the social structure of the economy is typical for the semi-arid tropics, comprising cotton production in central and southern India. So it is reasonable to generalize that Bt cotton produces important socioeconomic benefits in large parts of rural India. Taking into account direct and spillover effects, the technology is net employment generating and

causes sizeable aggregate welfare gains. Especially farmers benefit in terms of higher incomes, including poor and vulnerable farm households that constitute the largest proportion of village dwellers. This underlines that Bt cotton contributes to poverty reduction and rural development.

Methods Summary

SAM. The village SAM considers 156 agricultural and non-agricultural activities. Agricultural activities include the cultivation of cotton and numerous other crop and livestock enterprises. Non-agricultural activities include agricultural services (e.g., hiring out machinery), village production (e.g., construction and small-scale manufacturing), retail trade, private services (e.g., barber, doctor), government services (e.g., ration shop, post office) and transportation. An aggregate version of the SAM is shown in Supplementary Table 1.

Experiments. Our two simulation experiments consider an expansion of the village crop area by 10 acres, either grown with Bt or conventional cotton. These 10 acres are additional to the crop area already cultivated in Kanzara, and it is assumed that there are no constraints in the availability of other production factors. For the essence of the results, the magnitude of the area expansion does not matter. Based on the existing structure of the village economy, the multiplier model simply simulates the direct and

spillover effects resulting from the increase in a specific economic activity, in our case either Bt or conventional cotton production. All the resulting effects are proportional to the assumed area expansion, such that income distribution is not influenced by the choice of the concrete acreage. We used the representative data in Table 1 to calibrate the insecticide and yield differences between Bt and conventional cotton in the simulations.

Full Methods and any associated references are available in the online version of the paper at www.nature.com/nature.

1. FAO. *The State of Food and Agriculture; Agricultural Biotechnology: Meeting the Needs of the Poor?* (Food and Agriculture Organization of the United Nations, Rome, 2004).
2. Huang, J., Hu, R., Rozelle, S. & Pray, C. Insect-resistant GM rice in farmers' fields: assessing productivity and health effects in China. *Science* **308**, 688-690 (2005).
3. Qaim, M. & Zilberman, D. Yield effects of genetically modified crops in developing countries. *Science* **299**, 900-902 (2003).
4. James, C. *Global Status of Commercialized Biotech/GM Crops: 2007*, ISAAA Briefs No. 37 (International Service for the Acquisition of Agri-biotech Applications, Ithaca, NY, 2007).

5. Huang, J., Rozelle, S., Pray, C. & Wang, Q. Plant biotechnology in China. *Science* **295**, 674-676 (2002).
6. Morse, S., Bennett, R. & Ismael, Y. Why *Bt* cotton pays for small-scale producers in South Africa. *Nat. Biotechnol.* **22**, 379-380 (2004).
7. Crost, B., Shankar, B., Bennett, R. & Morse, S. Bias from farmer self selection in genetically modified crop productivity estimates: evidence from Indian data. *J. Agr. Econ.* **58**, 24-36 (2007).
8. Gandhi, V. & Namboodiri, N. *The Adoption and Economics of Bt Cotton in India: Preliminary Results from a Study*, Working Paper No. 20006-09-04 (Indian Institute of Management, Ahmedabad, 2006).
9. Qaim, M. & de Janvry, A. Bt cotton and pesticide use in Argentina: economic and environmental effects. *Environ. Dev. Econ.* **10**, 179-200 (2005).
10. Huang, J., Pray, C. & Rozelle, S. Enhancing the crops to feed the poor. *Nature* **418**, 678-684 (2002).
11. Elbehri, A. & Macdonald, S. Estimating the impact of transgenic Bt cotton on West and Central Africa: a general equilibrium approach. *World Dev.* **32**, 2049-2064 (2004).
12. Huang, J., Hu, R., van Meijl, H. & van Tongeren, F. Biotechnology boosts to crop productivity in China: trade and welfare implications. *J. Dev. Econ.* **75**, 27-54 (2004).

13. Anderson, K., Valenzuela, E. & Jackson, L. A. Recent and prospective adoption of genetically modified cotton: a global CGE analysis of economic impacts. *Econ. Dev. Cult. Change* **56**, 265-296 (2008).
14. World Bank. *World Development Report 2008; Agriculture for Development* (World Bank, Washington, D.C., 2007).
15. Friends of the Earth. *Who Benefits from GM Crops? The Rise in Pesticide Use, Agriculture and Food Issue 112* (Friends of the Earth International, Amsterdam, 2008) <http://www.foei.org/en/publications/pdfs/gmcrops2008full.pdf> (Downloaded on 11 April 2008).
16. Qaim, M. Bt cotton in India: field trial results and economic projections. *World Dev.* **31**, 2115-2127 (2003).
17. Qaim, M., Subramanian, A., Naik, G. & Zilberman, D. Adoption of Bt cotton and impact variability: insights from India. *Rev. Agr. Econ.* **28**, 48-58 (2006).
18. Bennett, R., Kambhampati, U., Morse, S. & Ismael, Y. Farm-level economic performance of genetically modified cotton in Maharashtra, India. *Rev. Agr. Econ.* **28**, 59-71 (2006).
19. Walker, T & Ryan, J. *Village and Household Economies in India's Semi-Arid Tropics* (The Johns Hopkins University Press, Baltimore, MD, 1990).

20. Planning Commission. *Poverty Estimates for 1999-2000* (Government of India, Delhi, 2001).
21. Chen, S. & Ravallion, M. Poverty and hunger special feature: absolute poverty measures for the developing world, 1981–2004. *Proc. Nat. Acad. Science* **105**, 16757-16762 (2007).
22. Adelman, I, Taylor, E. & Vogel, S. Life in a Mexican village: a SAM perspective. *J. Dev. Stud.* **25**, 5-24 (1988).
23. Subramanian, S. & Sadoulet, E. The transmission of production fluctuation and technical change in a village economy: a social accounting matrix approach. *Econ. Dev. Cult. Change* **39**, 131-173 (1990).
24. Parikh, A. & Thorbecke, E. Impact of rural industrialization on village life and economy: a SAM approach. *Econ. Dev. Cult. Change* **44**, 351-377 (1996).

Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

Acknowledgements The financial support of the German Research Foundation (Deutsche Forschungsgemeinschaft) is gratefully acknowledged.

Author Information Correspondence and requests for materials should be addressed to

A.S. (asubram@uni-goettingen.de).

Table 1 | Comparison of insecticide use, yields, and net revenues between Bt and conventional cotton plots in India

	2002-03		2004-05		2006-07	
	Bt	Conventional	Bt	Conventional	Bt	Conventional
Insecticide use in kg/acre	2.07*** (2.65)	4.17 (3.37)	2.05*** (2.68)	4.19 (10.48)	1.22* (1.41)	1.55 (1.51)
Yield in kg/acre	658.82*** (393.64)	490.86 (335.88)	742.94*** (327.62)	550.52 (291.22)	841.65*** (356.00)	589.93 (335.09)
Net revenue in Rs./acre	5294.22** * (8117.19)	3132.99 (6773.89)	4921.83*** (6290.90)	2152.08 (5476.80)	7120.82*** (7654.80)	4181.26 (7563.07)
Number of observations	133	301	165	300	317	56

Mean values are shown with standard deviations in parentheses. Data was obtained from three rounds of a farm panel survey carried out in the states of Maharashtra, Karnataka, Andhra Pradesh, and Tamil Nadu.

Details of the sampling framework are discussed elsewhere¹⁷.

*, **, *** Mean values are different from those of conventional cotton in the same year at a 10%, 5%, and 1% significance level, respectively.

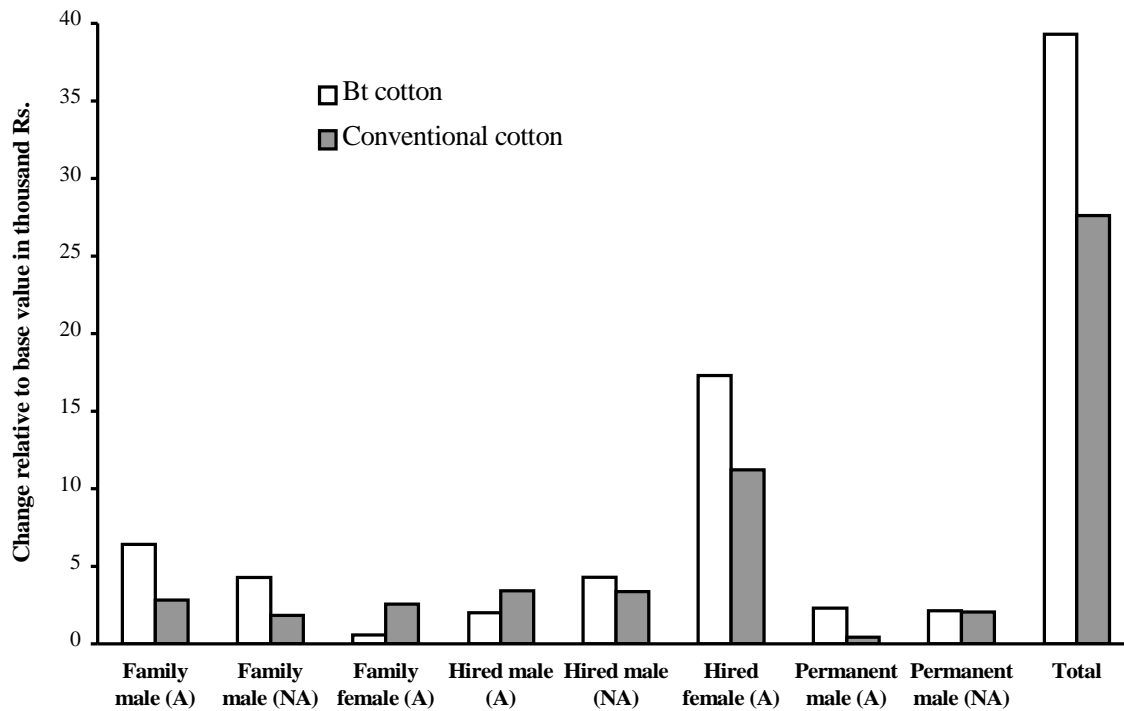


Figure 1 | Changes in returns to labor through increased Bt and conventional cotton production in Kanzara village. Simulations assume that the area under Bt and conventional cotton production is increased by 10 acres, respectively. Results are based on a SAM multiplier model and are shown for different categories of laborers. “A” stands for agricultural and “NA” for non-agricultural laborers.

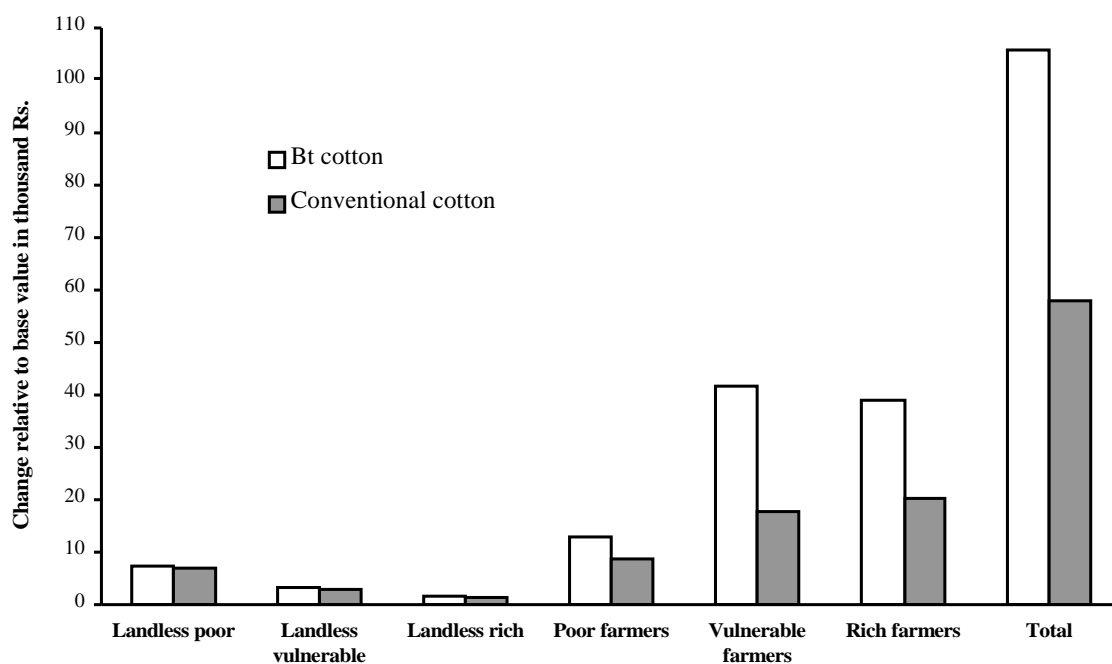


Figure 2 | Changes in household incomes through increased Bt and conventional cotton production in Kanzara village. Simulations assume that the area under Bt and conventional cotton is increased by 10 acres, respectively. Results are based on a SAM multiplier model and are shown for different categories of households.

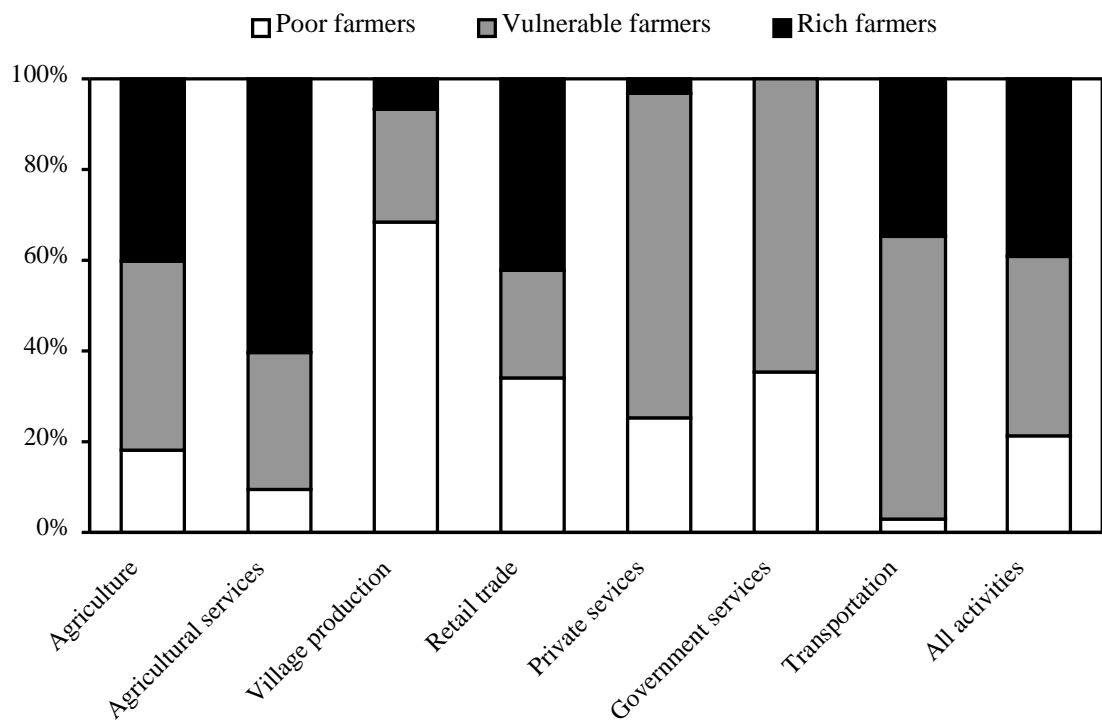


Figure 3 | Contribution of farm household categories to different economic activities in Kanzara village. The contribution of landless households is not included.

Supplementary Information

to

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Supplementary Table 1 | Aggregate village SAM for Kanzara village (2003-04 in Indian Rupees)

	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

Supplementary Methods

The SAM Multiplier Model

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. The rows and columns of the SAM can be

partitioned into endogenous and exogenous (Pyatt and Round 1979), 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:

$$y_n = n + x = A_n y_n + x, \quad (1)$$

$$y_x = l + r = A_l y_n + r. \quad (2)$$

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

$$y_n = (1-A_n)^{-1} x = M_n x. \quad (3)$$

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 and Sadoulet 1990; Parikh and 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. 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),

$$A_n = \begin{bmatrix} A_{11} & 0 & A_{13} \\ A_{21} & 0 & 0 \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \quad (4)$$

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 (Subramanian and Sadoulet 1990). Let \tilde{A}_n be given by,

$$\tilde{A}_n = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \quad (5)$$

From equation (3) 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,

$$y_n = (A_n - \tilde{A}_n) y_n + \tilde{A}_n y_n + x, \text{ or} \quad (6)$$

$$y_n = A^* y_n + (I - \tilde{A}_n)^{-1} x, \quad (7)$$

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

$$A^* = \begin{bmatrix} 0 & 0 & (I - A_{11})^{-1} A_{13} \\ A_{21} & 0 & 0 \\ (I - A_{33})^{-1} A_{31} & (I - A_{33})^{-1} A_{32} & 0 \end{bmatrix} \quad (8)$$

From equation (8) 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 (7) implies that the partitions of y_n are related to each other as points on a closed loop. In Supplementary Fig. 1, 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 Supplementary Fig. 1. This can be represented by the following equations:

$$y_1 = (I - A_{11})^{-1} A_{13} y_3 + (I - A_{11})^{-1} x_1, \quad (9)$$

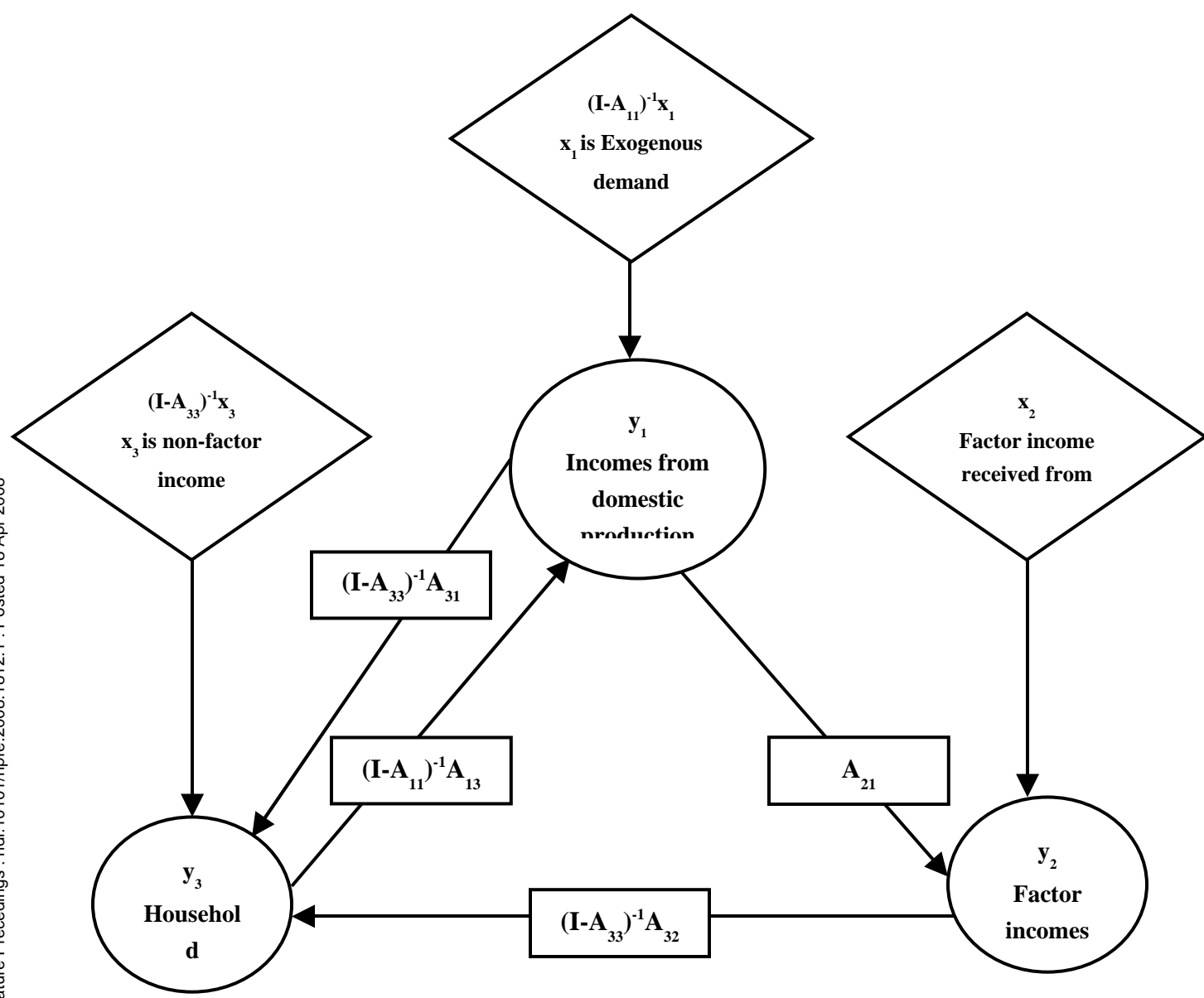
$$y_2 = A_{21} y_1 + x_2, \quad (10)$$

$$y_3 = (I - A_{33})^{-1} A_{31} y_1 + (I - A_{33})^{-1} A_{32} y_2 + (I - A_{33})^{-1} x_3, \quad (11)$$

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.

Simulations

Equations (9) to (11) and Supplementary Fig. 1 show the mechanisms through which the multiplier process operates. Our two simulation experiments consider an expansion of the village crop area by 10 acres, either grown with Bt or conventional cotton. Technically, this is implemented as an exogenous increase in cotton demand (initial injection) by the value produced on the additional 10 acres. Since yields in Bt are higher than in conventional cotton (Table 1), the value of the injection is also proportionally higher in the Bt cotton experiment. The injection generates a rise in cotton output of $(I - A_{11})^{-1} x_1$, which creates demand also for factors other than land (e.g., labor and capital). These factors are assumed to be available at given price levels, and their employment leads to the generation of additional value added $A_{21} y_1$. Apart from labor income, equation (10) 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 Supplementary Fig. 1 is closed through the pattern of household expenditures on commodities, which translates into new production and corresponding additional flows of income accruing to production activities given by equation (9).



**Supplementary Figure 1 | Schematic representation of the multiplier process
among endogenous accounts**

Supplementary References

Pyatt, G. & Round, J. Accounting and fixed price multipliers in a social accounting matrix framework. *Econ. J.* **89**, 850-873 (1979).

Subramanian, S. & Sadoulet, E. The transmission of production fluctuation and technical change in a village economy: a social accounting matrix approach. *Econ. Dev. Cult. Change* **39**, 131-173 (1990).

Parikh, A. & Thorbecke, E. Impact of rural industrialization on village life and economy: a SAM approach. *Econ. Dev. Cult. Change* **44**, 351-377 (1996).