WPS5896

Policy Research Working Paper 5896

Cotton, Biotechnology, and Economic Development

John Baffes

The World Bank
Development Economics
Development Prospects Group
December 2011

Policy Research Working Paper 5896

Abstract

During the past decade, cotton prices remained considerably below other agricultural prices (although they recovered toward the end of 2010). Yet, between 2000–04 and 2005–09 world cotton production increased 13 percent. This paper conjectures that biotechnology-induced productivity improvements increased supplies by China and India, which, in addition to keeping cotton prices low, aided these countries to cap-ture market share from (and cause losses to) non-users of biotechnology. By contrast, with a single exception, Africa has not adopted biotechnology and, not coincidentally, its cotton output declined by more than 20 percent between the first and second half of the past decade. The paper concludes that the development implications of biotechnology go beyond cotton and Africa. High energy prices have been an important driver of the recent commodity price boom. Therefore, investment and policy strategy responses to a cost-driven boom should be consistent with cost-saving alternatives. Biotechnology clearly meets this challenge.

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Cotton, Biotechnology, and Economic Development

John Baffes
THE WORLD BANK
jbaffes@worldbank.org

KEY WORDS: Biotech cotton, cotton prices, agriculture prices

This was prepared under auspices of the UK-supported Global Trade and Financial Architecture project. The views expressed are personal and should not be attributed to the World Bank. I would like to thank Ataman Aksoy, Jock Anderson, Armelle Gruère, Tassos Haniotis, Bernard Hoekman, Melinda Smale, and Terry Townsend for comments and suggestions on earlier drafts. Comments by seminar participants at the International Monetary Fund (March 01, 2011) and a meeting with staff of the International Food Policy Research Institute (March 17, 2011) are greatly appreciated.

Cotton, Biotechnology, and Economic Development

Although agricultural commodity prices may diverge from each other for short periods of time, they are expected to converge over the longer term since they respond to the same fundamentals and exogenous shocks. Moreover, when supply and demand conditions force prices to deviate, producers will shift land and other resources from lower- to higher-priced crops while consumers will shift from higher- to lower-priced products, thus balancing the market and inducing price convergence. Yet, during the past decade, the cotton market defied that logic. Between 2000-04 and 2005-09, the real agricultural commodity price index increased by 38 percent while real cotton prices declined 4 percent (figure 1). More surprisingly, world cotton production increased 13 percent. That is, despite declining cotton prices and sharply increasing prices of competing crops, growers supplied more cotton. Why?

The cotton market has been subjected to considerable domestic support which encouraged more production, thus exerting downward pressure on world prices. While the effect of subsidies has been a hotly debated subject, the literature review discussed in Appendix A reveals that such effect is in the order of 10 percent; that is, cotton prices are 10 percent lower than what they would have been in the absence of domestic support. This is a relatively small impact which by no means accounts for the large deviations between cotton and other agricultural prices—especially if one takes into account the fact that other commodity sectors have been subjected to policy distortions as well.

For the most part, the gap between cotton and other agricultural prices is explained by the use of biotechnology. Indeed, econometric evidence presented in Appendix B shows that the historical strong co-movement between cotton and other agricultural prices began weakening during the early part of the past decade and such weakening is explained by the use of biotechnology, especially by China and India. In other words, biotechnology-induced productivity improvements by China and India generated supply response which was large enough to keep cotton prices in check.

Between the first and second half of the past decade, China and India increased their combined cotton production by 47 percent (table 1). During the same period, cotton production in the rest of the world declined 7 percent while it declined 22 percent in Africa—not coincidentally, Africa did not adopt biotech cotton varieties. In short, early (and heavy) users of biotech cotton increased their market share at the expense of—and causing welfare losses to—non-users of biotechnology.

This paper examines the deeper reasons behind the uneven adoption of biotechnology in the cotton market. The next section places biotechnology in the context of the global cotton market and reaches the following conclusions. First, some countries have reached full conversion to biotech cotton while others have not introduced the necessary legal and regulatory framework. Second, when cotton biotechnology is introduced, conversion takes place quickly. Third, the benefits appear to be relatively large, especially in developing countries where between 15 and 20 percent yield increases and 50 percent reduction in insecticide use have been observed. Section 2 discusses the reasons surrounding the biotech controversy and notes that opposition to biotechnology not only has blocked its adoption in Africa and other low-income countries, but also may have slowed down the development of second generation technologies. Section 3 explains how Africa missed the opportunity to embrace the technology. The last section concludes and discusses policy implications and lessons that go beyond cotton and Africa.

1. Biotechnology and the cotton market

As in most aspects of life, the rules of allocating non-free resources are dictated by market forces or battles. Crops, including cotton, are no exception. Humans grow cotton for clothing while insects use it for food. Cotton growers win the battle by spraying the cotton plant with toxins. When the insects attempt to eat the plant (and, hence, the toxin), they die before inflicting irreversible damage. Here is where biotechnology comes in handy. Instead of the grower spraying the cotton plant, the toxin is inserted in the plant by genetically modifying the seed—a process similar to human vaccination.

Early stages of biotechnology made use of a family of soil organisms called *Bacillus thuringiensis* (Bt) that produced certain toxins. Research by several public and private institutions in the early 1980s focused on inserting the Bt gene into tobacco plants. While initial results had limited success, a major breakthrough was achieved in 1988 by Monsanto—a biotechnology company—and by 1990 the first Bt cotton varieties were commercialized (see Tripp 2009 for an extensive discussion of the development of biotech cotton varieties).

Biotech cotton was introduced commercially in 1996 in Australia, Mexico, and the United States. China followed suit a year later and so did Argentina and South Africa in 1998. As of 2009, 10 countries have used the technology, accounting for more than half of world cotton area and 55 percent of production, a figure that may be higher if one accounts for illegal use of biotech varieties—illegal biotech is widespread in Pakistan as it was the case in India a few years ago.

At least three countries have adopted fully biotech cotton (Australia, South Africa, and the United States). Argentina, China, Colombia, India, and

Mexico are heavy users as well where biotechnology accounts for two-thirds of cotton area. Brazil, which introduced the technology in 2006, currently allocates 20 percent of cotton area to biotech varieties. In Burkina Faso, almost one-third of its cotton area was under biotech varieties in the first year of its commercial release (table 2). At a global level, James (2009) reported that as of 2009, 29 countries had used biotechnology. Soybeans accounted more than half of global biotech area (52 percent), followed by maize (31 percent), cotton (12 percent), and canola (5 percent). Several other commodities are also using biotech seeds but their share in total biotech area is very small.

Because of high R&D expenditures, biotech seeds are more expensive than conventional ones. At the outset, if the costs of buying these seeds are lower than the savings realized due to fewer chemical applications, biotechnology will displace conventional seed technology. Otherwise, the technology will be abandoned. So far, it appears that the former is the case.

While the costs of the biotechnology are straightforward in the sense that they only reflect the costs of purchasing seeds, the benefits are more complex to evaluate because they are affected by several factors that go beyond the reduction in the number of chemical applications. To see this consider the following, purely hypothetical, scenarios (table 3). Suppose that growing one hectare of cotton requires 10 chemical applications at a cost of \$50 each or a total of \$500. Assuming yield of one ton of lint per hectare priced at \$1.50/kg, it would imply revenue of \$1,500 and a profit of \$1,000. If the use of biotech seeds (at the cost of, say, \$150 per hectare) reduces the number of chemical applications to 5, it increases the grower's profit to \$1,100, associated with an incremental net gain of \$100 (the difference between \$1,100 and \$1,000), which is the incentive to switch to biotechnology. Assume now another scenario whereby the use of insecticides is sub-optimal, with an effectiveness-equivalent of say, 5 applications per season, in turn achieving half the yield compared to the 10-application scenario, generating revenue of \$750 per hectare, with a profit of \$500.[1] If biotech seeds are used, in which case the 5 applications per season become optimal, the profit increases to \$1,100 (same as in the earlier scenario), generating an incremental net gain of \$600 (the difference between \$1,100 and \$500).

Thus, the adoption of biotechnology can be viewed as a move along the production possibilities frontier (scenario I) or a move to the production possibilities frontier (scenario II) depending on whether optimal or sub-optimal use of

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[1] The notion of sub-optimality used here is much broader than fewer chemical applications. It could include other aspects such as use of low quality chemicals, not spraying the right time, the proper amount, or the required type. These are common problems in developing countries due to poor research and extension services.

chemical applications took place prior to its introduction. In some respects, these two scenarios can be mapped to developed and developing countries where the input intensity may roughly correspond to the numbers used in this hypothetical experiment. Thus, the difference in incremental profit under the two scenarios ($100 *versus* $600), which reflects productivity increases, can be seen as the driving force behind China's and India's adoption of biotechnology and subsequent increase in cotton production.

The pros and cons of biotech cotton (and biotechnology in general) have been discussed extensively in a broad context and in terms of specific costs and benefits, the latter mostly from survey-based research. Despite early signs regarding the benefits of biotechnology, institutions were at first reluctant to engage in the debate (or take an "official position"), not only in terms of policy or financial assistance but also in terms of a general policy discussion. Such reluctance reflected, most likely, the controversial nature of the subject.

Perhaps, the first institutional study to discuss and explicitly acknowledge the broader benefits of biotechnology in developing countries was FAO's 2004 *The State of Food and Agriculture* report, which showed that on balance, biotech cotton growers were better off than growers of conventional seed varieties. Individual authors followed suit. Baffes (2005) argued that in addition to subsidy elimination and domestic policy reforms, adoption of biotech varieties should have been a priority among policymakers in low-income cotton producing countries. Falck-Zepeda, Horna, and Smale (2007) and Anderson, Valenzuela, and Jackson (2008) warned that the downward pressure on world cotton prices caused by the large-scale adoption of biotech cotton is likely to force other countries to adopt the technology in order to compete in the global market.

Numerous survey-based country-specific papers have evaluated the costs and benefits of biotech cotton. An earlier review by Smale, Zambrano, and Cartel (2006) surveyed 47 peer-reviewed articles published between 1996 and mid-2006. While they concluded that the evidence is promising in the sense that biotechnology is beneficial to producers, they also noted that it was too early to reach definite conclusions, in part due to methodological limitations and in part because the longer term economic impact is often shaped by institutional and political considerations the effects of which cannot be discerned within a limited timeframe.

Later reviews, however, reached more definite conclusions. Qaim (2009) summarized the evidence from 11 studies representing seven countries (table 4). The results show that, on average, introduction of biotech cotton varieties is consistent with a 50 percent reduction in insecticide use, 19 percent increase in effective yield and 160 percent increase in gross margin (measured in $US/hectare). Although insecticide reduction varies little among the cases reviewed, there was considerable variation in yield increase (from no change in Australia to 37 percent increase in India). Large variation was reported in the gross margin as well (from a low of $US 23 per hectare in Argentina to a high of $US 470 per hectare in India).

A more extensive review undertaken by Tripp (2009) covered six countries but was based on broader survey coverage (table 5). His results are remarkably similar to those of Qaim (2009). For example, the average reduction in insecticide costs is 41 percent, with relatively little variation among countries. The average change in yields is 15 percent, ranging from a 2 percent reduction in Australia to a 35 percent increase in South Africa.

Gruère and Sengupta (2011) reviewed 51 estimates based on 23 studies that focused exclusively on India and found even larger benefits. They concluded that, on average, use of biotech cotton reduces the number of chemical applications and pesticide costs by 36 percent each, increases yields by 34 percent, raises net returns by 84 percent, while it increases the costs of production by 15 percent.[2]

Numerous other models have evaluated the welfare gains from biotech cotton varieties. Depending on assumptions regarding adoption rates and methodology, global welfare gains range from a low of $1.5 to a high of $3.6 billion annually (see Bouët and Gruère 2011). Welfare gains in Africa vary from a low of $20 million annually (Bouët and Gruère 2011) to a high of $214 million (Anderson, Valenzuela, and Jackson 2008). Again, such range depends on numerous factors including modeling framework, country composition, and more importantly, price assumptions.

2. The biotechnology controversy

Despite its benefits, biotechnology remains a highly controversial subject which becomes evident when considering how unevenly countries responded. Some have fully embraced the technology while others have not even introduced the necessary legal and regulatory framework. From the perspective of high-income countries, the United States and Europe have taken different stances with the United States being the leader in both development and use of biotechnology and Europe taking a cautious approach. Other countries fall into one or the other camp with most African countries taking the precautionary approach.

Graff, Hochman, and Zilberman (2009) argued that adoption of biotechnology has been affected by the alignment of rent seeking behavior that influences the policy-making process. They also note that because companies in the

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[2] It should be noted that some studies appear in more than one review.

United States have a relative advantage in biotech innovation while Europe has dominance in agricultural pest-control markets, biotechnology advanced in the United States while conventional seed technology (which requires higher use of pesticides) dominated Europe. Paarlberg (2008, p. 119) argued that initially, "Europe's precautionary principle had honorable origins" and reflected sensitivities related to environmental problems that took place during the 1970s and 1980s.[3] However, the public opinion in Europe shifted against biotechnology—more so than North America—in part because of pressure by the NGO community (see below). Paarlberg (2008) also noted that, instead of using existing laws and regulations, Europe created a new and very demanding regulatory regime, thus erecting obstacles rather than creating opportunities for development and use of biotechnology.

At the time that governments were engaging in the debate of whether to adopt and how to regulate biotechnology, a strong anti-biotech movement emerged in developed and developing countries alike. For example, following FAO's publication of 2004 *State of Food and Agriculture*, a coalition of 670 NGOs and 816 individuals sent a letter ("FAO Declares War on Farmers not on Hunger") to FAO's Director General expressing their disagreement with the findings of the report and their dissatisfaction because they were not consulted (GRAIN 2004). Interestingly, a year later the *American Agricultural Economics Association* honored a key contributor of FAO's publication with its 2005 Quality of Communication award.

A telling illustration is how opposition to biotech cotton has unfolded in India. Its logic is based on the following arguments. In order for growers to buy biotech seeds they often borrow funds from financial institutions. If the crop fails, they will not have the money to pay back the funds and thus the financial institutions will not lend them again. Then, they turn to private moneylenders. If the crop fails again, the growers will not repay the private lenders, who, in turn, will exert a lot of pressure on the growers. Some growers cannot take such pressure and commit suicide.[4]

Various media outlets argued, often with graphic illustrations, that biotechnology has been the key cause of suicides in the cotton growing areas of India. The issue was picked up by western media outlets as well. The *New York*

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[3] The Forward of Paarlberg's book, *Starved for Science: How Africa Biotechnology Is Being Kept out of Africa,* was written by Norman E. Borlaug (agricultural scientist, often called the father of the green revolution) and Jimmy Carter (former President of the United States). They are both Nobel Peace Prize Laureates (1970 and 2002).

[4] Although the logic of these arguments is correct, the probability of each event occurring (conditional on occurrence of the previous event) becomes progressively low, especially in view of the spectacular performance of the Indian cotton sector during the relevant period.

Times published the article "On India's Farms, a Plague of Suicide" on September 19, 2006 while the TV channel PBS aired the episode "The Dying Fields" on August 28, 2008. On the more sensational side, reports have gone as far as naming India's cotton growing region the "suicide belt" (a term borrowed from the "cotton belt" in the United States). Gruère, Mehta-Bhatt, and Sengupta (2008) reviewed the Indian cotton biotechnology industry in detail and focused on the suicide issue. They concluded as follows (p. 38): "*Therefore, it is not only inaccurate but simply wrong to blame the use of Bt cotton as the primary cause of farmer suicides in India. In fact, our overview of the evidence suggests that Bt cotton has been quite successful in most states and years in India, contributing to an impressive leap in average cotton yields, as well as a decrease in pesticide use*."

Herring (2008) argued that biotechnology has been subjected to framing by its opponents for at least two reasons. The first reason has to do with the possibility that biotech seeds may, in the future, incorporate "terminator technology". In other words, plants from biotech seeds will not be able to reproduce thus raising fears that the entire food system would be dominated by multinational corporations which may manipulate the biotech seed market. Second, biotechnology has been stigmatized because the introduction of the insect-resistant trait into plants involved genetic engineering.

The logic behind the first argument is, at best, weak and, at worse, flawed simply because the "terminator technology" concern can be applied to all aspects of modern agriculture (or any other sector of the economy for that matter). Most of today's agricultural production depends on commercial inputs such as irrigation equipment, fertilizers, chemicals, fuel, electricity, tractors, and trucks, which certainly do not have the ability to reproduce—in fact, most of these inputs have been instrumental for the success of the green revolution. If some (or, even one) of those inputs are not available, output from commercial agriculture will disappear. While there may be imperfections in the way in which some of these markets function, there are plenty of companies willing and able to supply these inputs and no concerns have been expressed that the markets of, say, fertilizers or tractors have been subjected to manipulation. It is unclear why the biotechnology industry will act any differently compared to all other input-supply industries. But, even if the industry acted in a worrisome manner, regulation to ensure that anticompetitive behavior does not take place or funding of public research institutions to supplement private research would prevent likely problems.

Yet, the framing has been successful, in large part because of the way in which biotechnology was marketed. Biotechnology was commercialized in the mid-1990s as a genetically-engineered technology with the stated objective of increasing yields and generating higher profits for farmers in developed countries. However, at that time consumers were becoming more sensitive to food health and environmental considerations, they were shifting to organic products, and they were becoming aware of the negative impact of OECD agricultural subsidies on producers of low-income countries—the latter became apparent during the failed attempt to launch what would have been the Seattle-round of trade negotiations in December 1999. In short, a "transgenic", "genetically modified", or "genetically engineered" product was promoted at a time when consumers were already tuned to "organic", "fair trade" and "environmentally sustainable" products.[5] Indeed, in 2004, the author met with two senior managers of a seed company, one of whom strongly believed that the negative reaction against biotechnology reflected, for the most part, its name. He argued: "*Unfortunately, the name [transgenic crops] was left up to the engineers. In retrospect, it appears that cultural anthropologists or sociologists could have assisted the industry with a much better choice of name.*" He further noted that "biotech cotton" or "enhanced seed technology" would have been much better alternatives.

3. The collateral damage

Despite organized opposition, India's use of biotech cotton increased every single year since its introduction in 2002 and by 2009 had reached 80 percent adoption rate. Biotech cotton was initially used in India on an illegal basis. And, according to Herring (2007), it was the illegal use of biotech seeds that pushed the Indian government to put the legal and regulatory framework in place and eventually approve cotton biotechnology. In China, biotech cotton's share reached 70 percent in 2009. Between the first and second half of the past decade cotton production in China increased 31 percent with similar contributions from yield increases and area expansion (figure 2). India experienced a 51 percent output increase during this period, with yield increases contributing almost three-quarters to that expansion. These yield increases are in line with the ones reported in the literature reviews. Today, these two countries dominate the global cotton market, accounting for half of world's cotton output, up from one-third during the 1990s.

Cotton production in Africa declined 22 percent (17 percent due to area contraction and 5 percent due to yield losses). It was only in 2008 that Burkina Faso introduced the technology and the second year almost 30 percent of its cotton area was under biotech varieties. James (2009) estimated that biotech cotton in Burkina Faso is likely to generate economic benefits of about US$100 million per annum, based on yield increases and reductions in chemical applications experienced elsewhere. Again, these gains are very much in line with the benefits

[5] Not surprisingly, opponents of biotechnology took the name issue to extremes by calling biotechnology products "death seeds", "seeds of suicide", "frankencrops", and "frankenfoods".

reported in the literature discussed earlier. Anderson and Valenzuela (2007) showed that the benefits from full adoption of biotech cotton varieties by African cotton-producing countries could be even greater than the benefits of the removal of all cotton subsidies by the United States and the European Union.

In view of these gains, a simple (and relevant) question is what if Africa had matched India's and China's cotton expansion record during the past decade? Africa's output would have been 2.1 million tons instead of 1.1 million tons. Even at the past decade's low prices of $US 1.30/kg, that would have generated an additional $US 1.3 billion in export revenues per year. Moreover, if the realignment of cotton prices with other agricultural commodities that began during the second half of 2010 persists, the additional revenue could top $US 2.0 billion.[6] While such gains would have required other policies and investments to have taken place as well, they are so large that officials and policy makers in charge of agricultural policies and investment strategies should take notice.

Yet, concerns regarding biotechnology have been expressed at high levels of policy making in many African countries. For example, Uganda's Cotton Development Organization—the regulatory body of the cotton industry—chose to proceed cautiously by examining the pros and cons of this technology despite Cotton Research Institute's repeatedly emphasis on the need to venture into the area of biotechnology (Baffes 2009). Similarly, Zambia's cotton development trust attempted to set up the institutional structure and eventually introduce biotech cotton but the President of the country halted its activities, in response to pressure by various groups, including the Council of Churches. It was only in 2010 that the subject of biotechnology re-emerged in the public policy making arena (Yagci and Aksoy 2011).

Many authors have noted that Africa's precaution with biotechnology reflects more external influence rather than domestic concerns. For example, Paarlberg (2008) argued that the views regarding biotechnology of some African countries and their subsequent actions have been influenced directly or indirectly by many European governments or their citizens through mechanisms which include financial and technical assistance, activities through international organizations, NGO activity campaigns, and import marketing arrangements.

Regardless of the nature, origins, and degree of the opposition to biotechnology, commodity markets—and, perhaps, development—have been affected in at least two ways. First, because of the opposition, biotechnology adoption by developing countries was limited; ironically, that is where the technology turned

[6] To put these gains into perspective, consider that during 2009 IDA (International Development Association) net inflows to Africa were $US 3.2 billion while ODA (Official Development Assistance) flows reached $US 28 billion.

out to be most effective and is most needed. Second, the opposition may have slowed down the development of second-generation biotechnology since private companies are unwilling to invest in relevant R&D technologies because of uncertainty while publicly-funded (national and international) institutions limit their engagement in biotechnology-related research due to inadequate funding.

4. Conclusions and Policy Implications

During the second half of the past decade, commodity prices experienced the broadest and most sustained post-WWII boom. However, cotton prices remained stagnant—though they recovered towards the end of 2010. This paper conjectured that cotton prices were kept in check in large part due to biotechnology-induced expansion of supplies by China and India. Yet, Africa has a poor record not only in terms of biotech adoption but also in terms of having the necessary legal and regulatory framework in place. Only one African country—Burkina Faso—had utilized biotechnology as of 2011. Not coincidentally, the region's cotton industry has performed poorly. Between the first and second half of the past decade Africa's cotton output declined 22 percent. World cotton output increased 13 percent—India and China increased their production by 51 and 31 percent, respectively.

Against this background, this paper highlighted a number of stylized facts. First, the use of the technology at a global level has increased on a continuous basis since it was first introduced 15 years ago—on average, each year an additional 4 percent of global cotton area is converted to biotech varieties, and, with a few exceptions, this has been the case at the country level as well. Such adoption rates imply that biotechnology is cost-saving to producers (since they adopt the technology), it is welfare improving to consumers (because they buy cotton at lower prices), it is profitable to the seed companies (since they expand their business), and it is beneficial to the environment (because of less chemical applications). On a global basis, the use of biotech cotton varieties implies a 40-50 percent reduction in chemical applications and 15-20 percent increase in yields with relatively larger benefits accruing to cotton growers of developing countries. Second, if historical trends continue, almost all cotton will come from biotech varieties within a decade. Third, in addition to the legal and regulatory framework, the largest obstacle to introduce the technology appears to be political will. When the technology is introduced it takes off quickly, including in low-income countries such as Burkina Faso—the only African country to embrace the technology.

Despite such adoption rates and cost/benefit record, biotech cotton is still surrounded by controversy. The most ferocious debate takes place in India where numerous reports in the local (and international) press and other news outlets have argued repeatedly and continuously that biotech cotton is the key cause of suicides among cotton growers in the so-called "suicide belt", despite strong evidence to the contrary. While such opposition did not prevent India from utilizing the technology, it has caused irreversible damage elsewhere, especially in Africa.

Such outcomes not only expose a gap between developmental objectives and results on the ground but also give some valuable lessons. On the one hand, cotton growers in the United States and Europe received a considerable amount of domestic support and, in the former, access to biotechnology. On the other hand, emerging countries such as India and China gained access to biotechnology (despite strong opposition in the former) and on some occasions support. At the other end of the spectrum, African cotton growers not only did not use biotechnology or support but also were not given the opportunity to evaluate the technology (even worse, on some occasions they were taxed). All this has led to the following paradox: African countries such as Uganda and Zambia with per capita income of $US 1,000 not using biotechnology for a raw material destined for exports and high-income countries such as Australia, Canada, and the United States with per capita income of $US 40,000 using biotechnology for domestically consumed food commodities.

The development implications of biotechnology extend beyond cotton. As noted earlier, commodity prices are experiencing one of the broadest and most sustained booms of the post-WWII period. Such increases, which were seen initially as welcome developments, have alarmed government officials and policy makers alike. It is becoming increasingly apparent that although a host of factors fueled the boom, higher production costs due to increases in energy prices have played a key—and, perhaps, the most important—role (Baffes 2011b).

High energy prices will present challenges and, perhaps, transform the way in which agricultural commodities are produced, especially in view of environmental sensitivities. Therefore, investment and policy strategies to a cost-driven boom should be consistent with cost-saving alternatives. Biotechnology clearly meets this challenge. Indeed, researchers (e.g., Thompson 2011) are increasingly recognizing the role these technologies could play not only in alleviating temporary price pressures but also in shaping longer term price trends.

Table 1: Cotton production

	1990-94	*1995-99*	*2000-04*	*2005-09*	*1990-94*	*1995-99*	*2000-04*	*2005-09*
WORLD								
	Thousand tons				*Share of World (%)*			
China	4,483	4,311	5,314	7,269	24.4	22.3	24.9	29.9
India	2,149	2,767	2,864	4,742	11.7	14.3	13.4	19.5
US	3,649	3,708	4,123	3,844	19.9	19.2	19.4	15.8
Pakistan	1,591	1,646	1,869	1,986	8.7	8.5	8.8	8.2
Brazil	556	462	1,013	1,285	3.0	2.4	4.8	5.3
Africa	904	1,316	1,422	1,142	4.9	6.8	6.7	4.7
Uzbekistan	1,356	1,095	994	1,061	7.4	5.7	4.7	4.4
Others	3,692	3,993	3,703	2,952	20.1	20.7	17.4	12.2
WORLD	**18,380**	**19,300**	**21,303**	**24,282**	**100**	**100**	**100**	**100**
AFRICA								
	Thousand tons				*Share of Africa (%)*			
Burkina Faso	65	102	178	210	7.2	7.8	12.5	18.4
Mali	116	194	198	130	12.9	14.8	14.0	11.4
Zimbabwe	55	109	93	105	6.0	8.3	6.5	9.2
Nigeria	54	75	89	91	6.0	5.7	6.3	8.0
Benin	82	144	148	90	9.1	11.0	10.4	7.9
Tanzania	62	59	62	89	6.8	4.5	4.4	7.7
Côte d'Ivoire	101	133	129	68	11.2	10.1	9.1	6.0
Cameroon	51	78	99	63	5.7	6.0	6.9	5.5
Others	317	421	426	298	35.1	31.9	29.9	26.1
AFRICA	**904**	**1,316**	**1,422**	**1,142**	**100**	**100**	**100**	**100**

Source: United States Department of Agriculture (http://www.fas.usda.gov/psdonline)
Note: All figures in this table (and the paper) refer to cotton lint.

Table 2: Area under biotech cotton varieties (percent of area allocated to cotton)

	United States	Australia	Mexico	China	South Africa	Argentina	India	Colombia	Brazil	Burkina Faso	WORLD
1996/07	12.7	7.7	0.8	—	—	—	—	—	—	—	**2.0**
1997/08	25.5	14.0	7.8	0.7	—	—	—	—	—	—	**4.4**
1998/09	45.0	15.4	14.3	2.4	12.0	0.8	—	—	—	—	**6.6**
1999/00	58.7	22.7	12.5	14.2	28.0	3.9	—	—	—	—	**12.1**
2000/01	71.1	30.0	33.4	25.0	24.0	6.1	—	—	—	—	**15.7**
2001/02	76.7	30.0	27.4	32.0	74.0	4.6	—	—	—	—	**18.1**
2002/03	75.4	30.0	37.6	48.7	84.0	8.0	0.5	—	—	—	**20.2**
2003/04	75.1	60.0	41.4	51.6	86.0	10.0	1.1	0.5	—	—	**20.8**
2004/05	78.0	60.0	60.6	59.1	75.0	10.0	6.1	23.0	—	—	**24.3**
2005/06	81.0	90.0	57.4	62.2	84.0	20.0	14.1	40.0	—	—	**28.4**
2006/07	85.4	90.0	59.0	66.6	91.0	25.0	41.5	44.0	0.5	—	**36.5**
2007/08	90.2	95.0	60.0	61.0	95.0	25.0	66.3	57.0	13.0	—	**43.5**
2008/09	92.6	95.0	65.0	65.7	95.0	25.0	74.0	71.0	20.0	1.6	**47.1**
2009/10	95.0	95.0	62.0	68.0	95.0	85.0	79.3	61.0	20.0	30.5	**52.0**

Source: International Cotton Advisory Committee
Notes: '—' indicates that no biotech cotton was used.

Table 3: A hypothetical experiment on the costs and benefits of biotech cotton

	SCENARIO I Optimal use of chemicals		*SCENARIO II Sub-optimal use of chemicals*	
	Conventional	***Biotech***	***Conventional***	***Biotech***
Number of sprays/hectare	10	5	5	5
Cost of chemicals, $50/spray	500	250	250	250
Cost of biotech seeds, $	0	150	0	150
Yield, kgs/hectare	1,000	1,000	500	1,000
Revenue, $1.50/kg	1,500	1,500	750	1,500
Profit, $	1,000	1,100	500	1,100
Incremental profit, $	**100 (=1,100 - 1,000)**		**600 (=1,100 – 500)**	

Source: Author's calculations.

Table 4: The economic effects of biotech cotton

	Insecticide reduction (%)	*Effective yield increase (%)*	*Gross margin increase ($US/ha)*	*Number of surveys*
Argentina	47	33	23	2
Australia	48	0	66	1
China	65	24	470	1
India	41	37	135	2
Mexico	77	9	295	1
South Africa	33	22	91	2
United States	36	10	58	2
AVERAGE/SUM	**50 [53]**	**19 [31]**	**163 [303]**	**11**

Source: Qaim (2009), p. 672, Table 1.

Note: The average reported in the last row has been calculated by the author. Numbers in square brackets show the India/China average.

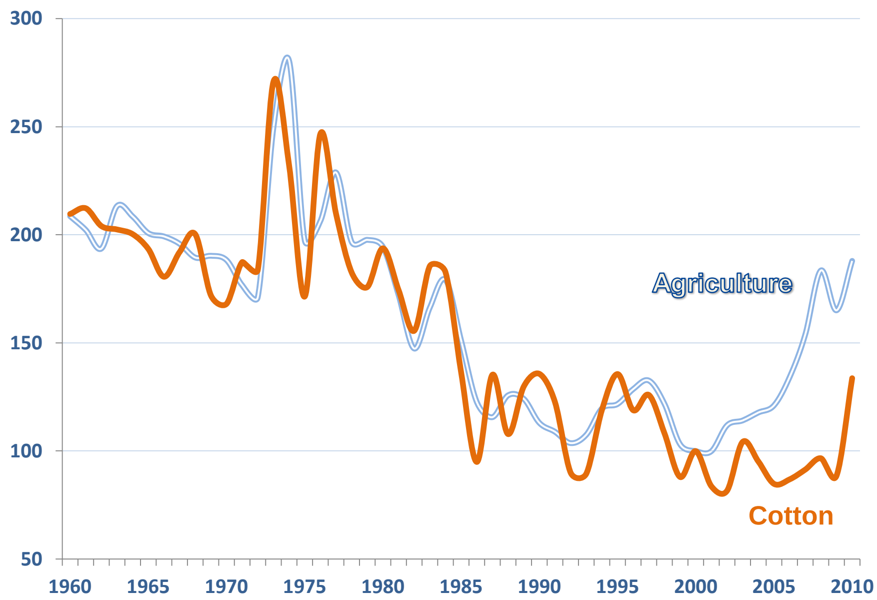
Table 5: Changes in yield and insecticide costs from biotech cotton

	Insecticide cost reduction (%)	*Yield change (%)*	*Number of surveys*
Australia	51	-2	2
China	65	25	3
India	27	15	10
Mexico	77	10	2
South Africa	38	35	9
United States	47	9	1
AVERAGE/SUM	**41 [46]**	**15 [20]**	**27**

Source: Tripp (2009), p. 74, Table 4.1.

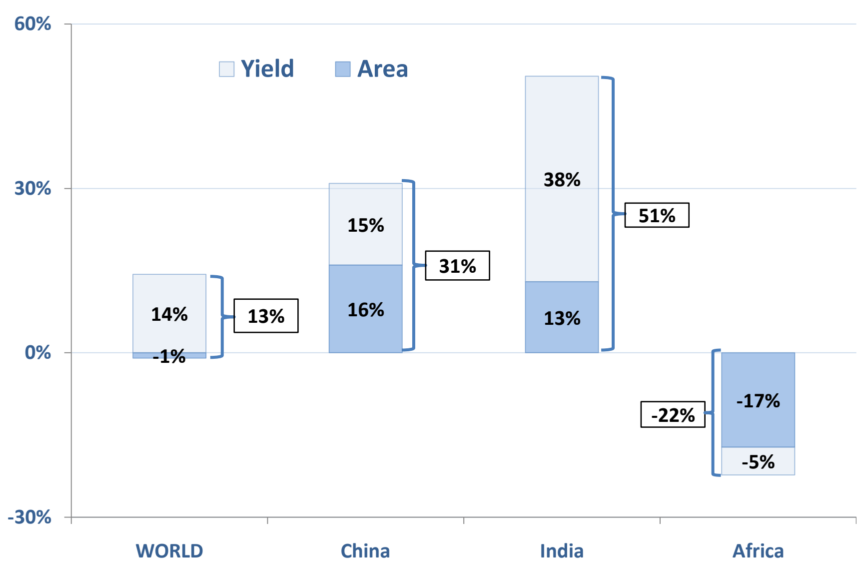
Note: The country averages reported in the last row have been calculated by the author. The original table reports results from individual surveys. Numbers in square brackets show the India/China average.

Figure 1
Agriculture and cotton price indices (Real, MUV-deflated, 2000=100)



Source: World Bank

Figure 2
Production growth decomposition into yield and area, 2000-04 to 2005-09



Note: Growth decomposition has been calculated as: $\log(Q_{2005\text{-}09}/Q_{2000\text{-}04}) = \log(A_{2005\text{-}09}/A_{2000\text{-}04}) + \log(Y_{2005\text{-}09}/Y_{2000\text{-}04})$, where Q, A, and Y denote production, area, and yield.

Source: Author's calculations based on USDA data

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Appendix A
The determinants of the gap between cotton and other agricultural prices

In addition to the biotechnology-induced supply response by China and India, two other factors have contributed to the gap between cotton prices and the broader index of agricultural prices. They are domestic support (with a negative impact on cotton prices) and biofuels (with a positive impact on food commodities). Both are discussed in what follows.

The cotton market has been subjected to considerable domestic support which encouraged more production, thus exerting downward pressure on world prices. Distortions due to subsidies are not limited to the cotton market. Most commodity sectors are affected by import tariffs and many also by domestic supports, export subsidies and export taxes (Aksoy and Beghin 2005; Anderson 2009). During the first half of the past decade, the United States (which accounts for one third of world exports) supported its cotton sector to the tune of $US 2 to 4 billion annually. The European Union provided considerable support as well—around $US 1 billion annually—though applied to much less cotton and hence lower impact on world prices. Numerous other countries subsidize their cotton sectors as well. However, they have received less attention either because their subsidies are small and indirect (e.g., India, Turkey, and some West and Central African countries) or because the accuracy of the statistics has been questioned (e.g., China). See ICAC (2010) for the latest update on cotton subsidies.

The effect of subsidies on the world price of cotton has been a hotly debated subject and the estimates vary widely. After reviewing the literature, Baffes (2005) concluded that a simple average over all models implied that world cotton prices would have been 10 percent higher without support. Sumner (2006) reached a remarkably similar conclusion. Based on evidence from various sources, he found a 10 percent increase in the world price of cotton to be a reasonable estimate if the cotton subsidy programs were removed under the cotton initiative and other farm production subsidies were also reduced substantially. Jales (2010) found that reforms consistent with the December 2008 DDA draft modalities would imply world cotton prices 6 percent higher over 1998-2007 (ranging between a high of 10 percent in 2001 and a low of 2 percent in 2007). Reforms by the United States consistent with full implementation of DSB's recommendations would have increased cotton prices by 3.5 percent (ranging between a high of 6.5 percent 2001 and a low of 1 percent in 2007). The Cotton Initiative goes back to 2002 when four African cotton producers (Benin, Burkina Faso, Chad, and Mali, the so-called C-4) argued that cotton subsidies caused world prices to decline and reduced their export revenue. In turn, the C-4 asked for financial compensation by bringing their case to the WTO. At about the same time, Brazil brought a case against the United States on cotton subsidies (see Baffes 2011b).

The 2006-08 food price boom was partly aided by growth in demand for biofuel production—albeit, much less than originally thought. Although the direct impact of biofuel demand is felt only by maize, sugarcane, and some edible oils, the indirect impact is felt by most agricultural crops, because of the strong substitutability both on the input side and on the output side—especially in animal feed and vegetable oils which are highly substitutable commodities. Because cotton is not a close substitute to any other commodity, there no substitutability on the output side. There is substitutability only on the input side as land allocated to cotton can be used for other crops. But even there, it is quite limited, at least in the short term, because other inputs, primary processing facilities, picking machinery, and other equipement are cotton-specific. Thus, converting cotton land to other crops and *vice-versa* takes more time compared to converting land from, say, wheat to maize. Indeed, between 2000-04 and 2005-09 (two periods that can be viewed as without and with biofuel as well), global area allocated to cotton declined by less than one percent. For example, although cotton area in the United States declined by almost 20 percent during these two periods, global (non-US) cotton area increased by 3 percent. By contrast, maize area (both globally and in the United States) increased more than 10 percent during this period.

Lastly, it should be noted that because cotton competes with synthetic fibers, which are by-products of crude oil, it is often argued that crude oil prices affect cotton prices above beyond the impact through production costs. Baffes (2007) estimated transmission elasticities from crude oil price to the prices of other commodities, including food and cotton. The average elasticity for food commodities was 0.18 while that for cotton was 0.14. Therefore, on that count, cotton does not respond any differently than food commodities.

Appendix B
The divergence between cotton and other commodity prices

Commodity price comovement has been discussed extensively in the literature. Pindyck and Rotemberg (1990) analyzed price movements of seven seemingly unrelated commodities (cocoa, copper, cotton, crude oil, gold, lumber, and wheat) and concluded that these prices co-moved in excess of what the macroeconomic fundamentals could explain. Explanations given included incomplete model, endogeneity, rejection of normality assumption, and bubbles or market psychology. Subsequent research, however, challenged the excess co-movement hypothesis on data and methodological grounds (see Ai, Chatrath, and Song 2006; Cashin, McDermott, and Scott 1999; Deb, Trivedi, and Varangis 1996; and LeyBourne, Lloyd, and Reed 1994). Although historically cotton prices have tracked other agricultural prices very closely, during the past decade, they diverged considerably from each other (figure 1). It is only during the second half of 2010 that the two indices began re-converging.

To evaluate the degree of such divergence, the following regression is used (see also Baffes 2011a):

$$log(P_t^C) = \mu + \beta_1 log(P_t^{AG}) + \beta_2 log(MUV_t) + \beta_3 t + \varepsilon_t. \qquad [1]$$

P_t^C and P_t^{AG} denote the price of cotton and the agricultural commodity price index in year t (both expressed in nominal dollar terms), MUV_t denotes the deflator, t is the time trend, and ε_t denotes the error term; μ, β_1, β_2, and β_3 are parameters to be estimated. The agricultural commodity price index consists of 24 commodities, including grains, edible oils, beverages, and raw materials. Cotton's weight in that index is 2.9%. Details regarding composition of indices, weights, and price data can be found at World Bank (2011).

The first two columns of table B1 show estimates for the 1960-2009 and 1960-10 periods, respectively. The exclusion or inclusion of 2010 was motivated by the desire the capture the effect of the recovery in cotton prices that took place during the second half of 2010. The estimate of β_1 is 0.61 (excluding 2010) and 0.66 (including 2010) are highly significant with adjusted-R^2s equal to 0.91 and ADF statistics of -6.03 and -6.21, respectively in turn implying strong comovement between cotton and other agricultural prices.

To examine the divergence between agriculture and cotton prices, [1] was reformulated by introducing a dummy variable, $D = 0$, 1960-2001 and $D = 1$, 2002-2010, applied to both μ and β_1. The break is expected to capture the introduction of biotech cotton in China and India. Hence, [1] becomes:

$$log(P_t^C) = \mu + D + \beta_1 log(P_t^{AG}) + \beta_1 D^* log(P_t^{AG}) + \beta_2 log(MUV_t) + \beta_3 t + \varepsilon_t. \qquad [2]$$

Results from [2] are reported in columns 3 and 4 of table B1. The econometric evidence shows that the long run relationship between the price of cotton and the other agricultural commodities was even stronger up to the early 2000s, but it weakened considerably during the past eight years. During 1960-2002 real agricultural prices were 4 percent higher than real cotton prices (2000 = 100); during 2003-10 the gap widened to almost 60 percent. Even in 2010, when cotton prices enjoyed a spectacular recovery, their annual average was 30 percent lower than the overall agricultural price index. The estimates show that the recent recovery of cotton prices induced some degree of convergence ($\beta_1 D$ increased from -0.51 to -0.34 when the observation for 2010 is included).

Lastly, [1] was re-estimated by adding biotech cotton area as a share of global cotton area, B_t^{SHARE}, as follows.

$$log(P_t^C) = \mu + \beta_1 log(P_t^{AG}) + \gamma B_t^{SHARE} + \beta_2 log(MUV_t) + \beta_3 t + \varepsilon_t. \qquad [3]$$

Results from [3] are reported in the last 2 columns of table B1. As in [1] and [2], the adjusted-R^2s are very high and the ADF statistics confirm stationarity of the error term at 1% level of significance. The estimate of β_1 is 0.85 and highly significant, remarkably similar to the estimate of regression [2]. The parameter estimate of the biotechnology share, γ, was negative and highly significant in both regressions, implying that biotechnology accounts for the post-2000 gap between cotton and other agricultural prices. Interestingly, the parameter estimate of the time trend—used as a proxy of technical change differential between cotton and other agricultural commodity sectors—is not significantly different from zero. This should not be surprising because the share of land allocated to biotechnology is, indeed, the best proxy for technical change.

To conclude, the econometric evidence shows that while for the 4 decades staring in 1960 cotton and other agricultural prices moved in a synchronous manner, they began diverging in the early part of the past decade. Such divergence is accounted for by the use of biotech cotton. The next section places biotechnology in the context of the global cotton market.

Table B1: Comovement between cotton and agricultural commodity prices

	[1]		[2]		[3]	
	1960-2009	1960-2010	1960-2009	1960-2010	1960-2009	1960-2010
μ	-0.23 (1.14)	-0.23 (1.14)	-0.02 (0.07)	0.02 (0.05)	0.39 (1.29)	0.17 (0.61)
D			2.32** (2.63)	1.47* (1.68)		
β_1	0.61*** (5.97)	0.66*** (6.34)	0.87*** (7.62)	0.89*** (7.34)	0.85*** (6.62)	0.86*** (6.64)
$\beta_1 D$			-0.51*** (2.80)	-0.34* (1.86)		
γ					-1.11*** (4.40)	-0.80** (2.27)
β_2	0.67*** (5.16)	0.60*** (4.49)	0.26 (1.63)	0.22 (1.31)	0.16 (0.80)	0.20 (0.97)
$100*\beta_3$	-2.29*** (7.31)	-2.11*** (6.29)	-0.97* (1.84)	-0.86 (1.52)	-0.35 (0.58)	-0.63 (0.96)
$Adj\text{-}R^2$	0.91	0.91	0.93	0.92	0.93	0.92
ADF	-6.03***	-6.21***	-7.17***	-7.00***	-7.01***	-6.78***

Source: Author's estimates based on World Bank (prices) and International Cotton Advisory Committee (cotton biotechnology area.)

Notes: The dependent variable is the logarithm of cotton price. The numbers in parentheses denote absolute *t-values* while asterisks denote parameter estimates significant at 10 percent (*), 5 percent (**) and 1 percent (***) levels, respectively. ADF is the Augmented Dickey-Fuller (Dickey and Fuller 1979) statistic for unit root and corresponds to the MacKinnon one-sided *p-value*. The lag length of the ADF equations was determined by minimizing the Schwarz-loss function. The standard errors and covariance matrix have been estimated in a heteroskedasticity-consistent manner using White's method.