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Economics Impacts of Genetically Modified Organisms: An analysis of Bt Cotton in India

Joseph LaHorgue
Claremont McKenna College

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Professor Benjamin Gillen

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Joseph LaHorgue

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Abstract:

The emergence of genetically modified organisms has sparked a multi-faceted debate, covering issues related to human health, ethics, and the environment. Discussions of the economics of GMO adoption are highly politicized and are influenced by large corporations and non-governmental organizations. This study aims to provide insight into the economic impacts of genetically modified organisms on individual farmers of cotton in India. The first GMO to reach commercialization in India was Bt cotton in 2002, which led to significant increases in revenue and yield among smallholder farmers. Using survey data collected between 2003 and 2009, I examine the economic impacts of Bt cotton and explore macro level changes in the Indian economy.

Introduction:

Overview of GMO Technology

Over the past several decades, improvements in genomics and biotechnology have led to breakthroughs in gene editing. Perhaps the most widely used, and debated, application of plant biotechnology is the genetically modified organism (GMO). Within the context of commercial agriculture, genetically modified seeds have entered markets in several countries and sparked controversy in political and social discussions. Since GMOs have been commercially produced for a relatively short amount of time, much of the fear surrounding them stems from the fact that the long-term effects of consuming GMOs remain unknown. Beyond the discussion of the health effects associated with their consumption, many aspects of plant genomics are the subject of fierce debate across the world.

The term GMO refers to an organism that has been altered using transgenics. Simply put, the process of transgenics allows researchers to produce traits in an organism that are entirely new, and do not appear naturally. This is achieved by inserting genetic material from a foreign species into the original organism's DNA. The use of transgenics is what separates the GMO from crops modified with other genetic engineering methods like CRISPR-Cas9. Since the agricultural revolution, selective breeding techniques have allowed farmers and seed producers to fine tune their products, weeding out undesirable traits over time. The GMO takes selective breeding a step further, resulting in products that have unique traits and are easily distinguishable from their predecessors. Given the complexity of transgenics, the introduction of genetically modified organisms into commercial agriculture could potentially have a significant impact on farmers, consumers, and the environment.

Key Components of the GMO Debate

Much of the debate on surrounding genetically modified organisms involves consumer concerns about the health effects of eating foods produced with GMOs. Within the past few years, the United States has passed legislation requiring all food producers to disclose their use of GMOs using labels on food packaging. People who maintain healthy diets often try to avoid eating foods with GMOs, and favor organic foods. Although academic research into the effects of consuming GMOs on a person's health have been inconclusive, many people are wary of transgenics and distrust the motives of large food and biotech corporations (Pew, 2016).

The potential environmental impacts of GMOs are widely discussed as well. In particular, the issues of plant biodiversity and pesticide resistance are frequently touched upon. Proponents of organic farming are worried that increased reliance on transgenics will lead to weakened, one-dimensional environmental systems. It is possible for transgenic material to be transferred from genetically modified crops to other plants via cross pollination. Such contamination, combined with changes in soil microbial ecosystems, could lead to widespread loss of crops in the event of pesticide resistance (FAO, 2005).

The introduction of genetically modified seeds into less developed economies also opens up opportunities for seed producers to exploit farmers. Adoption of GMOs into seed markets could lead to farmer dependence on corporations that control the price and supply of seeds. The cost of switching from traditional to genetically modified seeds could also lead to increased inequality among farmers, as poorer smallholders will be left behind by their competitors. Thus, the potential for positive economic outcomes is often overshadowed by the potential for unethical business practices among seed producing corporations.

Introduction of Bt Cotton

In this study, I focus my analysis on the commercialization and adoption of Bt cotton among farmers in India. The term "Bt" is short for *Bacillus thuringiensis*, a bacterium found in soil that can be used as a natural pesticide. *Bacillus thuringiensis* produces proteins that are toxic to many insects, which gives the bacteria their pesticide capabilities (Ibrahim, 2010). Since its discovery, Bt has become one of the most widely used pesticides and is safe for human consumption. Given their natural origin, Bt pesticides are popular among organic farmers (Chien, 2019).

Bt cotton contains DNA sequences from *Bacillus thuringiensis* that allow the plant to exhibit natural pesticide capabilities, which eliminates the need for farmers to use external Bt or synthetic pesticides on the crops. The particular strain of Bt cotton used by farmers in this study is called Bollgard II, and is produced by Mahyco Monsanto. Mahyco Monsanto Biotech is a joint venture between Maharashtra Hybrid Seeds Company Ltd. and Monsanto Investments India Private Ltd. (Bloomberg, 2019). The seeds are engineered to combat the Cotton Bollworm Complex (Qaim, 2012) and were first commercially released in 2002.

Literature Review:

Recent economic literature covering genetically modified organisms addresses topics ranging from effect of GMOs on seed markets to income of individual farmers. The regulatory process for transgenic crops is long, and many proposed crops have fallen victim to the bureaucracy of agencies involved and the lobbying power of NGOs and transnational corporations. Starting with large scale economic effects and moving toward case studies of genetically modified cotton in India, I will introduce relevant academic research that discusses the benefits and challenges associated with implementation of GMO technology in a commercial environment.

Lence and Hayes (2005) published in the *American Journal of Agricultural Economics* discusses the macro-level shifts in global grain markets caused by the emergence of genetically modified seeds. Through a series of market simulations, the authors examine how GMOs would alter equilibrium prices of commodity seeds and eventually influence macroeconomic indicators, including profit, revenue, consumption, and trading volume. The outcome of their simulations suggest that genetically modified crops will lead to increased production and profit margins, which ultimately lead to positive economic outcomes.

The study by Lence and Hayes suggests that despite the likelihood of positive outcomes, there are circumstances in which the introduction of GMOs would result in economic losses. Digging deeper, the authors describe how the success of genetically modified seeds will be influenced by consumer preferences and demand elasticity. Consumers who are committed to non-GMO products will experience an increase in the equilibrium price of such seeds caused by a shift in supply. Eventually, losses will occur when consumers favor non-GMO seeds, and market penetration is high enough to warrant identity-preservation measures among non-GMO producers. Overall, both the producers and consumers of grain will benefit from genetically modified crops as long as both parties are open to GMO technologies (Lence & Hayes, 2005).

The discussion of the challenges of GMO adoption is laid out in Barnet and Gibson (1999) in the *Journal of Economic Issues*. In the 20 years since the study was published, many of challenges forecasted by the authors have come to prominence. The primary obstacles outlined in the study were potential for pest resistance to transgenic seeds, complex regulatory processes, and the necessity for equitable and efficient contractual agreements between developers and farmers. Further, authors predicted that the regulation and commercialization of GMOs would become the subject of fierce ethical and political debate. The study references the difficulty of designing fair contracts between developers of GMOs (i.e. Monsanto) and farmers who license their technology. The core question of this debate is whether genetically modified seeds actually provide any real benefits to farmers. Those opposed to GMOs argue that all economic benefits created by genetically modified crops will be realized by corporations who develop and patent transgenic seeds. Ultimately, without adequate regulation and protection for farmers, the introduction of genetically modified seeds could lead to negative economic impacts from a macro perspective (Barnet and Gibson, 1999).

In a study in the *Journal of South Asian Development*, Bownas (2016) analyzes the three main perspectives on GMO adoption in India. The debate, which is highly politicized, is influenced significantly by the media, NGOs and multinational corporations. The first perspective, as described by Bownas, is one of liberal market economics which argues that GMO adoption should be a matter of farmers' choice. Thus, commercialized GMOs ought to be available to farmers looking for ways to improve their output. Another perspective, which Bownas calls the Agrarian Approach, views genetically modified crops as a weapon used by large corporations against farmers with little economic agency. Introducing this technology would lead to further dependence on potentially corrupt organizations that will lead to negative economic outcomes among farmers. The third perspective, which focuses on Equitable Development, argues that GMOs should be approved for commercialization on a case-by-case basis under appropriate contexts. This is likely the most pragmatic strategy and represents people in the middle ground between the poles. Given their stance, the Equitable Development side of the argument has largely been drowned out by the lobbying power of the first two perspectives. Within the context of India, the author suggests that adopting genetically modified crops will yield positive results for farmers and consumers alike, assuming there is adequate need for innovation in that particular market (Bownas 2016).

In the *Canadian Journal of Agricultural Economics*, Kolady and Herring (2014) outlines the implications of GMO policy on social welfare and market competition. The goal of the study is to examine the demonstrated and likely effects of regulatory uncertainty on social welfare and development of the agricultural biotechnology industry. The authors define a nonmarket failure as an economic or market failure caused by an inefficient regulatory process. One major source of nonmarket failures in the Indian regulatory process is the involvement of six ministries with competing goals and ill-defined areas of authority. Policies and goals for environmental and agricultural applications are handled by federal and state governments, respectively. Thus, issues like the regulation of biosafety and diversity fall under federal responsibility, despite their relevance in agricultural regulation conducted by state governments. Further, the Indian federal government is influenced significantly by anti-GMO agencies including Greenpeace, who regularly reject science-based studies on the effects of GMOs. Thus, policies produced through this process will have divergent outcomes and use resources inefficiently. Redundant and rising regulatory costs, as well as delay in regulatory approval can lead to negative socioeconomic impacts and foregone societal benefits. Overall, the authors suggest the need for a science-based, clear and predictable regulatory framework for GMOs in India (Kolady and Herring, 2014).

Questions surrounding economic impacts of GMOs among individual farmers have been explored in several studies. Morse, Bennett, and Ismael (2007) in the *Journal of Agribiotechnology Management and Economics* examines the role GMOs play in levels of income inequality among farmers of cotton in India. The theory tested in the study states that farmers who are wealthier will be able to afford genetically modified seeds. Poorer farmers, by contrast, will be unwilling to risk switching to GMOs or unable to afford to do so. Over time, the gap between wealthy and poor farmers would increase. The results of the study suggest that adopters of GMOs saw higher average household income, yields, and gross margins after adoption. Further, the introduction of genetically modified seeds led to a decrease in inequality measured by the Gini score, and inequality among adopters was lower than that of non-adopters. Ten years after commercialization of Bt cotton in India, adoption was over 90% and inequality was much lower (Morse, Bennett, Ismael, 2007).

A similar study published in PLOS One by Qaim and Kouser (2013) found statistically significant increases in daily caloric intake among GMO adopting farmers. Using a dataset made up of survey results that is similar to the one used in my analysis, the authors aimed to identify quality of life indicators that are improved after switching to genetically modified seeds. In the ten years after the introduction of GMOs in India, farmers of cotton experienced a significant increase in the rates of food security. The population of Bt cotton growers in the region was roughly 7 million, accounting for almost 11 million hectares farmed. Across the population of GMO adopters, the average daily caloric intake increased by roughly 5%, and included a wider variety of nutritious foods (Qaim and Kouser, 2013).

One area of the GMO debate that is frequently brought up by opposers of the technology are issues of pest resistance and other threats to the long-term efficacy of transgenic crops. Short-term outcomes are well documented, with multiple studies discussing the primary benefits of increased yields, and reduced usage and expenditure on pesticides. As discussed in Qiao (2015) in *World Development*, the primary concern going forward is estimating long run challenges that will not appear in cross sectional studies. The study uses 15 years of panel data collected from 1997 to 2012 on Bt cotton farmers in China, and captures average yields, profits, costs of seeds, and pesticide usage. Over time, all benefits of GMO adoption were stable in the sample. These results represent a growing population of research that expands beyond short run economic implications of genetically modified crops and highlight long run positive outcomes in both micro and macro terms (Qaio, 2015).

Qaim and Kathage (2012) published by the U.S. National Academy of Sciences highlights the long-term economic impact dynamics of Bt cotton in India. After compiling a survey-based panel dataset across the population of cotton farmers in India, the majority of which are smallholder farmers, the authors found that adopting transgenic Bt cotton seeds lead to a 24% increase in yields and 50% increase in profits that remained stable over time. The results suggest that Bt cotton had no significant effect on consumption expenditures in the early adoption period, but increased household living standard significantly in the later period. Further, the results show that smallholder farmers benefit from Bt cotton adoption, despite the common ideology that GMOs lead to greater inequality between large and small producers (Qaim and Kathage, 2012).

As a whole, research covering the economic impacts of transgenic GMO technology is diverse, spanning both micro and macro economics and the ethics associated with commercialization of genetically modified crops. The adoption of Bt cotton in India serves as a valuable case given the high degree of market penetration and availability of relevant data on the subject. That being said, further analysis is necessary in order to fully understand the macro effects of GMO adoption in the long run.

Description of Data:

The data used to conduct this study was collected in a panel survey of cotton farmers across four states in central and southern India, accounting for roughly 60% of the Indian cotton growing region. I obtained permission from the authors to use the data set from Qaim and Kathage (2012). The surveys were conducted in person and included data on farmers usage of Bt cotton seeds and other demographic information. The survey contains responses from 10 different districts and 63 villages, with respondents offering information on the most recent completed harvesting season. The panel data set contains responses from 533 unique households, and 1655 total observations.

The data was collected in four waves separated by two-year intervals. The first survey occurred in 2003, which collected data on the first year Bt cotton was commercially available in India (2002). Subsequent collections occurred in 2005, 2007, and 2009. All farmers who were included in the survey farmed cotton, and some grew other crops as well. Further, some farmers used only Bt cotton, while others split their plots between Bt and a hybrid alternative. Overall, the sample size grew marginally throughout the course of the surveys, with some turnover as respondents moved to different states or shifted focus to other crops. In total, 198 respondents participated in each of the four surveys over the period.

Key variables are discussed below:

Treatment Variables:

- **Adoption**: captures Bt adoption: 1 = yes, 0 = no, (***bt***)
- **Bt share**: portion of cotton plot that was planted with Bt cotton, (***bt_share***)
- **Bt size**: area of Bt cotton plot, (***bt_size***)
- **Fertilizer**: fertilizer used on cotton crop in kilograms, (***fert_kg***)
- **Insecticide**: cost of insecticide used on cotton plot, (***inscost***)
- **Bollworm cost**: cost of spraying against bollworm complex, (***bw_spraycost***)
- **Seed price**: cost of seed used per acre farmed, (***seedpriceacre***)

Outcome Variables:

- **Revenue**: total proceeds from sale of cotton, (***revenue***)
- **Logged revenue**: log of revenue, (***lrevenue***)
- **Net revenue**: revenue net of expenses, (***net_revenue***)
- **Logged net revenue**: log of net revenue, (***lnet_revenue***)
- **Yield**: the total cotton yield in kilograms (***yldkgs***)
- **Logged yield**: log of yield, (***lyield***)
- **Household expenditure**: household expenditure per year, (***hhexp***)
- **Food expenditure**: household expenditure on food, (***foodexp_hh***)
- **Non-food expenditure**: household expenditure on non-food items (***nonfoodexp_hh***)
- **GSDP**: gross state domestic product, (***gsdp***)

Control Variables:

- **Age**: age of the head of household, (***age***)
- **Education**: years of education of the head of household, (***edu***)
- **Year**: survey the observation occurred in (1=2003, 4=2009), (***year***)
- **Plot size**: size of plot farmed in acres, (***plot_sizeacres***)
- **Land ownership**: acreage owned by the household, (***land_own***)

Summary Statistics

The following sections outline summary statistics for relevant demographic, production, and outcome variables within the dataset. The summaries include the total number of observations, and measures of the mean, standard deviation, minimum, and maximum of each variable.

Demographic variables:

The farmers surveyed provided information on several demographic factors. Variables included are the age of the head of household, years of education of the head of household, total acres owned by the household, and the plot size (in acres) of Bt cotton. All variables are measured on an annual basis.

	Obs	**Mean**	**Std. Dev.**	**Min**	**Max**
Age	1431	45.0	12.6	10	87
Education	1431	7.2	5.1	0	21
Land ownership	1431	12.2	14.1	0	120
Plot size	1431	3.7	4.0	0	55
Bt size	1431	2.7	4.1	0	55

Production variables:

The farmers provided data on units of input into their plots. Variables included are the total amount (in kilograms) of fertilizer used, cost of insecticide used on the plot, cost of spraying for cotton bollworm complex, and the average price per acre of seeds. All variables are measured on an annual basis. Currency measured in rupees.

	Obs	Mean	Std. Dev.	Min	Max
Fertilizer	1431	284.1	211.1	0	2000
Insecticide cost	1431	1815.0	2158.4	0	18630
Bollworm cost	1431	973.7	1526.6	0	14100
Seed price	1431	848.9	424.1	0	4560

Outcome variables:

The outcome variables measure economic outcomes that are associated with adoption of GMOs. Variables included are total revenue per household, net revenue per household, and total household expenditure. All variables are measured on an annual basis. Currency measured in rupees. Logged variables are used in the regression analysis to provide normalized results.

	Obs	Mean	Std. Dev.	Min	Max
Revenue	1431	17074.91	10465.69	0.00	85000.00
Net Revenue	1431	8016.74	8700.47	-40573.33	58346.67
Yield	1431	792.80	472.00	0.00	3600.00
Household Exp.	1431	103291.30	99616.32	14555.00	1663660.00

Methodology:

Description of the Arellano-Bond Method

In my analysis, I use the Arellano-Bond estimator for dynamic panel data. For a number of reasons, the characteristics of the data set could lead to endogeneity without proper consideration of the type of panel data collected in the survey. The panel data set used in this study is characterized as “small-T, large-N” given its short time frame and large sample size. Dynamic panel data models include lags of the dependent variable as regressors, which lead to endogeneity and autocorrelation as the outcome of dependent variables will be caused by their previous outcomes. In this case, causality will likely be mutli-dimensional, leading to endogeneity among the dependent and explanatory variables. Including internal (lagged) and external instruments to address endogeneity with predetermined regressors and the error term, which can be removed through first-differencing (Mileva, 2007).

Further, state and farmer-level fixed effects will be correlated with explanatory variables, and unobserved demographic information will be contained in the error term. The Arellano-Bond method uses a first-differencing General Method of Moments (GMM) estimator to remove the fixed effects from the error term. Ultimately, using Arellano-Bond allows me to estimate the effect of various explanatory variables on dynamic dependent variables and control for auto-regressive tendencies in the models. While the estimation of these models requires relatively complicated econometric methods, we can interpret the estimated results in the usual way.

Description of Regression Models

With the first set of regressions, I aim to identify which demographic factors, if any, lead farmers to switch to Bt cotton. The purpose of this analysis is to address questions surrounding the availability of genetically modified seeds, costs of switching to Bt cotton, and inequality among farmers. These questions are widely discussed in political settings and academic research and allude to common perception of GMOs as vehicles for exploitation of farmers. To address this question, I regress adoption and Bt share against demographic variables, including age, education, land ownership, and household expenditure. Through these regressions, I aim to show that the adoption rate of genetically modified seeds was consistent and independent of demographic influence. If that is the case, the regression results will show no statistically significant estimators.

The second set of regressions will examine how adoption of Bt cotton leads to positive economic outcomes among farmers. To conduct this analysis, I regressed each of the outcome variables described earlier against production and demographic controls. I tested revenue, net revenue, yield, household expenditure, food expenditure, and insecticide cost against Bt adoption measures and production input variables. In order to establish positive economic outcomes, I expect to see statistically significant relationships between adoption or Bt share and revenue, which suggests increased revenue and profits can be attributed to adoption of genetically modified seeds. Further, I expect to see little explanatory power among production input variables, which will help establish causal relationships between adoption of genetically modified seeds and outcome variables.

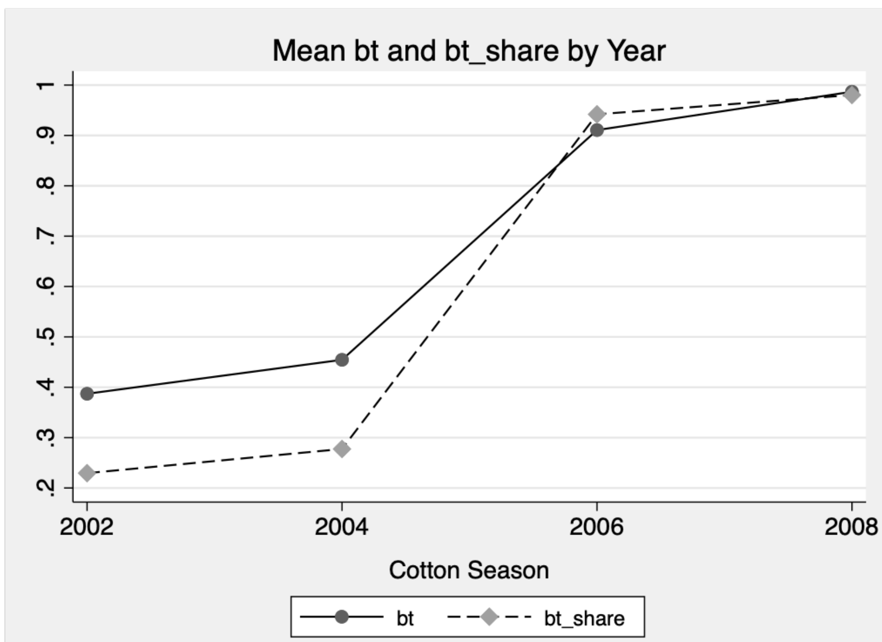
The final regression model aims to capture the effects of GMO adoption statewide on the Gross State Domestic Product (GSDP) of the states included in the study. After inputting GSDP data into the state-collapsed dataset, I regress gsdp against Bt adoption controls. Given the small sample size, it is unlikely to achieve statistically significant results. However, positive relationships between adoption and gsdp will allow us to address the macroeconomic impacts of GMO adoption and address further implications.

In order to achieve better model specification and easily digestible results, I use logged forms of the dependent variables against adoption and Bt share, both of which are confined between zero and one.

Results:

GMO Adoption Summary Statistics

Throughout the duration of panel study, the Bt adoption rate was grew rapidly and resulted in genetically modified seeds appearing in almost every farm surveyed. The ubiquity of the seeds speaks to their efficacy, and also suggests that adoption occurred independently of demographic factors. The figure below shows mean levels of adoption and Bt share, which together paint a picture of overall adoption of genetically modified technologies among farmers in the sample.



Source: Qaim & Kathage (2012)

The largest increase in both adoption and Bt share occurred between the second and third surveys (2004-2006 seasons), where the mean adoption doubled (.455 to .911) and mean Bt share more than tripled (.277 to .942). It is important to note that by the end of the survey period, genetically modified Bt cotton reached nearly 100% adoption. Not only was adoption of Bt cotton widespread across the sample, the shares of farmers' plots were made up almost entirely with genetically modified seeds by the second half of the survey period.

Regression Analysis of Demographic Factors

In order to better understand the uptick in adoption of Bt cotton, I regressed adoption and Bt share against demographic controls to identify any factors that lead farmers to switch to genetically modified seeds. I fit the model with the following regression equations:

1) $bt = \beta_0 + \beta_1 bt_{t-1} + \beta_2 age + \beta_3 edu + \beta_4 plot\_sizeacres + \beta_5 land\_own + \beta_6 hhexp + u$

2) $bt\_share = \beta_0 + \beta_1 bt\_share_{t-1} + controls + u$

The resulting regression results for adoption and Bt share are as follows:

		Adoption			***Bt share***		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
Lagged dependent	***L1.***	0.24	0.04	5.39	0.17	0.05	3.51
Age	***age***	0.00	0.00	-0.19	0.00	0.00	-0.07
Education	***edu***	0.00	0.01	0.22	0.01	0.01	0.91
Plot size	***plot_sizeacres***	0.01	0.01	1.09	0.01	0.00	1.61
Land ownership	***land_own***	0.01	0.00	2.41	0.00	0.00	0.14
Household Exp.	***hhexp***	0.00	0.00	-1.12	0.00	0.00	-1.16
time3	***time3***	0.46	0.04	11.60			

n = 458

The regression results suggest that by the end of the study, there were no demographic factors that maintained statistically significant relationships with the outcome variables adoption and Bt share. The only coefficients with any predictive power are the lagged dependent variables, as well as year 3 for Adoption. This suggests that farmers tested genetically modified seeds on a portion of their plots, before switching to an entirely Bt cotton plot a year later. As documented in the graph above, more than 90% of farmers had switched to Bt cotton by 2007, and the average Bt share was over 90% as well. In both regressions, we see limited explanatory power in all demographic factors. While the coefficient for land ownership is statistically significant, its magnitude at .007 is does not amount to any real changes in adoption Bt share.

The demographic factors may have had a larger effect on the outcomes of adoption and Bt share in the earlier years of the survey (2002-2004). Due to the recentness of the deregulation of Bt cotton, which occurred in 2002, most of the variation in the dataset would appear in the earlier years. The fact that over 90% of farmers switched to genetically modified seeds by 2006 supports my hypothesis that Bt cotton adoption occurred among farmers of all ages, education and income levels. However, it is possible that analyzing the early adoption rate would have yielded more interesting results. Ultimately, I was able to address the question of accessibility of GMOs related to economic inequality in my analysis. In the case of Bt cotton in India, the distribution of adopters was spread evenly across a diverse sample of farmers.

Economic Outcomes of GMO Adoption

The success of Bt cotton is reflected in the economic outcomes of adopting farmers in the study. To illustrate this, I analyzed the effects of GMO uptake variables (adoption, Bt share) and production inputs on a variety of outcome variables. The purpose of these models is to illustrate the boost in production and financial output caused by Bt cotton, controlling for other inputs. Starting with revenue and net revenue, I regressed outcome variables against adoption and Bt share and relevant production input controls. I used logged dependent variables to normalize the effects of GMO adoption to reflect percent changes in output. The regression equations are as follows:

3) $lrevenue = \beta_0 + \beta_1 revenue_{t-1} + \beta_2 bt + \beta_3 fert\_kg + \beta_4 inscost + \beta_5 plot\_sizeacres + \beta_6 land\_own + \beta_7 bt\_size + \beta_8 seedpriceacre + u$

4) $lnet\_revenue = \beta_0 + \beta_1 revenue_{t-1} + \beta_2 bt + controls + u$

As expected, adoption of Bt cotton had substantial impacts on both revenue and net revenue. Below is a simplified table of regression results:

		Revenue (logged)			***Net revenue (logged)***		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
Adoption	***bt***	0.37	0.12	3.04	0.54	0.23	2.30
Fertilizer	***fert_kg***	0.00	0.00	2.73	0.00	0.00	-0.41
Insecticide	***inscost***	0.00	0.00	1.54	0.00	0.00	-2.70
Plot size	***plot_sizeacres***	0.02	0.02	1.16	0.00	0.05	0.05
Land Ownership	***land_own***	0.00	0.00	-0.43	0.00	0.01	-0.24
Bt size	***bt_size***	-0.02	0.02	-1.06	0.00	0.05	0.00
Seed price	***seedpriceacre***	0.00	0.00	1.14	0.00	0.00	-0.89

n = 454

The coefficients for adoption are statistically significant in both logged revenue and logged net revenue models. According to this model, switching to Bt cotton will result in an increase in revenue of roughly 37% (p>.01) and an increase in net revenue of

54% (p>.05), after controlling for production inputs. In the context of farmer outcomes, this change represents a substantial spike in income independent of insecticide and seed acquisition costs. Further, the increases in revenue occur independently of land ownership and plot size, challenging the misconception of GMOs as being a tool to increase inequality between smallholders and large commercial farms. The results from similar regressions against Bt share show consistent results.

The fact that adopting Bt cotton leads to increased revenues and net revenues suggests that farmers benefit from genetically modified seeds. The question of surplus incidence is often raised by critics of GMO technology. In particular, Bownas (2016) characterizes how the Agrarian Approach describes genetically modified seeds as weapons used by large corporations to exploit farmers. The reasoning behind this argument stems from the fact that producers of bioengineered seeds are often monopolists in seed markets, and thus have significant influence on the price of seeds. In the context of Bt cotton in India, seed prices did rise throughout the six years of surveys, but fluctuated significantly year-to-year. Further, seed price was not a significant estimator of adoption, revenue, or yield throughout each of the models. Ultimately, these results favor the equitable development perspective in Bownas (2016), and the commercialization of Bt cotton in India serves as an example of efficient market pricing and licensing of transgenic technology.

Production Outcomes of GMO Adoption

Adoption of Bt cotton also led to increased yields and lower expenditure on insecticide across the sample. Total yield is a key measure of output, and indicates a farmer's ability to convert fertilizer and insecticide inputs into income. The following regressions show that output with genetically modified seeds was higher per unit input than output from traditionally bred seeds.

5) $yldkgs = \beta_0 + \beta_1 yldkgs_{t-1} + \beta_2 bt + \beta_3 fert\_kg + \beta_4 inscost + \beta_5 bw\_spraycost + \beta_6 plot\_sizeacres + \beta_7 land\_own + \beta_8 seedpriceacre + u$

6) $lyield = \beta_0 + \beta_1 lyield_{t-1} + \beta_2 bt + controls + u$

The regressions on yield show consistent results to those on income, with Bt adoption maintaining statistically significant relationships with both yield and logged yield. The regression results are as follows:

		Revenue (logged)			***Net revenue (logged)***		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
Adoption	***bt***	0.37	0.12	3.04	0.54	0.23	2.30
Fertilizer	***fert_kg***	0.00	0.00	2.73	0.00	0.00	-0.41
Insecticide	***inscost***	0.00	0.00	1.54	0.00	0.00	-2.70
Plot size	***plot_sizeacres***	0.02	0.02	1.16	0.00	0.05	0.05
Land Ownership	***land_own***	0.00	0.00	-0.43	0.00	0.01	-0.24
Bt size	***bt_size***	-0.02	0.02	-1.06	0.00	0.05	0.00
Seed price	***seedpriceacre***	0.00	0.00	1.14	0.00	0.00	-0.89

n = 454

As compared to analyzing income as an outcome Bt adoption, yield represents a tangible metric that is more closely related to the efficacy of genetically modified seeds. Measured annually in kilograms, the yield represents the total amount of cotton produced per plot. As expected, switching to genetically modified seeds lead to large and statistically significant increases in yield, controlling for inputs like fertilizer usage, insecticide usage, and size of the plot. Specifically, farmers who used Bt cotton saw an increase in yield of 255 kg per year, a roughly 28% spike. Adoption coefficients were significant at 1% confidence intervals in both cases.

A key benefit of GMOs is the decreased need for insecticide and pesticide. Farmers and consumers are concerned with exposure to chemicals in agriculture, and the emergence of GMOs as a solution has been met with controversy throughout the years. In the case of cotton in India, adoption of genetically modified seeds has led a reduction in the usage of insecticide. In particular, spraying against cotton bollworm complex decreased by 40% ($p>.07$) once farmers switched to Bt cotton (Figure 5). Interestingly, regression results suggest that switching to Bt led farmers to use substantially more fertilizer. After controlling for plot size, fertilizer use increased by 20% ($p>.01$) upon adoption of GMOs. Ultimately, the use of genetically modified seeds led to an increase in gross output of cotton, and led to decreased reliance of pesticides across the sample.

Bt Adoption and Household Expenditure

Despite the documented increases in yield and revenues associated with adoption of genetically modified seeds, measures of household expenditure did not experience the same relationship. After testing for changes in household expenditure, food expenditure and non-food expenditure, neither the Bt binary variable nor measure of Bt share had any explanatory power. My expectation was that expenditures would rise alongside revenue and net revenue. The results suggest that household expenditure is influenced by several other factors, including food prices and the number of dependents per household. The regression results show that GMO adoption, as well as yield and revenues were not significant, independently or jointly. More in-depth results included in the appendix (Figure 6).

Macroeconomic Outcomes of GMO Adoption

I address the question of macro-level impacts of GMO adoption by relating uptake of Bt cotton to state-wise GDP among the states included in the study. Farmers surveyed live in Andhra Pradesh, Karnataka, Maharashtra, and Tamil Nadu. While not the only states in which cotton farming occurs, they paint a fairly comprehensive picture of the cotton production industry in India, and regressing against their respective state gross domestic products will offer insights into the large-scale economic effects of GMO adoption. The variable gsdp is measured in percentage growth rate, and thus does not need to be converted to log form. The model is specified as follows:

7) $gsdp = \beta_0 + \beta_1 gsdp_{t-1} + \beta_2 bt + u$

8) $gsdp = \beta_0 + \beta_1 gsdp_{t-1} + \beta_2 bt\_share + u$

		GSDP			***GSDP***		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
Lagged Dependent	***L1.***	-0.17	0.21	-0.82	-0.09	0.27	-0.33
Adoption	***bt***	1.17	0.72	1.61			
Bt share	***bt_share***				1.05	0.57	1.85
constant	***_cons***	5.08	1.89	2.69	4.73	1.94	2.44

n = 16

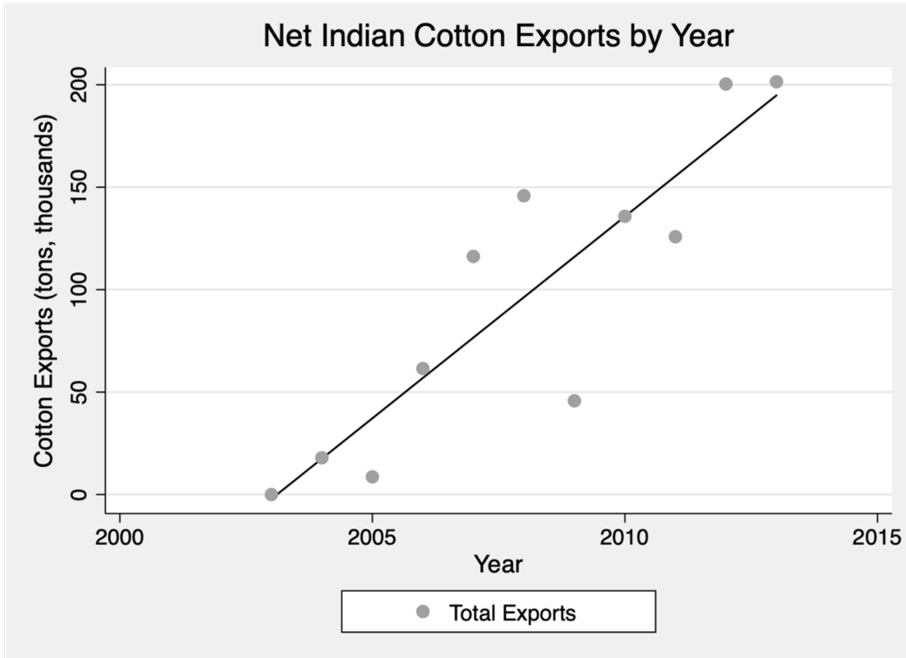
Overall, coefficients for both adoption and Bt share suggest that the outcome of GMO adoption will result in approximately 1% higher growth rate of gross state domestic product annually**.** While neither is statistically significant at the 5% level, Bt share is significant at 10%.

Ultimately, the adoption of Bt and the resulting spike in revenues led to increased economic activity, which is reflected in increases in state GDP of cotton producing states. Given that the dataset for state GDP growth is small in this context (n = 16), the outcomes of both regressions are indicative of trends in the broader Indian economy but are not meant to represent causal relationships.

Implications:

The empirical results suggest that farmers will benefit substantially from switching to genetically modified seeds, in terms of both revenue and yield. After controlling for relevant demographic and production related metrics, the results suggested that farmers who switched to genetically modified seeds were better off overall. On a macro level, the commercialization and adoption of Bt cotton coincided with a period of economic growth and increases in state GDP.

The long-term macro effects of GMO adoption helped usher in a new era in the Indian textile industry. Within two years of GMO commercialization, India transitioned from a net importer of cotton to a net exporter. Eventually, Indian exports grew substantially enough for India to rank third globally in cotton exports behind China and the United States.



Source: data.gov.in

As of 2018, Indian cotton production reached 27 million 480-pound bales, and exports totaled 4.2 million bales (National Cotton Council of America, 2018). At these levels, India is the largest producer of cotton in the world by a significant margin. Through this lens, the introduction of genetically modified cotton to farmers helped revitalize the struggling cotton industry in India, and vaulted the country into its current position as a leader in global cotton trade.

Conclusion:

The purpose of this study was to examine the effects of adoption of genetically modified seeds on economic outcomes of cotton farmers in India. As hypothesized, income and yields experienced increases that can be attributed to their transition toward

Bt cotton as their primary crop. The population of farmers, most of whom were smallholders, proved to be an effective sample with which I could focus on how individuals would benefit from new breakthroughs in seed technology. Contrary to previous notions about GMOs, smallholder farmers were able to capture a large portion of the economic benefits of switching to bioengineered seeds. Further, farmers of Bt cotton were able to use smaller amounts of pesticides in growing their crops, which in itself is an added benefit for environmental and human health reasons. Beyond benefits to individuals in the sample, I was able to extrapolate my results to states and India as a whole, and identify trends in GDP and exports that were influenced by the market penetration of Bt cotton.

My decision to focus on cotton allowed me to avoid questions of the effects of consumption of genetically modified foods over time. Cotton is not a food crop, and thus provides a good canvas for me to analyze economic outcomes of GMO adoption with farmers being the primary stakeholders. Going forward, studies focused on food crops will have to account for the influence of demand elasticity among health-conscious consumers who are wary of eating GMOs. As the technology underlying transgenics and GMOs develops, further studies on the implications of GMOs should address environmental concerns and continue to measure any changes in yields, revenues, and usage of pesticides.

Ultimately, this study serves as an example of the potential for genetically modified organisms to improve farmers' ability to turn their resources into income, and improve their economic agency. In the context of GMO commercialization and regulation, there is evidence that approval of products like Bt cotton will lead to substantial improvements in agricultural productivity and output, and help farmers to meet rising demand for crops in the future.

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Appendix:

Figure 1: mean levels of Adoption and Bt share by year

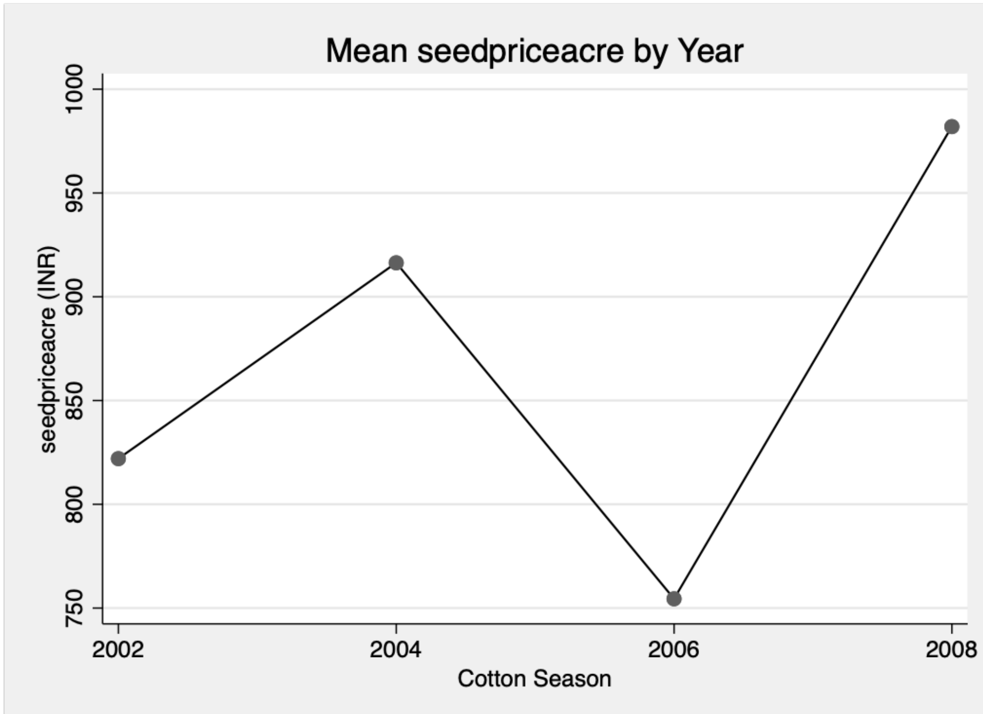
		Adoption		*Bt share*	
Year	**Obs**	**Mean**	**Std. Err.**	**Mean**	**Std. Err.**
2002	1431	0.39	0.03	0.23	0.02
2004	1431	0.45	0.03	0.28	0.02
2006	1431	0.91	0.02	0.94	0.01
2008	1431	0.99	0.01	0.98	0.01

Figure 2: Full regression results from equations 3, 4

		Revenue (logged)			*Net revenue (logged)*		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
Lagged dependent	***L1.***	0.03	0.05	0.62	-0.01	0.07	-0.16
Adoption	***bt***	0.40	0.12	3.31	0.93	0.30	3.15
Fertilizer	***fert_kg***	0.00	0.00	2.70	0.00	0.00	-0.46
Insecticide cost	***inscost***	0.00	0.00	1.51	0.00	0.00	-3.17
Age	***age***	0.00	0.00	-0.73	0.00	0.01	-0.58
Education	***edu***	0.00	0.01	-0.33	0.00	0.02	0.10
Plot size	***plot_sizeacres***	0.02	0.02	1.04	0.00	0.01	0.32
Bt size	***bt_size***	-0.02	0.02	-0.93	-0.72	0.32	-2.24
Land Ownership	***land_own***	0.00	0.00	-0.40	0.00	0.01	-0.41
time2	***time2***	-0.25	0.08	-3.05	-0.13	0.15	-0.85
time3	***time3***	-0.21	0.04	-5.13	0.19	0.08	2.57
constant	***_cons***	9.20	0.53	17.37	9.26	0.78	11.85

n = 454

Figure 3: mean Seed price by year



Source: data.gov.in

Figure 4: Full regression results from equations 5, 6

		Yield			***Yield (logged)***		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
Lagged Dependent	***L1.***	0.07	0.06	1.14	0.03	0.05	0.63
Adoption	***bt***	254.59	67.85	3.75	0.28	0.09	3.28
Fertilizer	***fert_kg***	0.55	0.13	4.32	0.00	0.00	3.26
Insecticide	***inscost***	0.01	0.02	0.61	0.00	0.00	2.07
Bollworm cost	***bw_spraycost***	0.02	0.03	0.89	0.00	0.00	-0.88
Plot size	***plot_sizeacres***	6.89	6.25	1.10	0.00	0.01	0.64
Land Ownership	***land_own***	-2.84	2.37	-1.20	0.00	0.00	-1.07
Seed price	***seedpriceacre***	0.07	0.06	1.14	0.00	0.00	1.73
time2	***time2***	145.33	58.21	2.50	0.09	0.08	1.16
time3	***time3***	105.71	32.70	3.23	0.11	0.04	2.58
constant	***_cons***	258.60	85.07	3.04	5.88	0.32	18.62

n = 454

Figure 5: Full regression results for Bollworm Cost, Fertilizer cost

		Fertilizer cost (logged)			Bollworm cost (logged)		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
Lagged Dependent	***L1.***	-0.01	0.16	-0.08	0.14	0.10	1.36
Adoption	***bt***	0.21	0.07	2.84	-0.40	0.22	-1.81
Plot size	***plot_sizeacres***	0.01	0.01	1.60	-0.02	0.03	-0.69
Land ownership	***land_own***	0.00	0.00	0.96	0.05	0.02	2.98
Insecticide	***inscost***	0.00	0.00	5.69	0.00	0.00	9.10
constant	***_cons***	5.13	0.93	5.50	4.31	0.93	4.63

n = 458

Figure 6: Full regression results for Household expenditure, Food expenditure

		Household expenditure (logged)			Food Expenditure (logged)		
Label	***Var***	***Coef.***	**Std. Err.**	**Z**	***Coef.***	**Std. Err.**	**Z**
L1.	***L1.***	0.16	0.11	1.48	0.11	0.11	1.06
Adoption	***bt***	0.01	0.08	0.14	0.03	0.06	0.49
Yield	***yldkgs***	0.00	0.00	0.68	0.00	0.00	-1.02
Household size	***hh_size***	0.06	0.01	5.10	0.06	0.01	6.05
Revenue	***revenue***	0.00	0.00	-0.33	0.00	0.00	0.93
Insecticide	***inscost***	0.00	0.00	-1.11	0.00	0.00	-1.46
Age	***age***	0.00	0.00	0.58	0.00	0.00	-0.57
Edu	***edu***	0.01	0.01	0.92	0.00	0.01	-0.30
Plot size	***plot_sizeacres***	0.00	0.01	0.02	-0.01	0.01	-0.80
Land Ownership	***land_own***	0.01	0.00	2.24	0.00	0.00	1.43
time2	***time2***	-0.22	0.11	-2.05	-0.16	0.08	-2.16
time3	***time3***	-0.22	0.06	-3.37	-0.07	0.05	-1.33
constant	***_cons***	9.01	1.29	7.00	9.13	1.17	7.81

n = 458

Tests for Joint Significance

Figure 6: Dependent: l*hhexp;* test *bt yldkgs revenue*

(1) bt = 0
(2) yldkgs = 0
(3) revenue = 0

chi2 (3) = 1.75
Prob > chi2 = 0.6256

Dependent: *lfood:* test *bt yldkgs revenue*

(1) bt = 0
(2) yldkgs = 0
(3) revenue = 0

chi2 (3) = 1.14
Prob > chi2 = 0.7663