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An Ex-ante Evaluation of the Economic Impact of Bt Cotton Adoption by Spanish Farmers Facing the EU Cotton Sector Reform

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Cotton production in the European Union (EU) is limited to areas of Greece and Southern Spain (Andalusia). The 2004 reform of the EU cotton policy severely affected the profitability of the crop. In this article we analyze how the introduction of genetically modified (GM), insect-resistant cotton varieties (Bt cotton) might help EU cotton farmers to increase profitability and therefore face the cotton policy reform. We first study farmers' attitudes toward adoption of Bt cotton varieties through a survey conducted in Andalusia (Southern Spain). The results show a positive attitude of Andalusian cotton farmers toward the Bt cotton varieties. Second, we perform an *ex-ante* analysis of the effects of introducing Bt cotton in Andalusia. Finally, we integrate the analysis of the effects of Bt cotton with the analysis of the EU cotton reform. Our results show that despite the significant economic benefits of Bt cotton, the current policy reform is likely to jeopardize the profitability of cotton production in the EU.

Key words: genetically modified Bt cotton, cotton bollworm (*H. armigera*), European Union cotton regime, survey, ex-ante analysis.

Introduction

Cotton is one of the most important industrial crops in the world, used for both fiber and seed production. More significantly, cotton is an important cash crop for a number of developing countries like Benin, Burkina Faso, Chad, Mali, Togo, Uzbekistan, Tajikistan, and Turkmenistan (Baffes, 2004). Roughly one-third of global cotton production is traded internationally, with the major exporters being the United States, Uzbekistan, and India, and the major importers being China and Southeast Asian countries.

The EU is considered a small player in the international cotton market, accounting for less than 2% of production and less than 5% of imports (Kragiannis, 2004). Cotton production in the EU is concentrated in some rural areas of Spain and Greece, where it constitutes an important land use and a significant element in the local economy (e.g., Arriaza, Gómez-Limon Rodríguez, Gonzales, & Ruiz, 2004.).

Cotton is attacked by a number of insect pests that reduce the yield, the most important of which is the cotton bollworm (*H. armigera*). Transgenic cotton varieties producing δ-endotoxins from the soil bacterium *Bacillus thuringiensis* (Bt) allow better pest control, reducing costs and, in some cases, increasing effective yields. Many cotton-growing countries, including most of the major cotton producers, have authorized Bt cotton and cultivate it on a large scale. Such varieties, introduced commercially in 1996, have been adopted by all major world cotton producers and, according to the International Cotton Advisory Committee (ICAC, 2007), now cover roughly 40% of the world cotton area. Genetically modified insect-resistant cotton varieties have played an important role in improving production efficiency (for a review, see Gómez-Barbero & Rodríguez-Cerezo, 2006).

Currently, no Bt cotton varieties are authorized for cultivation in the EU. An obvious question to ask is whether the EU farmers could benefit from a state-of-the-art technology that has proven to deliver sizeable benefits to cotton growers worldwide and is also used by many of their competitors. This question is now even more important, given the on-going reform in the EU cotton support system. Following a more general reform of the Common Agricultural Policy (CAP) in 2003, the EU cotton sector was also reformed in 2004. The main points of the reform include the elimination of price-support mechanisms and the introduction of (partially) decoupled payments. Preliminary analyses suggest that, as a result of the reform, cotton production in the EU will diminish dramatically unless significant cost reductions or productivity increases occur (e.g., Arriaza & Gómez-Limon Rodríguez, 2006; Arriaza et al., 2004; Kragiannis, 2004).

The purpose of this article is to extend the analysis of the impact of the cotton reform on cotton production in the EU (e.g., Arriaza, & Gómez-Limon Rodríguez, 2006; Kragiannis, 2004) by taking into account the effects of a hypothetical introduction of Bt cotton varieties. The first objective is to understand how farmers themselves in the EU perceive Bt cotton varieties and to assess their willingness to adopt such varieties. In order to do so, we survey cotton farmers in Andalusia (Southern Spain), where cotton bollworm infestations represent a serious problem. Next, the article analyzes how the introduction of Bt cotton varieties in the EU could affect cotton production under the reformed policy regime in one of the main growing regions of the EU. To this end we use a theoretical model to explore the effects of Bt cotton on pest control practices and farmers' profits. Then, on the basis of local available data, we calibrate the theoretical model and develop a numerical example to simulate the economic effects of introducing Bt cotton varieties in Andalusia.

The rest of the article is organized as follows. First, we briefly describe cotton production in the EU, with an emphasis on the policy changes in the cotton sector. Second, we describe the economic problem associated with the production of conventional and Bt cotton. Third, we use a multi-client survey to obtain relevant information about farmers' attitudes towards Bt cotton in Southern Spain. Fourth, we simulate the economic problem for cotton production in Southern Spain. In particular, the effects of the introduction of the Bt cotton varieties on insecticide applications and profits under two alternative policy regimes (i.e., the old regime and the reformed one) are presented. Finally, we discuss the implications of the numerical results with particular attention paid to the future of cotton growing in the EU.

Cotton Production Support in the EU

Cotton production in the EU is relatively small on a world scale. Nevertheless, in 1981 following the accession of Greece to the EU, the EU's 'cotton regime' was introduced with the aim to support cotton production in those regions where it was an important income source. In 1986, with the accession of Spain and Portugal, the regime was extended to producers in these countries. Over the years the regime has been amended several times, but until the 2004 reform its essential function revolved around common EU agricultural policy tools like the deficiency payment, the corresponding levy, and the maximum guaranteed quantity (MGQ). The deficiency payment was determined as a difference between the world market price and a target price set by the European Council, and was made to processors on condition that they paid a 'minimum price' to cotton farmers. The minimum price was set slightly below the target price. The application of the minimum price was limited to a MGQ. When production exceeded the MGQ, the minimum price was reduced accordingly, therefore reducing the subsidy amount.

Following the CAP reform in 2003, the cotton sector also was reformed in 2004 with a new regime to apply from January 1, 2006 (EC Regulation 864/2004). Under the new regime the support to cotton farmers is provided as a single decoupled payment (65%) and a cotton specific area payment (35%), with no minimum guaranteed price for growers. The total area eligible for the support in the EU is set at 440,360 ha divided between Greece (370,000), Spain (70,000 ha), and Portugal (360 ha). The cotton area payment for Greece is €594 per ha for the first 300,000 ha and to €342.85 per ha for the remaining 70,000 ha; for Spain the area payment is €1,039 per ha; and for Portugal, €556 per ha. However, in 2006, just one year after implementation, Spain raised a case against the reform in front of the European Court of Justice and the new regime has been suspended since.

The Economic Problem

The problem we wish to address relates to the effects of an introduction of Bt cotton on farmers' decisions about the use of pest-control inputs (i.e., insecticides in our case) and other agricultural inputs on yield and, ultimately, on profits. When modelling the effect of pest-control inputs, it is necessary to consider that such inputs are not yield-increasing *per se*, but rather constitute damage-abating factors (Lichtenberg & Zilberman, 1986). Economic theory predicts that the use of Bt varieties will lead to a reduction in insecticides applications (e.g., Ameden, Qaim, & Zilberman, 2005). The experience gained through the use of Bt cotton in China (Huang, Hu, Rozelle, Quiao, & Pray, 2002), South Africa (Shankar & Thirtle, 2005), India (Qaim, Subramanian, Naik, & Zilberman, 2006), Mexico (Traxler, Godoy-Avila, Falck-Zepeda, & De Jesus Espinoza-Arellano, 2003), Australia (Fitt, 2003), and the United States (Fernandez-Cornejo & McBride, 2002) confirm this. The economic model underpinning our analysis is illustrated in the Appendix.

With respect to the effect of the Bt trait on the realized yield there is mixed evidence. As already mentioned, Bt varieties are not specifically designed to generate higher yields but to decrease the use of (costly) insecticides. Nevertheless, Bt crops might increase realized yield by reducing pest damage through better pest

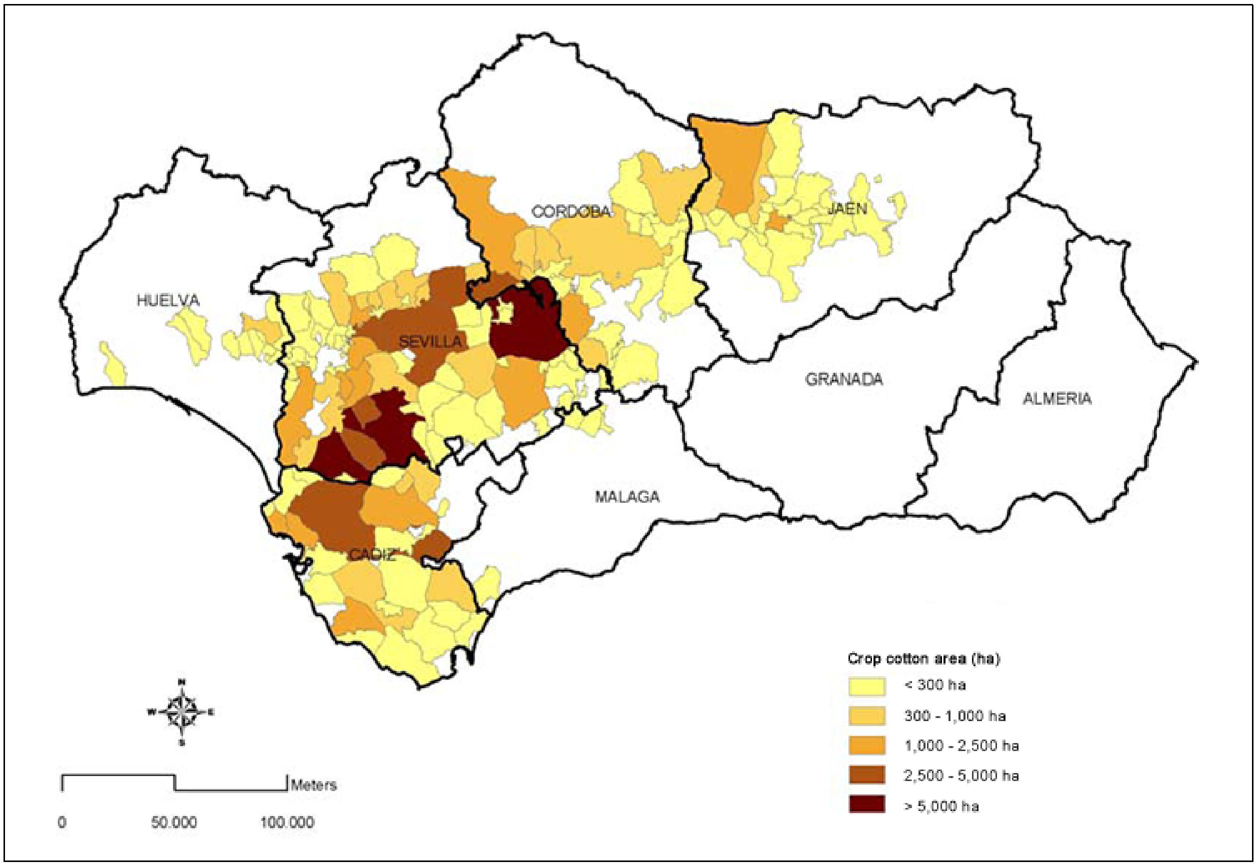

Figure 1. Average cotton area in Andalusia in 1999-2003, by municipalities.

control. This is likely to be the case, especially in developing countries where pest control is poor due to the unavailability and/or high cost of effective insecticides. Again, the existing evidence corroborates this since the realized yield improvement associated with the use of Bt cotton has been estimated at roughly 40% in South Africa (Shankar & Thirtle, 2005), 30-40% in India (Qaim et al., 2006), and 5-10% in China (Huang et al., 2002), but it appears to be in the range of 2% in the United States (Fernandez-Cornejo & McBride, 2002) and negligible in Australia (Fitt, 2003). The advantages of Bt cotton in developed countries are then related mainly to the reduction in pest control costs.

Attitudes Towards Bt Cotton in Southern Spain

Cotton Production in Southern Spain

Cotton production in Spain almost entirely (roughly 96% in 2007) takes place in the Guadalquivir river basin in the Andalusian provinces of Seville, Cordoba, Cadiz, and Jaen (USDA FAS, 2007). Figure 1 illustrates the map of the eight provinces of Andalusia with the distribution of the cotton crop area (average from 1999-2003).

Cotton production in Andalusia accounts for just 1.3% of useful agricultural surface, but its cultivation in the region is perceived to be important from a social point of view. Arriaza et al. (2004) estimate that cotton generates 113 hours work/ha (excluding harvesting operations, which are normally subcontracted). Given an estimated harvested area of more than 40,000 ha in 2006, this is equivalent to more than 640,000 on-farm work days per annum. Moreover, in Andalusia there are more than 20 ginning factories, which employ around 250 permanent staff and 950 temporary staff (Arriaza et al., 2004).

Concerning the typology of cotton farms in Andalusia, it has been estimated that roughly 50% of farms grow cotton as a monoculture, 25% use a cotton/maize rotation, 20% use a cotton/sugar beet rotation, and 5% use a cotton/sugar beet/wheat rotation (Arriaza et al., 2004). Cotton production, as a monoculture or in rotation with maize and sugar beet, is intensive in pesticide use, irrigation, and fertilizer requirements, which in turn generates environmental impacts in terms of soil erosion and diffuse pollution (e.g., Relchelderfer, 1990). It is estimated that in Andalusia pest control costs account for 19-24% of total direct costs and irrigation account for 15-20% of total direct costs (Bilbao et al., 2004). The number of insecticide treatments varies with location and climatic conditions, but in Andalusia it is common to apply as many as 7-8 treatments. The main cotton pests include Lepidoptera (e.g., *H. armigera*, *E. insulana*), Homoptera (e.g., *A. gossypii*), Tisanoptera (e.g., *Thrips* species), and Aracnida (e.g., *Tetranychus* species). The cotton bollworm (*H. armigera*) is one of the most important insect pests in cotton-growing regions worldwide, including Southern Spain. The extensive use of insecticides to control cotton bollworm has subjected this pest to a high selection pressure. Insecticide resistance to major chemical groups has been documented in Australia, Asia, and Africa (e.g., McCaffery, 1998). In Spain, a milder degree of resistance has been detected (Torres-Vila, Rodriguez-Molina, Lacasa-Plasencia, & Bielza-Lino, 2002).

Water requirements in cotton vary between 7,000-13,000 m^3/ha depending on local conditions, but a minimum of 5,000 m^3/ha is considered necessary to have acceptable yields. Soil water in Andalusia is not sufficient to sustain cotton production (96% of cotton production is irrigated), and it is estimated that an additional 5,500-6,000 m^3/ha is being provided through irrigation. The most common irrigation method is 'surface irrigation' (accounting for 51% of the cotton area in 2003), followed by 'drop irrigation' (28% of the cotton area in 2003) and 'aspersion irrigation' (16% of the cotton area in 2003) (Bilbao et al., 2004).

The Survey

The theoretical framework presented in the Appendix provides a background to understand farmers' decisions about whether to adopt Bt varieties. An individual farmer will decide to adopt the Bt varieties if the difference between the profit associated with Bt and conventional cotton exceeds a certain threshold. The threshold might reflect the farmer's attitude toward Bt varieties. Some farmers will have a higher threshold and will require Bt varieties to outperform conventional varieties more before adopting them. Even when the Bt technology outperforms conventional varieties under all circumstances, it is possible that some farmers will not adopt simply because they are extremely averse to the use of GM varieties.

In 2004, a multi-criteria survey of cotton producers was carried out in order to obtain information on important socio-economic aspects of cotton production in Andalusia. A section of the questionnaire aimed at obtaining information about the attitudes of farmers in Andalusia toward GM Bt cotton varieties.[1] The survey was sent by mail to the total population of cotton growers in the 21 districts of the region; 830 cotton farmers responded. However, because 200 farmers did not answer the question regarding which district they belonged to, when results are broken down by farming district, only 630 answers were considered. The purpose of the survey was to ascertain (a) the farmers' degree of knowledge about GM Bt cotton, (b) their willingness to adopt the technology, and (c) the prevailing pest-control practices. On average, 58% of respondents were aware of GM Bt cotton, 30% did not know, and 12% did not answer this question. The results of the survey are summarized in Table 1 and indicate that in only four districts (Condado and Campiña del Norte districts in Jaén, Sierra Sur in Seville and Condado Campiña district in Huelva), the cotton area corresponding to those farmers who declare a knowledge of GM cotton represents less than 25% of the total cotton area cultivated by the responding farmers. The responding farmers in the remaining districts show a high or relatively high level of knowledge.

Concerning farmers' attitudes toward GM Bt cotton in the main cotton-producing districts (see Figure 1), such as the Guadalquivir Valley, the Marisma marshlands, the Campiña de Cádiz, and La Janda, responding farmers willing to adopt GM Bt cotton cultivate more than 75% of the cotton area of all responding farmers. The survey's results indicate that among those farmers who were aware of GM Bt cotton, 95% were willing to adopt. On the other hand, after having been provided succinct information on the Bt technology, only 4% of the responding farmers who were unaware of GM Bt cotton (cultivating roughly 30% of the cotton area covered by the survey) were willing to adopt. The overall average adoption rate stands at roughly 56% of respond-

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[1] *Survey of cotton producers in Andalusia conducted in 2004 in collaboration with the Andalusian Institute for Research and Training in Agriculture, Fisheries and Organic Production (IFAPA). The results of the survey (with exception of the component relative to the attitudes towards GM Bt cotton) have been published as a report (listed in the references as Bilbao et al., 2004).*

Table 1. Survey results.

Province	District	Number of surveyed farmers	Number of surveyed farmers who declared to know GM cotton	Number of surveyed farmers who would adopt GM cotton if available	Cotton planted area of surveyed farmers	Cotton planted area of surveyed farmers who are aware of GM cotton	Cotton planted area of surveyed farmers who would adopt GM cotton if available	Average number of insecticides applications
Cádiz	Campiña de Cádiz	69	24	28	836.06	560.19	656.82	6.18918919
Cádiz	Costa Noreste de Cádiz	32	25	27	525.73	475.58	482.38	5.38709677
Cádiz	De la Janda	7	3	7	72.41	21	72.41	6.71428571
Cádiz	Campo de Gibraltar	3	2	2	19	15	15	4
Córdoba	La Sierra	7	5	3	112.69	97.6	80	4.75
Córdoba	Campiña Baja	56	39	50	947.69	836.75	929.05	5.25
Córdoba	Las Colonias	40	32	33	352.82	319.8	313.22	4.56410256
Córdoba	Campiña Alta	2	1	1	20	5.5	14.5	5.75
Huelva	Condado Campiña	28	3	5	154.15	13.45	49.85	7.56666667
Jaén	Sierra Morena	43	19	25	169.96	96.22	112.16	4.55
Jaén	El Condado	1	0	0	5	0	0	3
Jaén	Campiña del Norte	17	2	6	57.34	5.15	16.65	3.88888889
Jaén	La Loma	21	11	13	68.62	42.12	48.66	3.85
Jaén	Campiña del Sur	3	2	3	18.57	17.07	18.57	3.66666667
Sevilla	La Sierra Norte	7	4	4	97	77	77	6.64285714
Sevilla	La Vega	148	54	117	1323.29	783.36	1168.58	7.80113636
Sevilla	El Aljarafe	2	0	0	10.07	0	0	9.5
Sevilla	Las Marismas	7	7	7	260.01	260.01	260.01	6.4
Sevilla	La Campiña	135	89	108	1401.64	1060.42	1220.16	6.80569948
Sevilla	La Sierra Sur	1	0	0	18	0	0	8
Sevilla	De Estepa	3	1	1	27.91	16.71	16.71	3.5

ing farmers, representing around 85% of the cotton area that was covered by the survey. These results indicate how in 2003/2004 responding cotton farmers in Southern Spain believed that the use of GM Bt varieties could significantly improve cotton economic performance.

Concerning the prevailing pest-control practices, the survey elicited the number of insecticides applications in the 2003/4 growing season. The results suggest that the average number of insecticide treatments applied by responding farmers to cotton fields in this season varied with the farm's location. In the middle and lower reaches of the Guadalquivir, where average temperatures are higher, considerably more treatments were applied (between 6-7 and sometimes more than 7 treatments) then elsewhere in Andalusia. When averaged across all districts, responding cotton farmers applied 6 insecticides treatments per year.

Numerical Example

With the reform of the cotton sector, farmers will not receive a minimum guaranteed price for their produce, but will have to sell it at the (lower) prevailing world price. As a result, the crop profitability is likely to decline, and the use of Bt varieties could allow farmers to cut down insecticide applications and reduce variable production costs. To some extent, the use of Bt cotton varieties might help farmers to better respond to the effects of the cotton reform. This aspect needs specific attention and is analyzed in detail in the following sections through a numerical example for cotton production in Andalusia.

Functional Forms and Parameter Values

At this point we wish to use the theoretical framework presented in the Appendix to provide a numerical example. In doing so, we refer to cotton production in Andalusia and analyze the problem of controlling the cotton bollworm. The exercise has only an illustrative purpose to assess the implications of the EU's new cotton regime and the potential impact of an introduction of Bt cotton varieties. Hence, its results should be interpreted carefully since the model specification is based on the calibration of general functional forms on the basis of available local data.

The Production Functions

For the production function, we consider water (irrigation) as the only input. This is because irrigation costs represent the most significant component of direct cultivation costs after pest-control costs. We are implicitly assuming that all other factors of production have already been allocated (or equivalently they are allocated in fixed proportions). This assumption allows us to significantly reduce the number of decision variables and simplify the numerical solution. We assume a production function of the Cobb-Douglas form because of its tractability so that

$$f^C(x) = f^G(x) = K(irr + 1) \tag{1a}$$

$$0 < a < 1 \quad 0 \leq irr \leq 1. \tag{1b}$$

The variable *irr* indicates irrigation intensity (rather than actual water consumption) and is assumed to be bounded between 0 and 1, reflecting low and high irrigation intensity, respectively. When the irrigation intensity is set to its minimum (0) the 'basic' yield K will be obtained. We assume decreasing marginal productivity with respect to irrigation intensity. Average yield of unginned cotton in Southern Spain from 2000-2003 was 3.3 tons/ha (Bilbao et al., 2004). In 2007, following the 1-year implementation of the cotton reform and the consequent reduction in input applications, cotton yields in Spain have declined by 30% (USDA FAS, 2007). On the basis of such information, we set $K = 2.2$ and $\alpha = 0.6$, obtaining a yield range of 2.2-3.3 tons/ha.

Pest Infestation, Insecticide Effectiveness, and Bt Efficacy

Although cotton in Southern Spain is attacked by a number of insect pests, *H. Armigera* is by far the most important. In our analysis, we therefore explicitly refer only to the cotton bollworm. Although not entirely accurate, such an approximation is capable of generating plausible results. Essentially the effect of other pests is implicitly incorporated in the production function.

The cotton bollworm population after insecticide treatment has been applied and Bt varieties have been deployed has been defined as $\hat{N} = Nh(z)\eta$ (Equation 1b).[2] Recall that for conventional varieties we simply assume $\eta = 1$.

Novillo, Soto, and Costa (1999), in an experiment on the effect of Bt cotton on cotton bollworm in Southern Spain, report infestation levels of 15-18 larvae per 20 plants when no treatment (insecticides or Bt) was applied. In our base case we set N = 20 (i.e., 20 larvae per 20 plants). The authors illustrate how the Bt cotton treatment reduced the number of larvae by more than 95%. Similar values have been found in other parts of the world (e.g., Sharma & Pampapathy, 2006). We therefore set $\eta = 0.05$ (i.e., 95% of the pest population is killed by the Bt trait).

The insecticides kill function h is defined as

$$h(z) = e^{-\gamma z} \tag{2a}$$

$$\gamma > 0. \tag{2b}$$

In the base case we set $\gamma = 0.95$, which implies a high degree of susceptibility to the insecticides since 60% of the pest population is killed with one treatment. As already mentioned, cotton bollworm has been shown to develop resistance to many insecticides. In order to explore the implications of such a possibility, we carry out a sensitivity analysis for $\gamma = 0.5$.

The Damage Function

In the Appendix we define the damage function $0 \leq D(\hat{N}) \leq 1$ to indicate the proportion of the yield that is lost to the pest population after pest control has been exerted. In our case, $\hat{N}$ is measured in number of (sur-

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[2] *Recall that $0 < h(z) < 1$ is the proportion of the insect population killed through the application of insecticides z, while $0 \leq \eta \leq 1$ is the fraction of the insect population that survives the 'Bt treatment' (see Appendix).*

Table 2. Simulation results.

Case	Cotton variety	Policy	Irrigation (intensity)	Insecticides (# applications)	Gross margin (€/ha)
Base	Conventional	Old	1	5.6	1,334
		New	0.65	4.2	120
	Bt cotton	Old	1	2.5	1,423
		New	0.65	1	209
$\beta = 0.1$	Conventional	Old	1	4.9	1,378
		New	0.65	3	164
	Bt cotton	Old	1	1.7	1,467
		New	0.65	0.3	253
$\beta = 0.4$	Conventional	Old	1	6.3	1,290
		New	0.65	4.9	76
	Bt cotton	Old	1	3.2	1,379
		New	0.65	1.7	165
$\gamma = 0.5$	Conventional	Old	1	7.9	1,135
		New	0.23	4.6	5
	Bt cotton	Old	1	2	1,394
		New	0.56	0	251

The parameter γ indicates the elasticity of the kill function with respect to the insecticides applications (z). The parameter β reflects the damaging power of the pest.

viving) individuals per 20 plants. We use the following specification:

$$D(\hat{N}) = 1 - e^{-\beta\hat{N}} \qquad (3a)$$

$$\beta \geq 0. \qquad (3b)$$

According to the European Plant Protection Organization, two larvae per plant can destroy all the bolls in a period of 15 days. On the basis of this information we set $\beta = 0.2$ in our base case and carry-out sensitivity analysis for $\beta = 0.1$ and $\beta = 0.4$.

Prices, Production Costs, and Subsidies

With the old cotton regime, farmers received a minimum guaranteed price. The average target price received by cotton farmers in Spain from 2000-2003 was around €1000 per ton (Bilbao et al., 2004). With the reformed regime, cotton farmers have to sell the cotton at the world price. Data from the International Cotton Advisory Committee (ICAC) reveal that the world average cotton price from 2000-2005 stood at around $0.56US per pound of ginned cotton. Assuming an exchange rate of $1.20 to €1 and a 30% fiber yield (Arriaza et al., 2004), this is equivalent to a price of around €300 per ton of unginned cotton. Yet, under the new regime, Spanish cotton farmers will also receive a cotton-specific area payment of €1,039 per ha (for each ha of cotton planted, not necessarily harvested).

In our numerical example we assume the only decision variables to be irrigation intensity and number of insecticides applications. Bilbao et al. (2004) report how cotton irrigation costs in Southern Spain range from €220-380 per ha, depending on the irrigation system used. We assume that when intense irrigation is applied (i.e., *irr* = 1), the average irrigation cost stands at €300 per ha. For insecticide application, the authors report a cost of €60 per ha per application. The costs of other inputs enter into our profit function as fixed costs (i.e., exogenously determined). Drawing on Bilbao et al. (2004), we assume that such production costs for conventional varieties stand at €1,300 per ha. The main component of direct costs are pre-sowing operations (around €350 per ha), weed control (around €200 per ha), and collection (around €370 per ha). For Bt cotton varieties we assume an additional cost of €100 per ha, which accounts for higher seed costs and pest refuge management (author calculations based on cotton seed costs and refuge strategies in the United States). Although this might not be entirely appropriate (i.e., the presence of refuges does not increase costs, but rather reduces revenues) it turns out to be a reasonable approximation.

Basic Results and Sensitivity Analysis

In line with the theoretical framework presented in the Appendix, we carry out the analysis by looking at the economic performance on a per-ha basis of conventional and Bt cotton varieties under two different policy settings: the old cotton regime and the reformed one. Such results can then be used to extract a number of propositions on the future of cotton growing in Andalusia. In the analysis we report gross margins, therefore excluding the share of indirect costs.[3] The results of the economic analysis are reported in Table 2. In order to appreciate the results, we also compare the gross margin for cotton with gross margin for oleaginous and protein (OP) crops, which represent the most likely alternative to cotton in Andalusia (Arriaza et al., 2004). In 2005, the average gross margin for OP crops in Andalusia stood at around €500 per ha (Instituto Nacional de Estadística, 2005).

From Table 2 it is evident how the use of Bt cotton varieties always reduces the number of insecticide applications and, therefore, yields higher gross margins. In the base case, under the old cotton regime, the use of Bt cotton varieties reduces the number of sprayings from 5.6 to 2.5. This is consistent with available evidence; our survey (section four) shows how, on average, cotton farmers in Andalusia applied 6 insecticides treatments in 2003/4, while other studies on Bt cotton adoption indicate reductions in sprayings by 2.6-6 applications (e.g., Huang et al., 2002).

In our analysis, due to lower insecticides costs, the gross margin increases from €1,334 to €1,423 per ha (+6.7%). Gross margins for conventional cotton in Southern Spain have been estimated at €816-1,952 per ha, depending on the production system (Arriaza et al., 2004). The range of gross margin advantage of Bt cotton reported in other studies varies from +73% in some regions of India in 2003 (Morse, Bennett, & Ismael, 2005) to +2.2% in the United States (Fernandez-Cornejo & McBride, 2002). The high increase in India, and in developing countries in general, is due to lower availability of insecticides and the significant effective yield improvement associated with the adoption of Bt varieties in these countries (e.g., Shankar & Thirtle, 2005). In Andalusia, where pesticide access is good, the main benefits of Bt cotton are related to reduced spraying costs and therefore will be more limited. Even so, assuming that our results about farmers' attitudes toward Bt cotton could be extended to the whole Spanish production and Bt varieties would have been planted on 46,000 ha (i.e., 85% of the 54,000 ha planted in 2007), the total benefits of Bt cotton to Spanish growers would have exceeded €4 million.

When insecticide resistance among the pest population is significant ($\eta = 0.5$) and/or when the pest is more disruptive ($\beta = 0.4$), the number of insecticide spraying with conventional varieties is higher than in the base-case scenario (7.9 vs. 5.6 in the old regime, and 4.6 vs. 4.2 in the new one). However, when Bt varieties are introduced, the number of spraying is lower than in the base-case scenario (2 vs. 2.5 in the old regime, and 0 vs. 1 in the new one). This occurs because with insecticides resistance the use of insecticides is highly inefficient compared to the use of Bt varieties. Therefore the benefits of deploying Bt varieties are likely to be higher when pest resistance to common insecticides is significant.

While the introduction of Bt cotton in Andalusia would improve farmers' gross margin, our simulation suggests that the implementation of the new cotton regime will severely affect the profitability of the crop. Because of the lower output prices farmers receive under the new regime, they reduce the use of inputs (in our case, irrigation and pesticides).[4] In this context, the use of Bt varieties increases gross margins from €120 to €209 per ha (+74%). However, despite such a considerable increase, cotton farming is still less profitable than alternative crops (average gross margins for OP crops in Andalusia stands at ~ €500 per ha), and therefore the cotton area is destined to decline. Again, this is in line with the existing evidence: following the one-year implementation of the cotton reform, the planted cotton area in Andalusia dropped from 90,000 ha in 2005 to 54,000 ha in 2007 (-40%).

Discussion and Conclusions

The analyses of the farm-level effects of Bt cotton have been mainly performed after the technology uptake (i.e., *ex post*) and focused principally on developing countries (e.g., Qaim et al., 2006) and to a lesser extent on devel-

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[3] *Notice that we specifically refer to gross margin as the difference between revenues and direct production costs. Given our model specification (where some inputs are applied in fixed proportions to irrigation) some of the direct costs (e.g., fertilizers, cultivation, etc.) enter the profit function as 'fixed' (i.e., exogenously determined) costs.*

[4] *This is what actually happened already in Southern Spain in 2006 and 2007, where lower input use reduced the average cotton yield by 30% (USDA FAS, 2007).*

oped countries (e.g., Fernandez-Cornejo & McBride, 2002). However, to the best of our knowledge, a detailed analysis of the potential effects of Bt cotton in the EU does not exist yet.

In this article, we extend the previous analyses in at least three ways. First, we use a survey to ascertain farmers' attitudes toward GM Bt cotton in Andalusia. The results show that, should GM varieties be authorized for cultivation in the EU, the majority of Spanish farmers in the sample would be willing to adopt them. Second, we develop a numerical simulation in order to perform an *ex ante* analysis of the effects of Bt cotton in Andalusia. We explore how the introduction of Bt varieties could affect cotton farmers in Andalusia, where the cotton bollworm is a serious pest. Our results show how the increase in gross margin, associated with the introduction of GM Bt cotton, ranges between €89-259 per ha with the old regime and €89-246 per ha with the new regime. Third, we integrate the analysis of Bt cotton with the analysis of the EU cotton reform. Currently, the analyses of the effects of the EU cotton reform (e.g., Arriaza, & Gómez-Limon Rodríguez, 2006; Arriaza et al., 2004; Kragiannis, 2004) are based on the assumption that only conventional cotton varieties are used. By allowing a reduction in production costs, Bt varieties could help EU cotton farmers to counterbalance to some extent the effects of the sector reform and better face international competition.

We are able to derive a number of stylized facts from the numerical example. Further analysis (not presented here to shorten the discussion) shows that even with Bt varieties, at current cotton world prices of €300 per ton, Spanish farmers would need to reduce their production costs from €1,400 to €1,109 per ha (-20%) without affecting current yields for cotton to be as profitable as alternative OP crops. With total liberalization of the world cotton production, it has been estimated that the maximum increase in cotton world prices could be around 25% (as reported in Baffes, 2004). With world cotton prices at €380 per ton and with the use of Bt technology, Spanish farmers would still need to reduce their production costs by €43 per ha (around 3%) for cotton to be as profitable as OP crops. However, cotton price projections indicate only a moderate increase up to a maximum 10% (Townsend & Gruere, 2007). Assuming a cotton price of €320 per ton, it would require a cost reduction of €232 per ha (16%) with yields unchanged for cotton to be competitive with OP crops in Andalusia. Despite the small and declining size of cotton area in Spain (and in the EU more in general) and the high regulatory costs associated with the introduction of new GM varieties in the EU, it appears that companies like Monsanto are still interested in obtaining access to the EU market, as this might be a precursor to accessing the larger Turkish market (i.e., Turkey will most likely align its regulatory regime to the EU one).

Our results suggest that even with the introduction of Bt varieties, cotton production in Andalusia (and in the EU more in general) is likely to decline unless additional support is paid to cotton farmers (e.g., Arriaza, & Gómez-Limon Rodríguez, 2006). At the same time a process of extensification is also likely to occur. As it stands now, the new regime allows farmers to claim the cotton area payment even if the crop is not harvested. At least some farmers will therefore plant cotton in order to get the area payment, then keep the use of agricultural inputs to a minimum and not harvest the crop in order to cut costs. In 2007 in Andalusia only 45,000 ha out of 54,000 ha planted were harvested, thus leading to a further decline in local cotton supply. Hence, domestically, the decline in cotton production may, in all likelihood, also have knock-on effects on the cotton processing industry in rural areas of Spain with the concomitant social implications. On the other hand farmers in developing countries might benefit from cotton price increases as a consequence of the EU reform (e.g., Minot & Daniels, 2005).

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Appendix

To simplify the analysis, we consider production per unit of land and, drawing on Ameden et al. (2005), we model the farmers' decision problem as one of profit maximization. For conventional cotton varieties we have

$$\pi^C = \underset{x,z}{\boldsymbol{Max}}\; pf^C(x)[1 - D(\hat{N})] - wz - c^C x - F^C + S \quad \text{(A1a)}$$

$$\hat{N} = Nh(z) \quad \text{(A1b)}$$

$$\frac{df^C}{dx} > 0 \quad \frac{d^2 f^C}{dx^2} \leq 0 \quad \frac{dD}{d\hat{N}} > 0 \quad \frac{dh}{dz} < 0 \quad \frac{d^2 h}{dz^2} \geq 0, \quad \text{(A1c)}$$

where p is the output price; f^C represents the production function of conventional varieties per unit of land; x indicates (the vector of) agricultural inputs other than insecticides (e.g., water for irrigation, seeds, fertilizers, etc.); D is the proportion of the output lost to the pest; $\hat{N}$ is the pest population after the application of insecticides; w is the price of insecticides; c^C is the price (vector) of the other agricultural inputs; F^C represents other (fixed) costs; and S is the EU cotton area payment. From Equation A1b it is evident that $\hat{N}$ depends on the pest population before insecticides treatment N and on the proportion of the pest population $0 < h < 1$ killed through the application of insecticides z. Increasing the use of insecticides will increase the proportion h of pests killed but at a decreasing rate (as in the last two inequalities in Equation A1c). Damage levels are increasing in pest population (as in the third inequality in Equation A1c). The production function shows decreasing marginal returns (as in the first two inequalities in Equation A1c). Solution to Equation A1a, given Equations A1b and A1c, will determine the optimal level of agricultural input use x^{C*} and pest control z^{C*} in conventional varieties. The first order necessary conditions (FONC) include $p\frac{df^C}{dx}\left[1 - D\left(\hat{N}\right)\right] = c^C$ and $-pf^C(x)N\eta\frac{dD}{d\hat{N}}\frac{dh}{dz} = w > 0$ (i.e., farmers equalize the value of the marginal product of inputs to their price). The second order conditions (SOC) require $p\frac{d^2f^C}{dx^2}\left[1 - D\left(\hat{N}\right)\right] < 0$ and $-pf^C(x)N\left[\frac{d^2D}{d\hat{N}^2}\left(\frac{dh}{dz}\right)^2\eta N + \frac{dD}{d\hat{N}}\frac{d^2h}{dz^2}\right] < 0$.

When GM varieties are used, the problem is

$$\pi^G = \underset{x,z}{\mathbf{Max}}\; pf^G(x)[1 - D(\hat{N})] - wz - c^Gx - F^G + S \tag{A2a}$$

$$\hat{N} = Nh(z)\eta \tag{A2b}$$

$$\frac{df^G}{dx} > 0 \quad \frac{d^2f^G}{dx^2} \le 0 \quad \frac{dD}{d\hat{N}} > 0 \quad \frac{dh}{dz} < 0 \quad \frac{d^2h}{dz^2} \ge 0. \tag{A2c}$$

The interpretation of Equations A2a—A2c is analogous to Equations A1a—A1c, where the superscript G indicates that we are dealing with GM varieties. GM Bt varieties do not have higher yields *per se* ($f^G = f^C$) but allow for better pest control. As in Ameden et al. (2005), this is modelled by assuming that when Bt varieties are used, a smaller proportion of the pest population N survives. In Equation A2b we account for the proportion $0 < \eta < 1$ of the pest population that survives the 'Bt treatment.' The FONC for Equations A2a and A2b are $p\frac{df^G}{dx}\left[1 - D\left(\hat{N}\right)\right] = c^G$ and $-pf^G(x)N\eta\frac{dD}{d\hat{N}}\frac{dh}{dz} = w > 0$, and the SOC require $p\frac{d^2f^G}{dx^2}\left[1 - D\left(\hat{N}\right)\right] < 0$ and $-pf^G(x)N\left[\frac{d^2D}{d\hat{N}^2}\left(\frac{dh}{dz}\right)^2\eta N + \frac{dD}{d\hat{N}}\frac{d^2h}{dz^2}\right] < 0$. The solution to Equation A2a, given Equations A2b and A2c, will generate the optimal input demand x^{G*} and insecticides application level z^{G*} for Bt varieties.

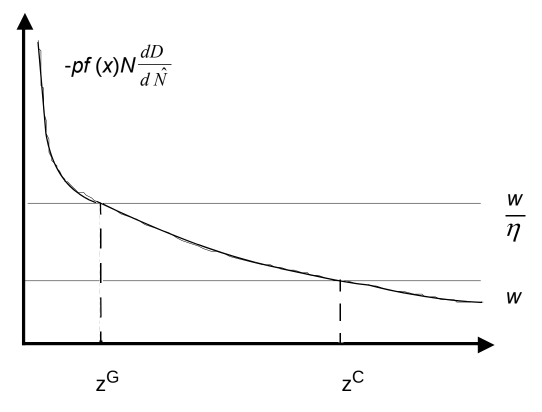

Figure A1. Illustration of the derivation of optimal insecticides use for Bt varieties (z^G) and conventional varieties (z^C).

Figure A1 provides a diagrammatic illustration of the FONC for optimal insecticide use for GM varieties. It is obvious that by increasing the proportion η of the population that survives the Bt trait will lead to higher insecticide use. Using conventional varieties is equivalent to have $\eta = 1$. Everything else equal, conventional varieties ($\eta = 1$) require more insecticides.