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SOCIOECONOMIC IMPACT ASSESSMENT OF THE DIFFUSION OF GM COTTON CULTIVARS IN BRAZIL

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RESUMO

The aim of this paper is to assess socioeconomic impacts of GM cotton seed adoption in Brazil. Based on an analysis of pooled data and panel data from 157 farms was estimated a cotton production function for the state of Mato Grosso. The results indicate that the adoption of herbicide tolerant (Ht) GM cotton causes insignificant impacts on yield and significant impact on gross operating margin of the farmers. In the case of the adoption of insect resistant (Bt) GM cotton, the results suggest that the evidences are not sufficient to affirm that the productivities and the gross operating margin differ among Bt cotton seeds and conventional seeds. Regarding the dynamics of pesticide use, the present study confirms the findings of Seixas and Silveira (2014) and indicates that the adoption of GM cotton in Brazil impacted the number of insecticide applications, but does not significantly impact the number of herbicide applications. It is argued that the representative structure of cotton production in Brazil is completely different from all others observed in previous meta-analysis of GM impacts, such as Carpenter (2010) and Klumper and Qaim (2014). The majority of Brazilian cotton is held in large areas of cultivation owned by commercial farms. One can therefore expect that the slower pace of GM cotton diffusion in Brazil is not associated with a lack of information of the farmers, but rather by the deep knowledge that the agents holds on pest control methods. Although Brazil holds the second position in the global ranking of GM crop area, there are few assessments about the impact on agriculture biotechnology diffusion in the country.

Palavras-chave: Agriculture. Technological Innovation. Biotechnology.

ABSTRACT

O objetivo deste artigo consiste em acessar o impacto socioeconômico resultante da adoção de algodão geneticamente modificado no Brasil. Para isso, foram estimados modelos econométricos com dados empilhados (pooled) e com dados em painel (efeitos aleatórios) a partir de uma amostra com 157 fazendas produtoras de algodão no estado de Mato Grosso. No caso das sementes

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tolerantes a herbicida, não há evidências suficientes para afirmarmos que a produtividade destas difere quando comparadas às sementes convencionais. Na avaliação econômica, as sementes tolerantes a herbicida apresentaram vantagens em termos de margem operacional bruta. Quanto aos impactos produtivos e econômicos decorrentes da adoção de sementes resistente a insetos, não há evidências suficientes para afirmarmos que a produtividade e a margem operacional bruta diferem entre as sementes resistentes a insetos e as convencionais. Com relação a dinâmica de uso de pesticidas, o presente estudo reafirma os achados de Seixas e Silveira (2014) e indica que a adoção de algodão transgênico tem impacto sobre a aplicação de inseticidas, mas não demonstrou impacto significativo sobre o número de aplicações de herbicida. Argumenta-se que a estrutura do setor produtivo representativa do estado de Mato Grosso é completamente diferente das analisadas em metanálises prévias sobre o tema, como as desenvolvidas por Carpenter (2010) e Klumper e Qaim (2014). Pode-se, portanto, esperar que a maior lentidão do processo de difusão esteja associada não à falta de informação dos agricultores, mas ao contrário, pelo conhecimento profundo que detém sobre métodos de controle de pragas do algodão e que, portanto, ponham seu foco nos ganhos de produtividade e rendimento quando decidem adotar novas tecnologias. Embora o Brasil ocupe a segunda posição no ranking global de área com cultivos geneticamente modificados, há poucas avaliações sobre o impacto da difusão da biotecnologia agrícola no país.

Keywords: Agricultura. Inovação Tecnológica. Biotecnologia.

INTRODUCTION

A genetically modified (GM) crop is one in which genes with desirable characteristics are inserted into the plant via genetic engineering processes, and in turn is utilized for agricultural means. These genes can originate from either the same species of plant or from different organisms. Basic genetic engineering techniques for plants were developed at the beginning of the 1980s, and the first genetically modified cultures were approved for commercial use in the mid-90s.

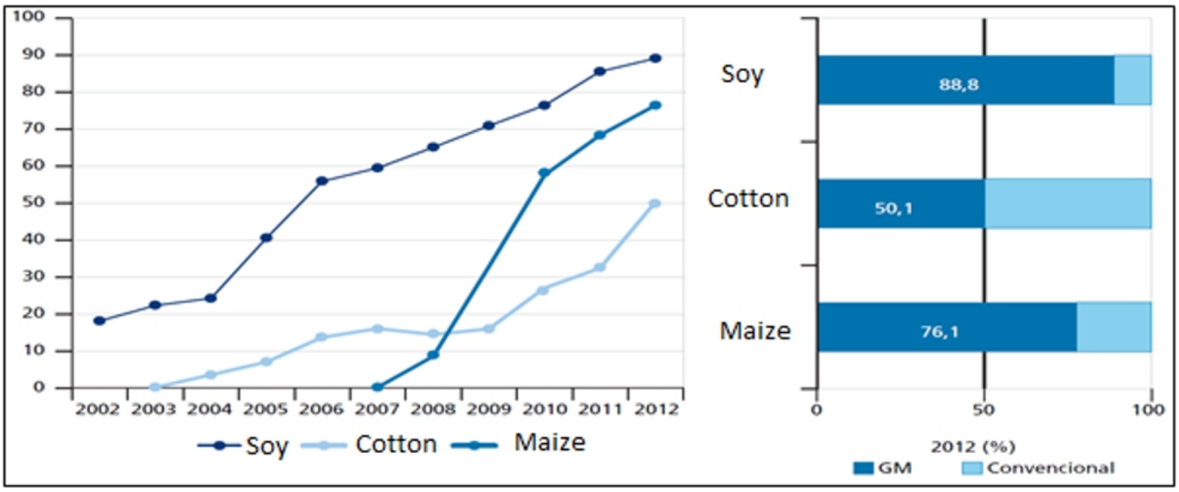
Globally speaking, the cultivated area of transgenic crops increased more than a hundredfold between 1996 and 2013, from 1.7 million to 175 million hectares. For instance, around 18 million rural producers started using transgenic seeds in 2013. These observed levels of diffusion make transgenic seeds the most successful agricultural technology in recent decades. The five biggest countries in GM cultivated area- U.S.A., Brazil, Argentina, India and Canada - holds 97% of the area with GM seeds worldwide. From a different perspective, James (2013) highlights that around 90% of the farmers adopting GM seeds (16.5 million farmers) are located in developing countries. Therefore, agricultural biotechnology markets are substantially composed by the demand from farmers at developing countries.

The number of publications to assess the socioeconomic and environmental impacts of GM crops evolved in the same pace and quantity to the diffusion of these innovations. In this context, Qaim (2009), Finger et al. (2011), Barrows et al. (2014) and Klumper and Qaim (2014) conducted meta-analysis of the studies which assessed the impacts of GM seeds in many countries. Roughly speaking, the analysis indicated that the adoption of GM seeds resulted gains in productivity and profitability, especially for farmers in the developing countries.

GM seeds have been available in Brazil since the mid 1990s, by the entrance of GM soybeans in the South region. The year of 1998 marked the first commercial approval of a plant biotechnology event in the country. However, there was only after the Law nº 11.105/2005 (New Biosafety Law) that safety standards and enforcement mechanisms for the construction, cultivation, production, handling, transportation, transfer, import, export, storage, research, marketing, consumption, release into the environment and disposal of genetically modified organisms and their derivatives were defined in Brazil. The new biosafety law enforces the Brazilian National Biosafety Technical Committe (CTNBio) as the exclusive and final jurisdiction to judge risk assessment and so, assess the safety of GMOs and biotechnology products in Brazil, under the aspect of human, animal and environmental health. Yokoyama (2014) presents a timeline of interim measures set forth by Brazilian Federal Government aiming the regulation of imported GM soybean seeds cultivation and commercialization, prior to the establishment of the new biosafety law in 2005.

Since the very first approval of GM soybean in 1998, CTNBio has approved a total of 30 new plant biotechnologies, divided in 5 events for soybean, 12 events for cotton, 29 events for maize, 1 event for bean and 1 event for eucalyptus. Figure 1 presents the pattern of GM seeds diffusion in Brazil, highlighting the three cultures in which GM seeds are commercialized. Regarding GM soybean, the adoption rate has remained above 90% in the last two harvests. GM Corn has been commercialized since the 2007/2008 season and registered a process of fast diffusion. In this scene, second season corn which is planted in the second harvest using a rotation system with other cultures stood out. In this case, transgenic crops occupied 80% of the cultivated area in a time period of six harvests.

Figure 1: Diffusion pattern of GM seeds in Brazil.



Source: Céleres, 2013.

Figure 1 shows that GM cotton do not follow a diffusion pattern similar to those observed in the other cultures, maintaining a maximum share of 50% of the cultivated area. Motivated by this stylized curve of diffusion, the following research questions were posed: What are the socioeconomic impacts of GM cotton adoption in Brazil? Does GM adoption results in productivity and profitability increase to Brazilian cotton farmers? The answer to this question does not aim to conclude the discussion about the determinants of GM cotton adoption, but provides important evidences for future studies to stand on. Additionally, the paper is intended to contribute as an input for decision makers in the seed supply and farming sectors.

In pursuit of the goals set the article is divided in five sections. After the introduction, the following section will provide a literature review on GM impact assessment. For means of simplification, the literature review is concentrated on empirical studies for the assessment of GM economic impacts at the farm level. Section 2 will present stylized facts about cotton crops in Brazil, with an emphasis on the time period in which the crop was reintroduced into the country (the mid-90s) and the structure of the cotton seed market. This period is described as a *sui generis* case regarding the resurgence of cotton farming in production systems that are completely distinct from those used in the country before that time. Section 3 of the article will present the impact assessment methodology, which is based on econometric model estimations of pooled and panel data. The item also comprises a brief description of the panel methodology adopted for primary data collection. Section 4 will present the statistics described in the sample and discuss the principle results of the econometric models. Section 5 will present the main conclusions regarding GM cotton economic performance and adoption. The results confirm the hypothesis that the weak diffusion of genetically modified cotton seeds in Brazil reflects the reduced economic impact of these seeds when compared to conventional seeds.

INNOVATION DIFFUSION IN AGRICULTURE AND THE SOCIOECONOMIC IMPACTS OF GENETICALLY MODIFIED SEEDS

Improved seeds are at the centre of defining strategies aimed at the appropriate intensification of the use of land by small farmers; farmers that are risk averse, due to the low adoption costs and divisibility of the seeds (BARRET, 1996). The first wave of GM crops to be commercialized has embodied traits intended to improve pest management and therefore reduce or eliminate losses from insect damage or weed competition. These technologies do not raise yield potential, but they can improve yields substantially owing to improved pest and weed management (CARPENTER, 2010).

Klumper and Qaim (2014) conducted a meta-analysis of publications that evaluated the impacts of GM crops on crop productivity, the use of pesticides and / or profitability of farmers. For this purpose, studies were identified through lexicographical searches based on keywords in the ISI Web of Knowledge, GoogleScholar, EconLit, and AgEcon Search. The works were only sampled if they were grounded on primary data of the agricultural firm or field trials. In total were identified 147 studies with a predominance of primary assessments at developing countries. On average, results indicate that the adoption of GM technology has reduced the use of chemical pesticides by 37%, increased crop yields by 22% and increased profits for farmers by 68%. Moreover, yield gains and pesticide reductions are larger for insect resistant crops than for herbicide tolerant crops. From another perspective, the authors indicate that productivity and profitability were higher in developing countries than in developed countries. The difference is justified by the fact that farmers in developing countries use inefficient techniques of pest management and control of weeds and thereby leverage the impacts of GM seeds. Therefore, conclusions about impacts that are based on aggregate ratings do not capture the specificities of soil, climate and structural conditions of each country or even region.

Since the beginning of its diffusion, genetically modified cotton seeds have generated economic benefits such as reducing use of pesticides, better pest control and productivity increases. Those benefits have been achieved in countries like China (PRAY et al., 2001), India (QAIM; ZILBERMAN, 2003; BENNET et al., 2004; MORSE et al., 2005) South Africa (THIRTLE et al., 2003; GOUSE et al., 2003) and Pakistan (ALI; ABULAI, 2010). In these countries, productivity increases generated by Bt cotton seeds were directly converted into higher net benefits for farmers.

Besides productivity, the size of those benefits has depended on the weight of Bt cotton seeds and pesticide use in the total cost of production. In general, the higher prices charged by the GM seed have been compensated by the cost reduction with low pesticide use. Therefore, Bt cotton adoption has generated reductions in the total cost of production. However, as observed by Morse et al. (2005), cases of increase in total cost of production attributed to the higher prices charged by Bt cotton seeds may still occur.

In addition to direct economic benefits, there are evidences that the reduction in insecticide use caused by the adoption of Bt cotton is also generating benefits for the environment and the health of farmers. In China, where it is common to use backpack sprayer application, Bt cotton adopters have reported fewer cases of pesticide contamination than those who grew conventional seeds (PRAY et al., 2001; PRAY, 2002).

Qiao (2015), using econometric model of panel data, found that the economic benefits generated by the adoption of Bt cotton remained stable or even increased over the years in China. Kathage and Qaim (2012) showed that Bt cotton productivity gains in India remained stable between 2004 and 2008. Considering a period of fifteen years of adoption (1997-2013), Qiao (2015) found that Chinese producers have sprayed less pesticides and obtained higher yields in the final years of adoption when compared to earlier years. Using a dynamic analysis, both studies indicate that the positive impacts of Bt cotton seeds are neither restricted to the early years of the adoption nor the short term.

Unlike what happens in the case of insect resistance technology, few studies on the economic impacts of herbicide tolerant cotton adoption have been carried out worldwide. In Brazil, Alves et al. (2012) evaluated the economic performance of herbicide tolerant cotton over conventional seed. Alves et al. (2012) affirmed that GM cotton with glufosinate tolerance (Ht) was found ease of handling for weed control when compared to the conventional seed. In terms of profitability, the adoption of Ht cotton seeds presented a return of 3.4% to 10.2% higher than conventional varieties. The results showed that the total cost of production was lower for the Ht cotton compared to the conventional cotton. This occurred because GM cotton demanded lower expenses with herbicides, mechanical operations, manual weeding and labor. As consequence, the gross margin of herbicide tolerant cotton adopters was higher, despite having not occurred differences in productivity (yield) and sales price between GM and conventional cotton.

The type and magnitude of the impacts of transgenic seeds are extremely heterogeneous between countries and regions, particularly due to the different levels of pest pressure and the effectiveness of pest management techniques. Moreover, it is noteworthy that the scarcity of published studies about GM impacts in Brazil is alarming, since the country has the second largest area of GM seeds in the world.

The dynamics of cotton cultivation in Brazil is a *sui generis* case of structural change in a crop production system, marked by the replacement of family farms with low technological intensity by the cultivation in capital intensive commercial farms using modern inputs. The process is marked by the sharp increase of cotton production at the Mato Grosso and the declining of traditional cotton regions such as the Northeast, and the states of São Paulo and Paraná. In the former regions the production was based on small farms, with high use of family labor, low capital intensity and technology adoption. On the other hand, cotton in Mato Grosso is carried out on large farms, with intensive use of modern inputs in all stages of the production process and characterized by no tillage cultivation[1].

At the beginning of the 2000s, the cotton production system in Mato Grosso was successfully transferred to areas of expansion in the Brazilian agricultural frontier at that time. Thus, the "MATOPIBA" region became a productive extension of the business model utilized in the cultivation of cotton in the Central-West. As a consequence of the process described so far, the state of Bahia went from holding less than 5% of national production of cotton fiber in the 1999/2000 harvest, to being responsible for around 30% of production in the 2012/2013 harvest (CONAB, 2015).

The primary destination of nationally produced cotton is the national textile industry. Exports correspond to 20% of production (CONAB, 2015). During the 2012/2013 harvest, the cotton in Brazil occupied 900 thousand hectares and produced 1.3 million tons of cotton fiber. As stated by Pimentel (2012), the majority of cotton production is located in two regions of the country and executed by mega growers with plantation plots reaching over 10 thousands hectares. For instance, primary data used in this article reports an average cultivated area of 1,296 hectares, with a maximum of 15,000 hectares. Sampled average productivity, during the 2009 and 2013 seasons, was 4,035 kilograms of cotton per hectare with a maximum of 5,400 kg. Together, MATOPIBA and Mato Grosso comprised about 90% of the cotton area cultivated in the 2012/213 season in Brazil. Regional concentration of production unfolds into reduced opportunities for cultivar/biotechnology development. This argument is reinforced by the reduced number of cotton cultivars - about 200 cultivars - registered on the National Registry of Cultivars (RNC).

For instance, other crops such as soybean and maize have over 1 thousand cultivars registered each. Local firms and national research organizations are responsible for 110 cotton cultivars and have a share of approximately 50% of the domestic cotton seed market. In the last decade, the participation of international companies in the Brazilian cotton seed market has grown, particularly in terms of the number of transgenic cultivars registered.

The first commercial approval of a biotechnology event for the cotton crop in Brazil was in 2005. Almost ten years later, GM cotton cultivars occupied 47 per cent of total cotton area, or 463 thousand hectares in the 2012/2013 season (CÉLERES, 2013). Royalty collecting system of GM cotton cultivars follow the structure of the soybean market, with the same tape test and contractual terms applying to the moment of the grains delivery at the warehouse. Table 1 presents the biotechnologies for cotton commercially approved in the country. Notice that the biotechnology market is controlled by multinational companies, although national firms have a relevant market share of the seed market.

Table 1: Cotton Biotechnologies in Brazil.

Biotechnology	Insect Resistance	Herbicide Tolerant	Firm	Year of Approval
Bolgard I	X		Monsanto	2005
Roundup Ready		X	Monsanto	2008
Liberty Link		X	Bayer	2008
Bolgard I Roundup Ready	X	X	Monsanto	2009
Widestrike	X	X	Dow Ag	2009
Bolgard II	X		Monsanto	2009
GlyTol		X	Bayer	2010
TwinLink	X	X	Bayer	2011
MON 888913		X	Monsanto	2011
GlyTol TwinLink	X	X	Bayer	2012
GlyTol Liberty Link	X		Bayer	2012
Bolgard II Roundup Ready	X	X	Monsanto	2012

Source: CTNBio, http://www.ctnbio.gov.br/upd_blob/0002/2086.pdf

Until 2015, cotton biotechnologies were incorporated into fifty-seven (57) distinct cultivars, as disclosed on the National Register of Cultivars (RNC). Delta & Pine, Bayer and Tropical Breeding and Genetics (TMG) hold approximately 85% of transgenic cotton cultivars registered in Brazil. Embrapa, Mato Grosso Cotton Institute (IMAT) and Dow Agroscience are the other suppliers of GM cotton.

The launch of the first GM cotton in Brazil took place shortly after the commercial approval by CTNBio of the biotechnology Bolgard I, in 2005. After that, during the three subsequent harvests, Brazilian farmers have access to the transgenic cultivars of Delta & Pine: NUOPAL and Deltapine 90B. Only after the 2009/2010 season that firms other than Delta&Pine began to supply GM cotton seeds in Brazil. As for example, the multinational Bayer that started to offer the cultivars FM 966 LL containing the LL25 biotechnology (Libert Link), which makes the plant resistant to glufosinate ammonium. Nowadays, Bayer, TMG and MDM comprise about 90% of the Brazilian cotton seed market (CÉLERES, 2013).

As shown by Arza et al. (2012), in both Argentina and Brazil, the events incorporated into the cotton seeds did not significantly control the pests present in the field. Miyamoto (2013) shows that although cotton farmers consider the boll weevil (*Anthonomus grandis SP*) to be under control in the state of Mato Grosso – as a result of using chemical and cultures methods – the continuation of the use of various insecticides in the productive cycle tends to reduce the benefits of transgenic seeds. It can therefore be expected that the slower pace of diffusion of GM cotton in Brazil is not associated to the lack of information of the farmers, but rather by the deep knowledge that the agents holds on pest control methods.

In summary, cotton crops in Brazil nowadays present distinct productive structures compared to those observed up until the mid-1990s. Production moved to the Central-West, followed by an expansion into the MATOPIBA region. Using a unique farm level dataset from cotton producers in Brazil, the present study evaluates the economic performance of GM cotton seeds. The main goal is to assess the impacts of insect resistant (Bt) and herbicide tolerant (Ht) cotton on yield and profit.

METHODOLOGY AND RESEARCH DATA

The data used in this article were taken from a periodic analysis carried out by a private consulting company in the seeds and agricultural biotechnology area. For this study, we sought out information about the cotton production system in 157 farms in the state of Mato Grosso. Data from 2009 to 2013 seasons was compiled, resulting in a sample with 303 observations, separated according to cultivated plots within the farms. Thus, each observation corresponds to plot *i*, in the year *t*, producing cotton with a specific cost structure and technological package. The economic data was indexed for the base year 2013 and transformed into logarithms. To investigate how multicollinearity influences the configuration, an estimation of the variance inflation factor (VIF) was taken. The models were adjusted with robust estimators that corrected the estimates for heteroscedasticity.

The restriction of the research to the Mato Grosso state is due to an attempt to control the diversity of production conditions under which agricultural development takes place (type of climate, quality of soil, temperature, incidence of pests and disease, etc). Agricultural activity presents technological trajectories with regional characteristics, which determine how the culture is managed, and consequently, the effects of biotechnologies on production. Thus, it would be a mistake to consider the principle producing state as homogeneous. From an agronomic point of view, it could impoverish the econometric model interpretation. This argument justifies the division of the sample into two regions, characterized by similar production structures but different growing conditions. The variables analysed in this study are described in Table 2.

Table 2: Description of the variables used.

Abbreviation	Description
Year	Pooled data referring to 2009 to 2013.
GOM	Gross operating margin. Measured in R$ per hectare
Productivity.	Productivity. Measured in arrobas per hectare (1@ = 15Kg).
Pricepl	Cotton fiber price received by the producer. Measured in R$/Kg.
Area	Cultivated area. Measured in hectares.
Gtrait	Groups of *traits*. 1) conventional cultivars – reference category; 2) herbicide tolerant cultivars (gt2); 3) Cultivars with the Bt gene, resistant to insects (gt3).
Reg	Regions. Reg 1 (reference region): Primavera do Leste, Dom Aquino, Campo Verde, Chapada dos Guimarães, Jaciara, Poxoréu, Rondonópolis, Alto Garças, Pedra Preta, Guiratinga, Alto Taquari, Itiquira and Novo São Joaquim; 2) Reg 2: Lucas do Rio Verde, Nova Mutum, Sorriso, Diamantino, Campo Novo do Parecis, Tangará da Serra, Tabaporã and Santa Rita do Trivelato.
N	Quantity of nitrogen applied, measured in Kg of N per hectare.
K	Quantity of potassium applied, measured in Kg of K_2O per hectare.
P	Quantity of potassium applied, measured in Kg of P_2O_5 per hectare.
Apher	Number of herbicide applications per hectare.
Apinset	Number of insecticide applications per hectare.
Herb	Expenditure on herbicides, measured in R$ per hectare.
Inset	Expenditure on insecticides, measured in R$ per hectare.

Source: elaborated by the authors.

The main objective of the article is to estimate the effects of GM cotton adoption on yield per hectare and gross operational margin (profit) per hectare. For this purpose, were developed and estimated two econometric models where the type of GM cotton seed used figure as an explanatory variable: a cotton yield function and cotton profit function. The methodology is based in Kathage and Qaim (2012) for evaluate the impacts of Bt cotton adoption in India and adapted to the Brazilian case.

In order to compare the results, two econometric specifications were adopted. Model 1 was adjusted to the pooled data (considering different intercepts and constant angular coefficients), where characteristics of interest were controlled using binary variables. The specification of the model is shown in Equation (1):

$$Y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \delta t + e \qquad (1)$$

The coefficient β_j expresses the impact of the variation of a unit of X over Y, and δ marks the differences in the intercept in relation to the reference categories, when binary variables are inserted into the model.

Model 2 is adjusted to the panel data (random effects), as shown in Equation (2). Because fewer degrees of freedom are consumed compared to the fixed effect model, when X values of a unit of a cross-section vary only slightly between periods, the random effects model is most recommended (WOODRIDGE, 2001). The Hausman test was carried out to verify the bias in the estimates of model 2.

$$Y_{it} = \alpha + \sum_{j=1}^{k} \beta_j X_{jit} + w_i \qquad (2)$$

Where $$w_{it} = c_i + e_{it}$$

Y_{it} is the dependent variable for the unit of cross-section *i* on period *t*, X_{jit} is the matrix of factors that affect Y_{it}, β_j is the coefficients vector and w_{it} is the compound error, split into two components; where c_i is the variation between individuals and e_{it} is the general variation between observations.

The panel data method prevents the results from being contaminated by non-random selection biases from the analysis units. This phenomenon can occur when the most successful farmers adopt new technology earlier or to a greater degree than the other agents in the sample. The most successful farmers have access to greater revenues and profit as a result of any technological package, which can result in inflated estimates in terms of the impacts when compared to the farmers who do not adopt the technology (KATHAGE; QAIM, 2012). The Hausman test was carried out to verify the existence of selection bias and thus test the superiority of a fixed-effect over a random-effects specification.

RESULTS AND DISCUSSION

The general objective of the present study is to evaluate if the productivity and profitability gains resulting from adopting GM cotton seeds observed in small family farms are transferred to the specific situation in Brazil, in which cotton (for historical reasons) is largely grown in large areas by rural business owners. GM cotton technology can influence cotton profit mainly through three channels, namely changes in yield, changes in agrochemical cost, and changes in seed cost (KATHAGE; QAIM, 2012).

The sample represents the adoption of conventional, herbicide tolerant (Ht) and insect resistant (Bt) cotton seeds in the Brazilian state of Mato Grosso. It is affirmed that the sample is representative to the cotton farmers in Brazil, as it comprises about 15% of the cotton area of the country. Cotton in Brazil is grown by commercial farms with extensive areas and intensive modern inputs. In these agricultural firms, technology adoption is a process in which the decision involves a team of employers such as agronomists, field managers and external consultants. The substitution of cultivars follows a learning curve in which the area is gradually occupied by the new seeds. Table 3 compare selected variables of the 303 cotton plots of the sample, the data are grouped according to seed type.

Table 3: Descriptive statistics (mean comparison test between the groups).

	2009-2013		
Plot Level Information	**Conventional**	**Ht**	**Bt**
Seed Cost (R$/Hectare)	149.26	260.55***	333.01***
	(71.91)	(106.11)	(107.33)
Insecticide applications (number/hectare)	13.10	12.90	10.07***
	(3.63)	(3.50)	(2.10)
Herbicide applications (number/hectare)	4.13	4.64	3.82
	(1.53)	(1.60)	(1.51)
Insecticide Cost (R$/Hectare)	641.51	606.29	458.57***
	(223.04)	(260.57)	(203.76)
Herbicide Cost (R$/Hectare)	334.62	286.06***	313.23
	(149.47)	(121.17)	(87.53)
Yield (Arroba/Hectare)	272.45	263.09***	267.05*
	(31.33)	(28.00)	(30.25)
Direct Cost (R$/Hectare)	4,081	3,721***	3,623***
	(588.74)	(498.43)	(524.10)
Gross Margin (R$/Hectare)	3,047	3,339***	3,387***
	(1,284)	(938.47)	(1,261)
No.of plots	164	82	56

Source: Research data

*,**,*** Indicates that the difference between the averages of the groups are statistically significant to 10%, 5% and 1%, respectively. The values in parenthesis correspond to the standard deviation.

As shown, conventional seeds (non-GM) have on average higher yields when compared to Ht and Bt seeds. These finding indicate that GM cotton adoption in Brazil haven´t lowered the crop losses and conventional plots are outperforming the GM ones in terms of yield per hectare. The average number of applications of herbicides in plots cultivated with Ht seeds is the largest in the sample, but the differences are statistically insignificant. It is possible to observe a reduction of 15% in herbicide costs in favour of Ht cotton when comparing with conventional seeds. The result confirms the weak substitution between herbicides with different principle active ingredients, caused by the adoption of Ht seeds (SEIXAS; SILVEIRA, 2014).

On the other hand, it is possible to observe a reduction of 28% in insecticide costs in favour of Bt cotton when comparing with conventional seeds. Bt cotton outperformance in terms of profitability could led to the conclusion that the diffusion of this type of seeds is expected in Brazil. Yet, when looking to the sample data, Bt cotton diffusion does not follow the pattern observed for the soybean and maize crops. The descriptive statistics presented in Table 3 provide valuable insights into the impacts of GM cotton seeds in Mato Grosso, although there is influence from selection biases. The regression analyses were applied with the intention of controlling possible non-random errors when evaluating the impacts.

Table 4 shows the estimated yield (productivity per hectare) performance of adopting GM cotton seeds, expressed in arrobas (@) per hectare. The Hausman test presented a result of 0.1376, i.e. if we say that the estimator of the random effects model is inconsistent will be subject to an error of about 14%. Thus, H_0 is not rejected and the random effect estimates can be considered consistent with a significance level of up to 10%. Model 1 is the pooled data estimates, while Model 2 presents the results for the panel data (random effects).

Independent Variable	**Model 1**	**Model 2**
Constant	4.751***	4.768***
	(0.19)	(0.19)
Ln Nitrogen	0.083***	0.079***
	(0.020)	(0.021)
Ln Phosphorous	0.0044	0.0041
	(0.018)	(0.017)
Ln Potassium	0.0712***	0.0717***
	(0.020)	(0.021)
Herbicide Applications	0.00862	0.00868
	(0.005)	(0.005)
Inseticide Applications	-0.0014	-0.0017
	(0.002)	(0.002)
Year 2012_Dummy	-0.039	-0.040
	(0.024)	(0.02)
Year 2011_Dummy	-0.077***	-0.075***
	(0.019)	(0.019)
Year 2010_Dummy	0.0508***	0.0510***
	(0.017)	(0.0175)
Ln Area	0.0146***	0.0145***
	(0.005)	(0.005)
Region 2_Dummy	-0.0827***	-0.0825***
	(0.014)	(0.014)
Ht_Dummy	-0.027	-0.022
	(0.018)	(0.018)
Bt_Dummy	-0.001	-0.006
	(0.021)	(0.0216)
VIF	1.72	-
R^2	0.3947	-
Hausmann	-	0.1376

Sources: Research Data

*,**,*** Indicates that the estimated coefficient is statistically significant to 10%, 5% and 1%, respectively. In both models, the dependant variable is the productivity of cotton, measured in arrobas per hectare. The values in parenthesis correspond to the standard deviation.

The results do not present sufficient evidence to accept the hypothesis that the adoption of GM seeds would impact the productivity of cotton farmers in the Mato Grosso state. In this sense, non-adopters of GM seeds could access the same productive potential of the GM seeds for a lower price per seed bag. Carpenter (2010) and Kathage and Qaim (2012), claim that the productive potential of transgenic seeds (productivity under optimal conditions of control) is not greater than the productive potential of conventional seeds. In this case, the adoption of GM seeds could be explained by the seeking for non-pecuniary gains, such as a reduction in the perception of risk associated with the production.

The model indicates that the number of herbicide and insecticide applications have no significant impact in the productivity. This is because whatever the technology package adopted, farmers in Mato Grosso have enough knowledge to manage their agronomic practices to control pests and weeds with the same level of efficiency on productivity. Thus, the time of performing the control of insects and weeds constitutes an important component of the production system. In order to reduce productivity losses, cotton farmers of the sample conduct a greater number of agrochemicals applications while adopting or no GM seeds.

Estimates regarding the effect of the area size on productivity are statistically positive and significant. This is due to the greater management skills of large farmers when compared to smaller ones. Among these management skills can include better time management, since the existence of increased operational capacity results in ability to meet the demands of growing in a shortest time, avoiding losses. From the estimates of both models, for each 1% increase in the size of the cultivated area there is a 0.014% increase in productivity, while keeping constant the other independent variables.

The effect of climate on productivity is exposed to inserting dummy variables for years in the estimates. The results of both models state that, regardless of other explanatory variables, the year 2010 was more productive and the year 2011 was less productive compared to the base year (2013). The model estimates 1 indicate that productivity in 2010 was 5.08% higher than in 2013, while the second model estimates higher productivity on the order of 5.10%. As for the year 2011, the model estimates 1 claim the yield was 7.7% lower than in 2013, while the second model estimated lower productivity on the order of 7.5%.

The variable which captures the effect on yield of different qualities of soil for cultivation (reg 2) as well as the occurrence of precipitation different schemes, demonstrated statistically significant in both models. From the first model, it estimated that productivity in region 2 is 8.27% lower than in region 1, regardless of other explanatory variables. Starting from the estimates of the model 2, the productivity in region 2 is less than 8.25% in region 1, regardless of other explanatory variables. This result may be related to differences in rainfall regimes of the compared regions. In region 1, the rain starts earlier than in region 2, allowing the sowing cotton earlier, which results in higher productivity. Moreover, there are important differences in the quality of land for cotton cultivation across regions.

Table 5 presents the results of estimates of the impacts of transgenic crops on the gross operating margin in the cultivation of cotton at the Mato Grosso state. The Hausman test showed a result of 0.2034, that is, if we say that the estimator of the random effects model is inconsistent will be subject to an error of about 20%. In other words, it rejects H_0 and the estimated random effects can be considered consistent up to 10% significance.

Table 05: Estimates of the impacts of adopting biotechnology on the gross operating margin.

Independent Variable	Model 1	Model 2
Constant	-7.3083***	-4.7772***
	(1.52)	(1.58)
Ln Productivity	3.005***	2.607***
	(0.312)	(0.235)
Ln Cotton Fiber Price	2.565***	2.374***
	(0.382)	(0.251)
Ln Herbicide Cost	-0.023	-0.040
	(0.035)	(0.032)
Ln Inseticide Cost	-0.307***	-0.253***
	(0.061)	(0.058)
Ln Fertilizer Cost	-0.4053***	-0.3887***
	(0.0835)	(0.0724)
Ln Seed Cost	-0.096	-0.093
	(0.121)	(0.082)
Year 2012_Dummy	0.2036***	0.1643***
	(0.048)	(0.054)
Year 2011_Dummy	-0.063	0.119
	(0.099)	(0.083)
Year 2010_Dummy	0.013	-0.002
	(0.111)	(0.093)
Year 2009_Dummy	-0.170*	-0.075*
	(0.176)	(0.128)
Ln Area	0.017*	0.032*
	(0.013)	(0.018)
Region 2_Dummy	-0.070*	-0.079*
	(0.127)	(0.152)
Ht_Dummy	0.099*	0.107**
	(0.059)	(0.068)
Bt_Dummy	0.023	0.046
	(0.079)	(0.081)
VIF	2.38	-
R^2	0.5847	-
Hausmann	-	0.2034

Sources: Research Data

*,**,*** indicates that the estimated coefficient is statistically significant to 10%, 5% and 1%, respectively. In both models, the dependant variable is the gross operating margin, measured in R$ per hectare. The values in parenthesis correspond to the standard deviation.

The results of the estimated economic impact of biotechnology adoption on gross operating margin (GOM), comparing insect resistant cultivars (Bt dummy) to conventional cultivars, demonstrate insufficient evidence to affirm that the biotechnology adoption impacted positively the gross operating margins in both models. It is suggested that part of the margin that would be appropriate by producers due to lower use of insecticides is transferred to seed companies due to the difference between the price of conventional seeds and seeds insect resistant (IMEA, 2015). In this context, the seeds prices differential (Bt and conventional) helps to explain the low diffusion of Bt seed in the sample.

The analysis of the relationship between spending on insecticide and gross operating margin demonstrate the importance of this input at the Mato Grosso state. As presented in the estimates of model 1, every 1% increase in spending on insecticide has a negative impact of 0.30% on the gross operating margin. The estimates of the model 2 show that for every 1% increase in spending on pesticides there is a negative impact of 0.25% on the gross operating margin. In this region, the cotton farming is intensive in the use of insecticides, mainly due to the boll weevil plague (*Anthonomus grandis SP*), whose control requires at least nine preventive applications, even with no incidence of plague.

Regarding the economic impact of the adoption of herbicide tolerant cultivars (Ht dummy), both models showed statistically significant results, 10% and 5% respectively. Instead of a reduction in the number of applications, Ht adoption resulted in the replacement of herbicides with higher levels of toxicity. The seeds of herbicide tolerant crops are on average more expensive than conventional seeds, but the glufosinate ammonium herbicide is cheaper than the herbicides used with conventional seeds (IMEA, 2015). As presented in the estimates of models 1 and 2, the adoption of herbicide tolerant cotton has a positive impact of 9.9% and 10.7% on the gross operating margin respectively, independent of the other explanatory variables. The results achieved for Ht cotton adoption in Mato Grosso are consistent to the results achieved by Alves et al. (2012).

On analysing the results of the estimates, considering the effect of different seasons on the profits per hectare, evidence suggests that the gross operating margins (GOM) - independent of the other explanatory variables - in 2012 and 2009 differed from the reference year (2013). The estimates from model 1 show that GOM in 2012 was 20.36% higher than the GOM in 2013, while in 2009 it was 17% lower than 2013. Model 2 estimates show that the GOM for 2012 was 16.43% higher than for 2013, while in 2009 it was 7.5% less than in 2013. The variable that captures the effect of different transportation costs between the producers on the MOB (Reg 2), did not show significant results in both models. This point will be investigated in further studies, since this result did not appear as expected.

The relationship between gross operating margin and fiber price received by producers is positive and statistically significant how was expected. From the estimates of the model 1, each 1% increase in fiber price generates an impact on the GOM of the 2.56%, while keeping constant the other independent variables. The model estimates 2 demonstrate that for each 1% increase in fiber price, there is an impact on the GOM of the 2.37%, while keeping constant the other independent variables.

The relationship between gross operating margin and productivity is positive and statistically significant. From the estimates of the model 1, each 1% increase in productivity generates an impact on the GOM of the 3.00%, while keeping constant the other independent variables. The model estimates 2 demonstrate that for each 1% increase in productivity, there is an impact on the GOM of the 2.60%, while keeping constant the other independent variables.

In summary, the principle results of this article can be grouped into three main points. In relation to the productive and economic impacts resulting from the adoption of Bt seeds, there is no sufficient evidence to confirm that productivity and the gross operating margin differ among Bt seeds and conventional seeds. Brazilian cotton farmers are capable of controlling insects just as efficiently by adopting the insect resistant trait or by using insecticides. The same reasoning can be applied to the case of herbicide tolerant seeds, due to the weak substitution between conventional herbicides and glufosinate ammonium to control weeds. In this case, the results suggest that the adoption of Ht seeds has impact over the gross operating margin of the farmers and no influence over the productivity of the crops.

CONCLUSIONS

The contribution of the present study consisted in analysing the relationship between productivity and profit gains from adopting transgenic cotton cultures in Brazil. The results indicate that the adoption of herbicide tolerant (Ht) GM cotton causes insignificant impacts on yield and significant impact on gross operating margin of the farmers. In the case of the adoption of insect resistant (Bt) GM cotton, the results suggest that the evidences are not sufficient to affirm that the productivities and the gross operating margin differ among insect resistant (Bt) seeds and conventional seeds.

In the particular case of Brazil, where farmers have a well-defined cotton production function, the results are in keeping with the reality observed. This is due to the fact that in the growing environment there are different pests against which the insect resistant trait is not effective in its control. In addition to the previously mentioned Boll Weevil (*Anthonomus grandis* SP), the aphid (*Aphis gossypii*), the Acari (*Polyphagotarsonemus latus* and *Tetranychus urticae*), the cotton leafworm (*Alabama argillacea*) and the heteropteras (*Nezara viridula* and *Euschistos heros*), among others, exist. In relation to the seeds that contain the herbicide tolerant gene, it was noted that the number of applications is similar between conventional and transgenic seeds.

It can therefore be deduced that the delay in diffusion process of transgenic cotton seeds is associated not to a lack of information on the part of the farmers, but to their deep knowledge on pest and weed control methods, therefore the focus on productivity and profit gains changes when they decide to adopt new technologies.

The principle focus of the research on the adoption of transgenic crops included an evaluation of their economical and productive impacts. Considering that we are entering into the second decade in which transgenic have been used in cotton cultures, the empirical research content should encompass the more advanced methods available to answer the relevant questions from the point-of-view of public interest and specific sector policy makers, such as: impacts on poverty and inequality in agricultural communities, and the effects on human health and the environment.

NOTES

[1] The expansion of cotton in Mato Grosso materialized the absolute advantages of the agricultural production in Brazilian Cerrado, by the production of two crops with high productivity in the same year. It is stated that the double cropping system, with soybeans as a first crop and corn or cotton competing for area in the second crop, was possible due to the shortening of the soybean maturity in the first season.

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