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RESEARCH PAPER

Ex-ante impact assessment of GM maize adoption in El Salvador

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ABSTRACT
Bacillus thuringiensis (Bt) white maize was field tested in El Salvador in 2009. Results showed sufficient pest abatement, eliminating the need for insecticide applications, and an average yield increase of 18% above that of the most widely cultivated conventional hybrid. This article presents an ex ante economic impact assessment of Bt maize adoption in El Salvador. Ten-year economic surplus projections show a considerable welfare gain for the overall economy, with consumers being the principal beneficiaries. Trade implications of adopting Bt maize are analyzed and appropriate alternatives to possible market shutdowns are explored. Results obtained in this study could compliment the agronomic evaluation of Bt maize and become part of the Salvadoran government decision process on Bt maize adoption.

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Introduction

Bacillus thuringiensis (Bt) white maize was field tested in El Salvador in 2009. White maize (henceforth maize) is a Salvadoran dietary staple; for subsistence farmers, it is the cornerstone of household food security. The crop is cultivated in mountainous regions with average gradients of over 15%, and primarily, by subsistence farmers on land parcels between 0.3 and 2 ha in size.[1,2] These realities drive the Salvadoran Ministry of Agriculture (MAG) to constantly search for technologies and better management practices, that can be diffused to smallholder farmers. Eventually, genetically modified (GM) Bt maize was considered, and subsequently, field tested. Results showed sufficient pest abatement, eliminating the need for insecticide applications, and an average yield increase of 18% above that of the most widely cultivated conventional hybrid.[3]

Although a regulatory framework for commercialization of GM crops exists, for unclear reasons the Salvadoran government does not allow GM crop cultivation.[4] Additionally, there is minimal public information on the costs and benefits of GM crops to the Salvadoran economy. This article presents an ex ante economic impact assessment of Bt maize adoption in El Salvador. In the following section, the framework and methodology with which Bt maize impacts are measured is outlined and detailed. Next, parameter specifications and assumptions are explained, after which results are presented and discussed. A brief conclusion summarizes the impact assessment.

Economic Evaluation of Bt Maize Adoption

There are various methods with which to assess the ex ante adoption of GM crops. Method selection depends on data availability, the GM crop being considered and any accompanying externalities. The methodology most often used to estimate economic benefits of GM crop adoption is based on the economic surplus model detailed by Alston et al.[5] This model consists of a set of supply and demand equations that model the market as a system. Mathematic manipulation of these equations permits the estimation of total surplus and its disaggregation into consumer surplus (CS), producer surplus (PS) and gross technology revenue (π). The latter being the revenue that accrues to the biotechnology firm in the input market, and other relevant actors in the Bt maize seed supply chain (e.g., seed multiplying farmers, wholesalers of seed, etc.). The model is elicited by making assumptions on parameters such as size and openness of the

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economy; demand and supply elasticities; magnitude and nature of the shift in supply; and the adoption path and rate of the technology.[6–8]

Notwithstanding its limitations (ignoring transaction costs and general equilibrium effects), the model is versatile enough to allow for the estimation of economic impacts from GM crop adoption. In the Salvadoran case, as there is no information on dynamic linkages between sectors, a partial equilibrium model was employed to assess Bt maize adoption.

Beginning at an initial price and quantity equilibrium in the Salvadoran maize market, Bt maize is expected to increase productivity. Thus, the domestic maize supply curve shifts downward from S_0 to S_1; whereas, demand for maize is assumed to remain constant (Figure 1). Linear curves, and a parallel shift in supply (K) were assumed in order to model the impact of Bt maize adoption.[9] The price of maize will decrease from P_0 to P_1 because of expected cost reductions and increased volume of produced maize. As a result, consumer surplus increases equal to the area P_0abP_1, the change in producer surplus is equal to the area P_1bI_1 – P_0aI_0, and total surplus increases equal to the area I_0abI_1. Calculations are computed for all the years of the consideration period (10 years) in which supply curve shifts are expected to be caused by GM maize adoption. After 10 years, the degree of pest abatement provided by Bt maize is likely to change (decrease).

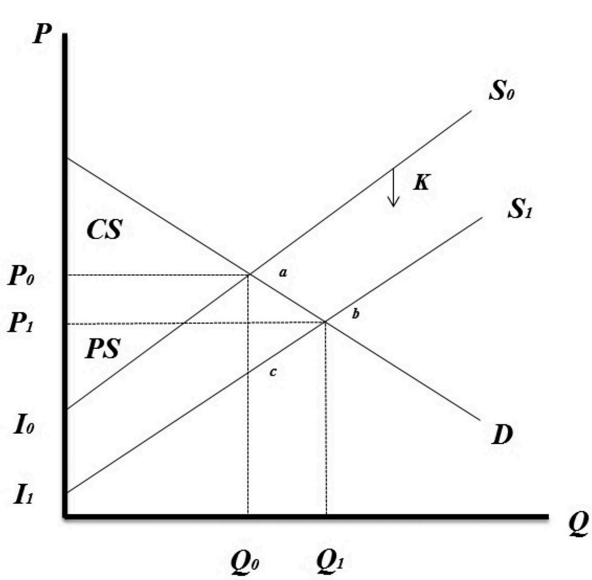

Figure 1. Change in economic surplus from Bt maize adoption in El Salvador.
Source: Adapted from Alston et al.[5]

El Salvador is in the process of phasing out a tariff-rate quota on white maize imports (which will result in more open trade) from the United States under the Dominican Republic-Central America free trade agreement (CAFTA-DR).[10,11] A closed economy was assumed because whether or not El Salvador adopts technologies for its maize sector, ceteris paribus, in 2025 maize imports will represent less than 5% of total average maize production (1996–2014).

Following Alston et al.[5], the annual change in producer surplus (ΔPS) and change in consumer surplus (ΔCS) from Bt maize adoption are measured as:

$$\Delta PS = P_t Q_t (K_t - Z_t)\ (1 + 0.5 Z_t \eta) \tag{1}$$

$$\Delta CS = P_t Q_t Z_t (1 + 0.5 Z_t \eta) \tag{2}$$

where P_t and Q_t are the initial equilibrium price and quantity. K_t is the parallel shift in the supply curve in year t due to Bt maize adoption and is estimated as:

$$K_t = \{[E\ (Y)]\ /\ \varepsilon - [E(C)]\ /\ [1 + E\ (Y)]\}\ p\ A_t (1 - \delta_t) \tag{3}$$

where $E(Y)$ is the expected proportionate yield change per hectare, ε is the price elasticity of supply, $E(C)$ is the proportionate change in variable input costs per hectare to achieve the expected yield change, p is the success rate or the probability that Bt maize will achieve the expected yield, At is the adoption rate (proportional area of Bt maize to total maize production area in year t), and δ_t is the rate of annual depreciation of Bt maize (expected yield reduction) in year t. δ is assigned a value of zero because no decrease in yield is anticipated during the consideration period.[12] p is assigned a value of one because field trials have been undertaken and confirm that an average 18% yield increase is achievable. Moreover, the yield increase over conventional maize hybrids observed in Salvadoran Bt maize field trials is comparable to the yield increase offered by Bt maize in other countries, such as the Philippines (4%-33%) or Colombia (15.4%).[13,14]

Z is the absolute value of the reduction in price as a result of the supply shift and is computed as:

$$Z = K\varepsilon / (\varepsilon + \eta) \quad (4)$$

where η is the absolute value of the price elasticity of demand. Gross technology revenue is computed in the same fashion as Moschini et al.[15] and Krishna and Qaim:[16]

$$\pi_t = Q_{Bt}(P_{Bt} - P_c) \quad (5)$$

where π_t is the gross technology revenue accruing to the biotechnology firm and relevant Bt maize seed supply chain stakeholders providing GM maize seed in year t. Q_{Bt} is the potential coverage area of Bt maize in hectares, P_{Bt} is the price charged for Bt maize hybrid seed per hectare, and P_c is the price of conventional hybrid seed. Once a commercial GM crop has been developed, the seed reproduction process is identical for GM and non-GM crops. It is assumed that the conventional hybrid seed market is competitive, P_c represents the marginal cost of seed production, which is the same for conventional and Bt maize hybrids. Hence, $P_{Bt} - P_c$ is the gross Bt maize seed revenue from which no administrative, marketing or intellectual property rights enforcement costs are deducted. Bt maize seed development costs are assumed to be sunk and are not contemplated in the observed pricing decision.

Change in total surplus (ΔTS) then can be computed as:

$$\Delta TS = \Delta PS + \Delta CS + \pi \quad (6)$$

In the model, impacts are assumed to accrue for the entirety of the consideration period after initial adoption (10 years) in 2016. Thus, the net present value (NPV) is calculated from each annual surplus as follows:

$$NPV = \sum_{t=0}^{10} \Delta TS/(1+r)^r \quad (7)$$

$$NPV = \sum_{t=0}^{10} \Delta CS/(1+r)^r \quad (8)$$

$$NPV = \sum_{t=0}^{10} \Delta PS/(1+r)^r \quad (9)$$

$$NPV = \sum_{t=0}^{10} \pi/(1+r)^r \quad (10)$$

Following Napasintuwong and Traxler[7] and Hareau et al.[17], a discount rate (r) of 5% was applied.

Model Parameter Assumptions

El Salvador is the second largest producer of maize in Central America and virtually all production is destined for human consumption.[18] Table 1 shows total maize production, production area and average yields between 1996 and 2014. Land devoted to maize cultivation has remained relatively constant over this period with an average of almost 266,800 ha planted per year. However, though tending to increase, total production and yield have fluctuated over the same period as drought has become more commonplace. Nonetheless, El Salvador has been able to maintain an average yield of two MT/ha.

In 2009, 91% of maize seed sown was certified hybrid seed; the most common hybrid being H-59 developed in El Salvador.[19] The Salvadoran government supplied 52% of this hybrid seed through its subsidy program: ‘Family Agriculture Plan’ (Figure 2). This subsidy consists of 22 lbs. of certified hybrid seed purchased from private maize seed providers and 100 lbs. of ammonium sulfate.[2] Anyone who solicits the subsidy is eligible to receive it, regardless of whether the producer is a subsistence farmer or a large producer. Non-

Table 1. Maize area, production, average yield, and price per MT (1996–2014).

Year	Planted area (ha)	Total Production (MT)	Average Yield (MT/ha)	Price (USD/MT)
1996	279,090	622,491	1.6	295.5
1997	306,145	501,630	1.1	180.1
1998	295,400	556,418	1.3	188.6
1999	263,410	651,936	1.7	197.2
2000	259,259	576,055	1.6	205.7
2001	294,105	564,977	1.3	269.7
2002	247,441	637,040	1.8	198.0
2003	228,962	627,980	1.9	196.2
2004	220,424	662,277	2.1	263.3
2005	257,057	820,949	2.2	255.6
2006	244,108	615,023	1.8	232.5
2007	240,530	699,416	2.0	241.3
2008	256,420	868,259	2.4	242.9
2009	261,890	785,965	2.1	317.9
2010	253,894	768,113	2.1	296.1
2011	268,392	756,352	2.0	292.1
2012	284,262	925,839	2.3	339.5
2013	294,483	866,701	2.1	292.4
2014	314,343	809,596	1.8	338.6
Average	266,822	700, 896	2	255

MAG[19] data.

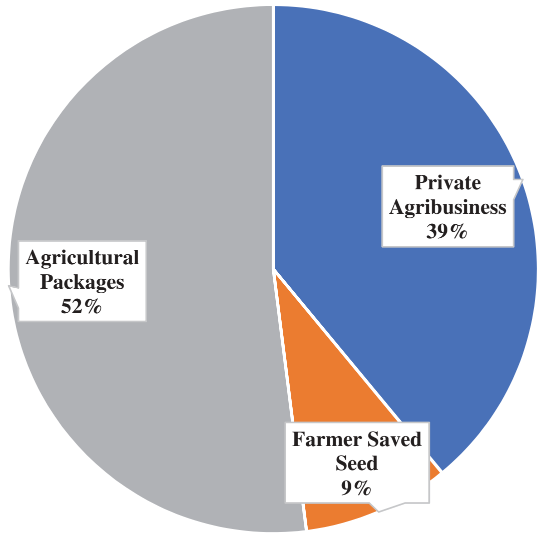

Figure 2. Salvadoran maize seed sector.
Source: Based on Ferrufino[20].

subsistence producers typically solicit an agricultural subsidy package and in addition, purchase hybrid seed so as to increase the amount of land they cultivate. The remaining 9% of sown seed were autochthonous maize landraces, predominantly cultivated in remote regions of the country by subsistence farmers disconnected from the maize market.[20,21]

The overall average cost for a producer planting 1 ha of maize is $1,047.72 (Table 2). This is based on the cost structure developed by MAG for a farmer planting the H-59 hybrid on a non-technical farm (no farm equipment used, all manual labor). According to the cost structure, insecticide and labor required for application accounts for 9% of total cost of conventional maize production. It was assumed that during the consideration period (10 years), except for what Bt maize alters, all other cost components remain unchanged even with gradual adoption.

Table 2. Maize production in El Salvador cost structure.

Cost component	Cost per hectare [USD]	Percentage of total costs
Land preparation seeding and crop work	244.04	23.3
Inputs	533.15	50.9
Harvest	99.48	9.5
Machinery used in harvest	85.65	8.2
Management and incidentals	22.4	2.1
Land rental	63	6.0
Total cost per hectare	1047.72	100
Cost per Metric Ton	374.18	

Source: Adapted from[22].

Equilibrium Price (P_t)

MAG data on the domestic price of white maize were missing for 7 years (1997 through 2000, 2007, 2008 and 2011). So as to not overstate the price per MT of maize, through interpolation a price of $255 per MT over the period 1996–2014 was computed. This price was assumed to be the equilibrium price for white maize in the Salvadoran economy.

Bt Maize Seed Price

The Honduran price of USD 130 per bag of 60,000 Bt maize seeds was used as a proxy because no price, or estimate of a price, for GM maize seeds exists for El Salvador. Moreover, according to field trial data, 62,500 maize plants per hectare are the ideal plant density. A bag of 60,000 seeds was assumed to be sufficient for the sowing of 1 ha of land.

However, an important issue came into focus when obtaining Bt maize seed price. Currently, maize seed cost is $74.16/ha. Bt maize seed is an additional $55.84 above the price of conventional seed, a 75.3% increase in price. Would the government continue the aid program to maize farmers given this price increase? To a financially constrained country with many social problems as El Salvador is, an increase in the price of the subsidy program may become unsustainable. Thus, a scenario in which the government discontinues the subsidy was also simulated.

Expected Increase in Yield (E(Y)) and Change in Variable Input Costs (E(C)) per Hectare

Although El Salvador is located in the tropics where pest pressure is severe, Bt maize provides sufficient pest abatement so as to not warrant insecticide applications.[3,23] Hence, insecticide costs and labor to apply it are deducted from the cost structure. This translates into an overall 9% decrease in per hectare production costs.

Price Elasticity of Supply (ε) and Demand (η)

Own-price elasticity of demand (η) and supply (ε) for maize in El Salvador were not available. In their absence, Iowa State University's Food and Agricultural Policy Research Institute (FAPRI) suggested values for Mexico of ε (0.22) and η (−0.12) were used. These elasticity values were chosen because of geographical proximity, and cultural similarity with El Salvador.

Adoption Rate (A_t)

It was assumed that adoption of Bt maize seed is proportional to the number of hectares of land planted with maize. Thus, the Honduran adoption path and rate of GM maize were considered to serve as a proxy for Salvadoran farmers. However, Falck-Zepeda et al.[24] note that despite years of public and private efforts promoting the use of improved maize varieties, adoption of these was still less than 20%. Given the high percentage use of hybrids by Salvadoran farmers, it was unreasonable to use this adoption path and rate. Moreover, when eliciting an adoption rate, the porousness of the border between El Salvador and Honduras must be considered. Illicit trafficking of merchandise between both countries has long been acknowledged.[25] It is suspected that because of this, GM maize seed may already be cultivated within the geographical borders of El Salvador, albeit on a small scale.

Thus, the initial adoption rate for the scenario in which farmers must acquire transgenic seed was assumed to be 30%. Farmers are already aware of the benefits of planting hybrids and are likely familiar with the success stories of Honduran farmers who use Bt maize seed. For the scenario in which the transgenic seed is provided by the government, the initial adoption rate was assumed to be 52%. Due to 91% of maize seed sown in the country being hybrid, a maximum adoption ceiling of 91% GM maize adoption was assumed to be reached within 10 years.

A logistic adoption curve was derived using the formula employed by Griliches[26], and Alston et al.[5]:

$$A_t = A^{MAX} / 1 + e^{-(-\alpha + \beta_t)} \qquad (11)$$

Where A^{MAX} is the maximum adoption rate. A_t is the adoption rate t years after the commercialization of Bt maize. α and β are parameters that define the path of the adoption rate that asymptotically approaches the maximum. The entire curve was generated by defining three points. Namely, A^{MAX} which was determined to be 91% because that is the ceiling of adoption and the initial adoption of 30% in one scenario and 52% in the other. With that information β can be expressed as a function of α, A^{MAX}, A_t and t.

$$\beta = [ln\ (A_t/\ A^{MAX} - A_t) - \alpha]\ 1\ /\ t \qquad (12)$$

Bt Maize Externalities

Should a GM maize hybrid be cultivated by Salvadoran farmers, it would be almost impossible to stop the flow of GM genes in the form of pollen into the environment. This issue requires in-depth analysis because of the European Union-Central America association agreement (EU-CA). Under this agreement, Salvadoran apiarists are able to export honey to niche European markets. On the 6th of September 2011, the European Court of Justice (ECJ) ruled that honey and food supplements containing GM pollen constitute foodstuffs which contain ingredients produced from GMOs.[27] Honey and food supplements are now classified under the (EC) 1829/2003 regulation on Genetically Modified Food and Feed.[28] In paragraph 11 this regulation specifies that:

> " … authorization may be granted either to a GMO to be used as a source material for production of food or feed and products for food and/or feed use which contain, consist of or are produced from it, or to foods or feed produced from a GMO."

The ECJ ruling applies to honey produced within and outside the EU. Given that maize is cultivated throughout the entire country, it is all but guaranteed that Bt maize pollen will find its way into honey exports. Currently, the EU allows honey to be imported from 'third countries' that cultivate GM crops, amongst the 82 'third countries' authorized to export honey to the EU, 41 currently have EU approved residue monitoring plans in place for honey.[29] Thus, two scenarios are explored: one in which Salvadoran apiarists maintain their exports to the EU (adhering to a residue monitoring program), and another in which they can turn to other free trade agreements.

Table 3. Economic surplus of Bt maize adoption (annuities in thousands of USD).

	Scenario 1				Scenario 2			
Year	*ΔTS*	*ΔCS*	*ΔPS*	*π*	*ΔTS*	*ΔCS*	*ΔPS*	*π*
2016	59,003	31,430	17,143	4,480	103,728	62,148	33,899	7,681
2017	74,506	39,706	21,658	5,645	111,547	66,840	36,458	8,248
2018	91,443	48,757	26,595	6,911	119,744	71,760	39,142	8,842
2019	108,891	58,091	31,686	8,210	128,307	76,901	41,946	9,460
2020	125,814	67,153	36,629	9,464	137,218	82,252	44,865	10,101
2021	141,293	75,449	41,154	10,605	146,456	87,800	47,891	10,764
2022	154,710	82,646	45,080	11,591	155,992	93,530	51,016	11,447
2023	165,808	88,603	48,329	12,403	165,796	99,421	54,230	12,146
2024	174,640	93,346	50,916	13,048	175,832	105,453	57,520	12,859
2025	181,453	97,006	52,913	13,545	186,059	111,602	60,874	13,583
NPV	848,482	503,206	274,476	70,800	1,076,410	645,287	351,975	79,148

Results

Table 3 shows the estimates of economic surpluses for both simulated scenarios. Total surplus increases as Bt maize adoption gradually reaches the adoption ceiling. Greatest total surplus is generated under Scenario 2 with total discounted value of economic surplus being just over USD one billion.

The greatest share of economic surplus accrues to consumers in both scenarios. Producers benefit less because a greater supply of maize will drive down domestic price and generate less revenue. Unsurprisingly, producer surplus is greatest in Scenario 2 in which the government substitutes conventional maize seed for Bt seed and continues the subsidy program. However, producers also benefit from less on-farm time and may enjoy health benefits from not having to apply insecticides to their maize fields.[30,31] This latter benefit should be of particular interest to Salvadoran authorities given that Azaroff,[32] has shown the presence of nonoccupational organophosphate insecticides in farmer's families, in rural El Salvador.

In both scenarios, consumers gain twice as much as producers. Price elasticity of both demand and supply are inelastic, in absolute terms the supply elasticity is larger than the demand elasticity resulting in a greater consumer surplus. This welfare distribution is similar to that found by Napasintuwong and Traxler[7], for GM papaya adoption and Krishna and Qaim[16], for Bt eggplant adoption. In both scenarios, of total surplus generated, over 90% accrues to Salvadoran consumers and producers. That is, only 8% of total benefit generated by Bt maize adoption accrues to the biotechnology firm supplying the Bt maize seed and relevant Bt maize seed supply chain stakeholders.

Salvadoran Honey Exports

Between 1998 and 2015, honey exports steadily increased and in 2016 they suffered a sharp decline (Figure 3). Germany is the principal importer of Salvadoran honey; at times being the only destination of Salvadoran exports. Between 1998 and 2016, El Salvador exported an average of average of USD 3.8 million worth of honey. If Bt maize adoption occurs and the EU subsequently requires Salvadoran honey exporters to undertake a monitored residue program, it can be expected that Salvadoran honey production costs will increase.[29]

Should Salvadoran apiarists be unable or unwilling to abide by a residue monitoring program, eight other free trade agreements are available to Salvadoran honey producers (Table 4). These markets may not be as attractive to honey exporters, but if the government were to allow Bt maize cultivation it may invoke the *compensation principle*, or the *Kaldor–Hicks* Criterion. Maize is a staple food and allowing Bt maize cultivation could potentially add USD one billion in benefits to the Salvadoran economy over the next decade. Honey exports are minimal; the government would most likely take these realities into consideration and incorporate them into their decision-making process.

Conclusions

This ex ante economic impact assessment shows that if Bt maize was allowed to be grown by farmers, El Salvador could substantially benefit from this technology. Most of the benefits would accrue to Salvadoran consumers and producers. Only a minimal amount of generated benefits would accrue to the biotechnology firm and relevant Bt maize seed supply chain

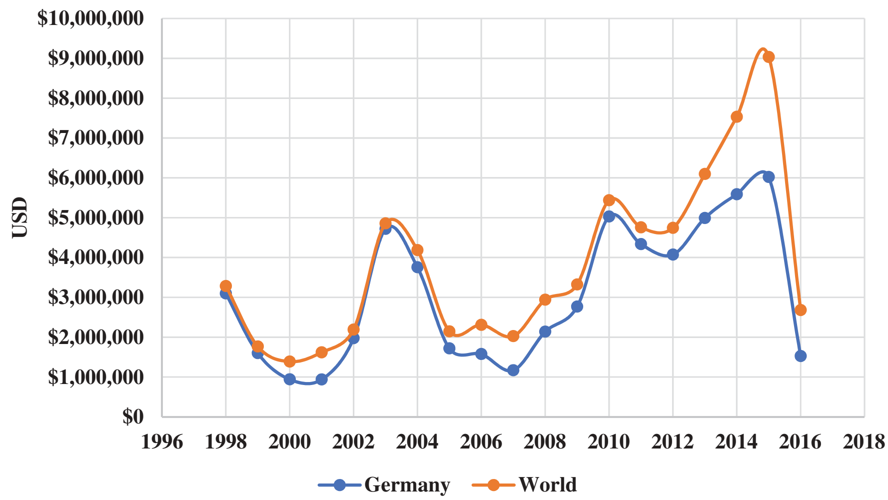

Figure 3. Salvadoran honey exports.
Source: Based UN Comtrade Database.[33]

Table 4. Honey specification in Salvadoran free trade agreements.

Name of Agreement	Tariff (%)	Name of Product	Date Became Effective
North Triangle-Mexico FTA	15	Natural Honey	March 15, 2001
El Salvador, Guatemala, Honduras- Colombia Free Trade Agreement	20	Natural Honey	February 1, 2010
Central American-Dominican Republic FTA	0	Natural Honey	October 4, 2001
Central American-Panama FTA	-	Natural Honey	April 11, 2003
CAFTA-DR	1.9 Cents/Kg	Natural Honey	March 1, 2006
Central America-Chile FTA	0	Natural Honey	June 03, 2002
El Salvador and Honduras-Republic of China (Taiwan)	15	Natural Honey	March 1, 2008
Central America	0	Natural Honey	-

Source: Based on MINEC[34] data.

stakeholders providing the Bt maize seed. Furthermore, honey exports are minimal. It is very likely that the domestic maize sector would take precedence over honey exports. Nonetheless, new markets and alternatives to maintain the EU market are explored and detailed. Results obtained in this study could compliment the agronomic evaluation of Bt maize and become part of the Salvadoran government decision process on Bt maize adoption.

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