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Biotechnology and Demand Concerns: The Case of Genetically Modified US Sugar Beets

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While genetically modified (GM) crops have provided significant agricultural productivity gains in recent years, some consumers oppose GM products as being unsafe. We use the case of GM sugar beets and their recent adoption by US producers to examine the effect of GM technology using a partial equilibrium framework. This analysis provides insights on the demand for sugar from GM US sugar beets versus sugar from non-GMO US sugarcane. We show that the negative demand impacts for sugar from GMO sugar beets can outweigh the supply-induced gains of GM sugar beet research and development. However, this is not likely to come about by mandatory labeling given the recent adoption of the National Bioengineered Food Disclosure Standard, which does not classify sugar as a bioengineered food.

Key words: biotechnology, genetically modified crops, sugar beets, sugarcane, sugar.

Introduction

While genetically modified (GM) crops have provided significant agricultural productivity gains in recent years, a portion of consumers oppose GM products as being unsafe. Even though enhanced agricultural productivity and efficiency gains through GM crops promise benefits to producers and society, a lack of demand for GM products could negate these benefits.

The majority of sugar beets grown in the United States are GMOs. We examine the impact of GMO sugar beet adoption in one product (sugar from sugar beets) in conjunction with sugar produced from non-GMO sugarcane, where questions arise as to whether or not sugar from these two sources are substitutes. There are significant gains from GMO technology provided that there is little consumer resistance to GMO adoption.[1]

Background

Genetically modified (GM) seeds for major crops became commercially available in the United States in 1996 (Fernandez-Cornejo, Wechsler, Livingston, & Mitchell, 2014). Since GM technology became available, the United States has consistently planted the most acres of GM crops in the world (James, 2014). GM crops currently grown in the United States include corn, soybeans, cotton, canola, sugar beets, alfalfa, papaya, and squash (Fernandez-Cornejo et al., 2014). Due to legal battles, GM sugar beets, originally approved for planting in the United States by the US Department of Agriculture, Animal and Plant Health Inspection Service (USDA APHIS) in 2005, were not fully available to be planted by farmers until 2009 (see McGinnis, Meyer, & Smith, 2010, for a review of this legal history). Accordingly, by 2009, 95% of sugar beets in the United States were GM (Dillen, Demont, Tillie, & Rodriguez Cerezo, 2013; McGinnis et al., 2010).

US farmers adopted GM sugar beets more rapidly than any other major US GM crop (Figure 1). Since 2009, approximately half of the domestically produced sugar in the United States has originated from non-GM sugarcane and the other half from GM sugar beets. In addition to the yield increases from GM sugar beets (Table 1), GM crops provide environmental benefits via decreased pesticide and other input usage.

Scientifically, even though sugar beets are GMOs, the sugar derived from these beets contains no traces of GM DNA (Klein, Altenbuchner, & Mattes, 1998). Thus, one can argue that sugar derived from either GM or non-GM sources are perfect substitutes. Even so, many consumers are opposed to GM products despite there being no scientific evidence showing GM products are unsafe (National Academies of Sciences, Engineering, and Medicine, 2016).

US sugar policy plays a major role in sugar production. It has three components: i) non-recourse loans, ii) marketing allotments, and iii) a tariff-rate import quota. Non-recourse loans are provided by the US government to help support the production and processing activities of the sugar industry. To operate this program at zero net-cost to the government, imports are restricted using

1. *This paper draws heavily on the empirical work of Kennedy, Lewis, and Schmitz (2017).*

Table 1. US sugar beet area, yield, and production.

Crop year	Planted	Harvested	Sugarbeets	Yield per harvested acre	Sugar	Recovery rate	Sugar yield per harvested acre
	--- 1,000 acres ---		1,000 tons	Tons	1,000 tons	Percent	Tons
1980/81	1,231.0	1,190.0	23,502	19.7	3,234	13.8	2.72
1985/86	1,125.0	1,102.0	22,529	20.4	2,988	13.3	2.71
1990/91	1,400.4	1,377.2	27,513	20.0	3,854	14.0	2.8
1995/96	1,444.6	1,420.1	28,065	19.8	3,916	14.0	2.76
2000/01	1,564.2	1,373.0	32,541	23.7	4,680	14.4	3.41
2005/06	1,299.8	1,242.9	27,433	22.1	4,444	16.2	3.58
2010/11	1,171.9	1,156.1	32,034	27.7	4,659	14.5	4.03
2015/16	1,159.8	1,145.4	35,371	30.9	5,119	14.5	4.47
2016/17	1,163.4	1,126.4	36,920	32.8	5,103	13.8	4.53
2017/18	1,131.2	1,114.1	35,325	31.7	5,221	14.8	4.69

Source: USDA National Agricultural Statistics Service's crop production data; USDA Farm Service Agency's sweetener market data; USDA World Agricultural Outlook Board's world agricultural supply and demand estimates (WASDE); USDA ERS's sugar and sweetener outlook.

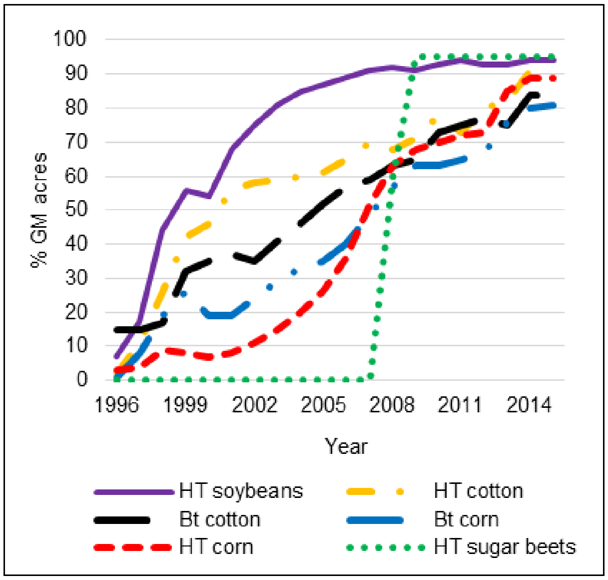

Figure 1. GM crop adoption in the United States.
Source: Dillen et al. (2013); USDA Economic Research Service (2016a, 2016b).

the tariff-rate quota to prevent prices from falling below forfeiture levels. Given these levels of support, marketing allotments are allocated between cane and beet sugar to prevent overproduction and further risk of loan forfeiture.

When these marketing allotments were first instituted, neither sugarcane nor sugar beets were GM. The adoption of GM products by one industry, in this case sugar beets, could have major impacts with respect to whether and how the US government is able to maintain its current sugar program at zero net cost to the government, as legislatively mandated.

The objective of this article is to determine the impact of GM sugar beet technology and its recent adoption in the United States. We employ a partial equilibrium framework to examine the benefits and costs of GM crop adoption. Potential producer gains via increased productivity and efficiency are compared with potential decreases in demand for sugar from GM beets due to the possibility of consumer aversion to GM products.

Theoretical Framework

Previous research has sought to determine the impact of adoption of biotechnology in agriculture. Anderson and Jackson (2003) use a global computable general equilibrium model to determine the welfare impacts of biotechnology adoption in the United States and the European Union for multiple commodities. Alston, Kalaitzandonakes, and Kruse (2014) employ a standard partial equilibrium framework to measure the economic impact of a single commodity, Roundup Ready soybeans. In analyzing the impact of biotechnology adoption in the case of sugar, Kennedy et al. (2017) utilize a partial equilibrium approach to determine the impact of biotech adoption on food security, using a welfare economic framework (Just, Hueth, & Schmitz, 2004; Schmitz, Moss, Schmitz, Furtan, & Schmitz, 2010). We adopt a similar approach here, as it permits us to use shifts in supply and demand to determine the price and welfare effects of various scenarios related to GM adoption.

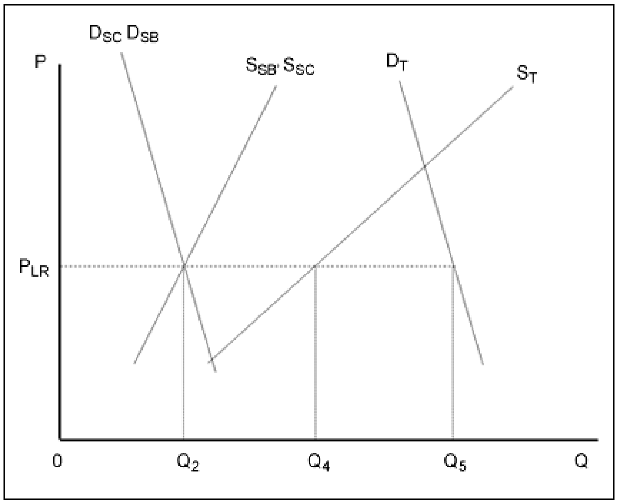

Figure 2. Scenario 1: Impact of GM sugar beet adoption—Reduced beet acreage with constant beet sugar demand.
Source: Authors.

In Figure 2, the total supply of sugar is S_T, where the individual supply curve for sugarcane S_{SC} is identical to the supply curve for sugar beets S_{SB}.[2] US domestic demand for sugar is D_T. US sugar policy regulates the domestic price of sugar through a non-recourse loan program, a tariff-rate quota (TRQ), and domestic marketing allotments. In this example, the non-recourse loan rate sets the effective domestic sugar price at P_{LR}. At the domestic price P_{LR}, domestic sugar beet producers will supply a quantity of Q_2 and domestic sugarcane producers will also supply a quantity of Q_2 for a total domestic supply of Q_4.

The goal of the US sugar policy is to avoid US sugar program expenses by maintaining the US price of sugar above the government loan rate by balancing TRQ imports and domestic marketing allotments. The 2008 US Farm Bill made it law that domestic marketing allotments account for at least 85% of estimated deliveries for domestic human consumption for the fiscal year (October to September). In this example, if an import quota of a quantity equal to or less than $Q_5 – Q_4$ is imposed, the domestic price will be equal to or greater than P_{LR}; prices at these levels would avoid any forfeitures of sugar under the non-recourse loan program. If we assume the government allows imports equal to $Q_5 – Q_4$, then the domestic price will equal P_{LR} and domestic consumption will equal Q_4.

We assume that the domestic sugar beet industry adopts GM sugar beets, which results in increased yields and lower production costs. To analyze the effect of sugar beet adoption by US producers, two production scenarios are considered. In the first scenario, production is fixed, where the yield gains from the adoption of GM technology result in a decrease in the area planted in sugar beets. We assume the reduction in sugar beet acreage will be transferred to the production of alternative field crops. In the second scenario, current sugar beet acreage is fixed, with the increased yields from the adoption of GM technology resulting in proportional increases in beet sugar production.

In conjunction with the two production scenarios, we also consider two alternative demand possibilities. In the first, demand is constant following the adoption of GM sugar beets (consumer demand for beet sugar does not decrease, nor does demand for cane sugar increase). In the second model, the US consumer demand for GM beet sugar declines while consumer demand for domestically produced cane sugar increases (i.e., consumers substitute US cane sugar for a portion of their beet sugar consumption).

We combine these production and demand possibilities to examine four scenarios: (1) reduced beet acreage and constant beet sugar demand; (2) fixed beet acreage and constant beet sugar demand; (3) reduced beet acreage and decreased beet sugar demand; and (4) fixed beet acreage and reduced beet sugar demand.

Scenario 1: Reduced Beet Acreage and Constant Beet Sugar Demand

The initial equilibrium for the US sugar market is given in Figure 2. It provides an example of how the market would react to the adoption of GM beets combined with an acreage reduction (Scenario 1). This is a specific case in which the acreage reduction exactly compensates for production gains through increased yields, leaving the supply curve S_{SB} unchanged. This is consistent with the case where the government-mandated domestic marketing allotment between sugarcane and sugar beets is a historically constant percentage. For example, the fiscal year marketing allocations for 2014, 2015, and 2016 provided 54.35% of the allotment to beet sugar and 45.65% to cane sugar (USDA, 2015). In general, the domestic marketing allotments can fluctuate by year

2. *The domestic marketing allotments provide sugar beets with 54.35% of the overall marketing allotment quantity and sugarcane with the remaining 45.65%. For simplicity, we assume the initial allotments to be identical: 50% for cane sugar and 50% for beet sugar.*

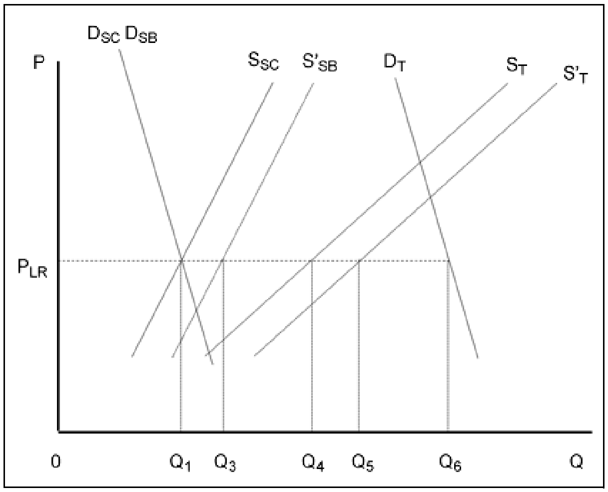

Figure 3. Scenario 2: Impact of GM sugar beet adoption — Fixed beet acreage with constant beet sugar demand.
Source: Authors.

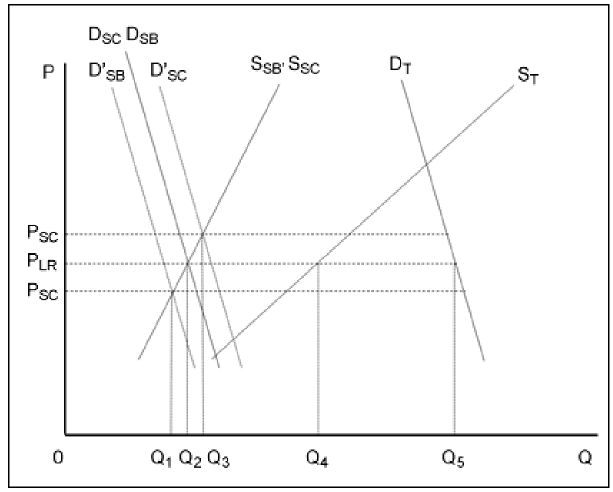

Figure 4. Scenario 3: Impact of GM sugar beet adoption — Reduced beet acreage with decreased beet sugar demand.
Source: Authors.

based on inventories, estimated production, expected marketing, and other factors (USDA, 2015).

All measures remain unchanged from the initial equilibrium assuming demand is unchanged. At the loan rate P_{LR}, domestic production of beet sugar and cane sugar are each Q_2 for a total domestic sugar production level of Q_4. Total US consumption is Q_5, requiring import limits of $Q_5 – Q_4$ to avoid forfeitures given the loan rate of P_{LR}.

This scenario does not cause any changes in the final domestic quantity of sugar produced or consumed. However, the acreage reduction related to beet production will shift to alternative agricultural uses, creating increased output in various potential food and feed crops. This freeing-up of agricultural land for alternative uses increases the availability of non-sugar food products.

Scenario 2: Fixed Beet Acreage and Constant Beet Sugar Demand

While an acreage reduction is a possible outcome of increased yields, marketing allotments for sugar beets could also increase depending on US sugar policy and supply and demand conditions in any given year. In this case, quantity is not fixed. Rather, increased yields will create increased production.

In Figure 3, Scenario 2 assumes that sugar beet acreage remains constant in conjunction with GM-induced yield increases. This results in a rightward shift in the supply curve for beet sugar to S'_{SB}. At the same time, the total domestic supply of sugar experiences an equivalent shift to S'_T. Given these yield-induced shifts in the beet sugar and total domestic sugar supply curves, production of beet sugar increases from Q_2 to Q_3 while total domestic production of sugar increases from Q_4 to Q_5. In order to maintain the loan rate at P_{LR}, the government could reduce the level of imports from a maximum of $Q_6 – Q_4$ to a maximum of $Q_6 – Q_5$.

The increase in domestic sugar production via increased sugar beet yields enhances sugar availability. It is important to note, however, that this increase in domestic production is merely a substitute for a product that could be imported from foreign countries (namely, the quantity $Q_5 – Q_4$) if the price is at the loan rate. Although these actions do increase the availability of a domestic product, given the trade entitlements available to the United States, this action may be described as an increase in self-sufficiency. However, assuming this action displaces foreign exports, this would then serve to increase the world supply of sugar, which would increase the world food supply.

Scenario 3: Reduced Beet Acreage and Decreased Beet Sugar Demand

To this point, the basic impacts of yield enhancement have been examined. However, the case of GM sugar beets becomes more complicated given potential concern among consumers regarding GM beet sugar in their diet. Figure 4 presents the reduced acreage scenario as before but considers the impact of a decreased US consumer demand for GM beet sugar. This is coupled with an equal and opposite increase in the demand for domestic cane sugar as compensation. Note that this scenario may be most likely if GM labeling becomes mandatory in the United States, requiring sugar from sugar beets to be labeled as GM.[3]

In Figure 4, domestic beet sugar demand shifts from D_{SB} to D'_{SB} due to consumer concerns. In reaction, we assume domestic cane sugar demand shifts from D_{SC} to D'_{SC} to fill the void left due to the movement from beet sugar. Assuming product identity is maintained, the domestic beet sugar equilibrium will occur at a quantity of Q_1, down from its prior Q_2 level, and a price of P_{SB}, which is below the loan rate price of P_{LR}. This would imply processor forfeitures under the nonrecourse loan program. Although the shift in consumer demand would result in a producer surplus loss to beet producers, they would receive compensation from the government through the nonrecourse loan program; the incentive to the producer remains to produce quantity Q_2, given the loan rate. The government would suffer potential losses at a maximum of $Q_2 * (P_{LR} - P_{SB})$ if sugar processors do not repay their government loans, forcing the government to take the processors' sugar as collateral. Rather than selling the beet sugar on the domestic market and risk driving the domestic beet sugar price even further below the equilibrium price P_{SB}, the government would likely sell this forfeited product under the sugar-to-ethanol provisions of the loan program to avoid exacerbated downward price pressures on the market. The exact loss to the government will depend on the price obtained for the forfeited sugar and the amount of sugar forfeited.

Without marketing allotments, the increased demand for cane sugar from D_{SC} to D'_{SC} will drive the domestic price of cane sugar up above the loan rate P_{LR} to P_{SC}, resulting in increased cane sugar production from Q_2 to Q_3.[4] Despite the zero net effect on total domestic demand D_T, the nature of the loan program results in zero quantity impact for beet sugar production and an increase in cane sugar production. The acreage reduction related to beet production will shift to alternative agricultural uses, yielding increased output in various potential food and feed crops. This freeing-up of agricultural land for alternative uses increases the availability of non-sugar food products.

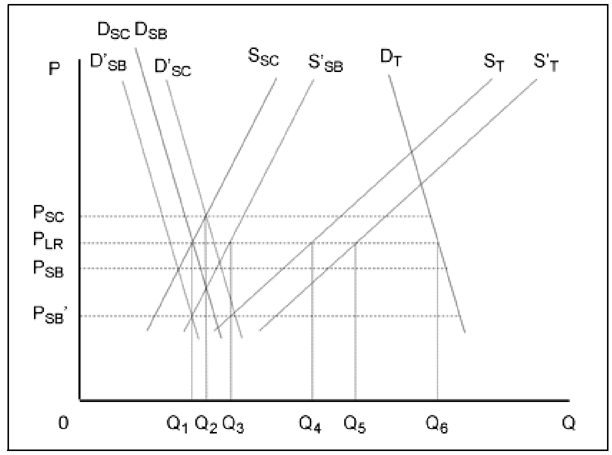

Figure 5. Scenario 4: Impact of GM sugar beet adoption—Fixed beet acreage with reduced beet sugar demand.
Source: Authors.

Scenario 4: Fixed Beet Acreage and Reduced Beet Sugar Demand

The fourth scenario examines the impacts of increased beet sugar production combined with reduced demand for GM beet sugar. Just as the adoption of GM sugar resulted in a decrease in GM beet sugar demand and an increase in cane sugar demand in Figure 4, Figure 5 combines these shifts in demand for domestic sugar with a rightward shift in beet sugar supply. This increased supply resulting from increased beet sugar yields combined with fixed acreage levels results in the new GM beet sugar supply of S'_{SB}.

Given the prevailing loan rate of P_{LR}, beet sugar production will increase from Q_1 to Q_3. However, due to the decreased demand for GM beet sugar, the domestic market clearing price for beet sugar drops to $P_{SB'}$. Beet sugar processors may choose to forfeit sugar under the non-recourse loan program. The outcome of this scenario depends on whether sugar processors choose to forfeit sugar held as collateral and whether the government chooses to dispose of this forfeited sugar in the market or under the sugar-to-ethanol provisions of the loan program. Elimination of these stocks through the sugar-to-ethanol provisions could result in a shortage in the market that either could create new opportunities for domestic cane sugar or could lead to increased sugar imports. An interesting caveat resulting from the potential increase in imports involves the question as to

3. *Some argue that refined beet sugar should be exempt from mandatory labeling, given that sucrose does not contain protein and is thus free of genetic modification.*
4. *It is important to note that current legislation imposes marketing allotments, which would prevent increased production of cane sugar beyond its allocation. This analysis shows the quantity that would be produced should those allotments be adjusted based on changes in consumer preferences.*

whether the imported product filling this void is GM-free.

The corresponding rightward shift in domestic cane sugar demand to D'_{SC} results in increased market prices for cane sugar above the loan rate to P_{SC}. The market price difference between GM beet sugar and non-GM cane sugar results in potential forfeiture under the nonrecourse loan program for beet sugar and prices above the loan rate for cane sugar. The government's decision regarding the proportion of forfeited beet sugar to sell on the market relative to the amount disposed of through the sugar-to-ethanol provisions of the loan program will determine whether the demand curve D'_{SC} will shift even farther to the right, potentially resulting in even greater welfare gains to cane sugar producers. These price impacts and the demand for domestic cane sugar are dependent on the amount of foreign sugar allowed to enter the domestic market.[5]

Price Impact of Increased Beet Sugar Yields

Given the USDA's nonrecourse loan and marketing allotment programs for sugar, the scenarios in which domestic demand for beet sugar remains constant will have a minimal price impact on the domestic market. Scenario 1, in which production remains constant, would have no impact on the sugar market; excess acreage would shift to other production sectors, affecting those markets. When acreage remains constant and production increases, as shown in Figure 3, the domestic price can be maintained at or above the loan rate by decreasing the import quota to avoid forfeitures.

The cases where demand for beet sugar shifts due to perceived product differentiation will impact prices. The ultimate outcomes will depend on the policy response of the USDA. In the case of reduced beet acreage and decreased demand (Figure 4), the equilibrium market price for beet sugar falls to P_{SB}. Since this is below the nonrecourse loan rate of P_{LR}, beet sugar could be forfeited to the government. Potential options on the part of the government would include, but are not limited to, some combination of the following: (1) transfer a portion of the sugar beet marketing allotment to sugarcane producers to avoid forfeitures; (2) decrease the nonrecourse loan rate for sugar beets to be consistent with the new equilibrium conditions to avoid forfeitures; (3) dispose of forfeited sugar through the sugar-to-ethanol provisions of the loan program and potentially incur government costs; and (4) dispose of forfeited sugar through domestic or international markets and potentially incur government costs.

The scenario in which beet sugar supply increases and beet sugar demand decreases will result in an even greater decrease in domestic beet sugar prices. Figure 5 shows both a supply effect and a demand effect on beet sugar prices. The initial increase in demand from D_{SB} to D'_{SB} results in a demand induced price decrease from P_{LR} to P_{SB}. The downward pressure on prices is further exacerbated when supply shifts outward from S_{SC} to S'_{SB}, causing a supply-induced price effect as the price moves to $P_{SB'}$. The government is now faced with the same problems and potential solutions as outlined in the previous paragraph; however, the problem is now aggravated due to increased beet sugar production and lower beet sugar prices. The adjustment of marketing allotments and loan rates would increasingly become a viable alternative as greater volumes of sugar are forfeited in combination with lower equilibrium prices.

While these events have not yet come to fruition, if mandatory labeling were adopted and sugar from beets were labeled as GMO, this could serve as a catalyst for these scenarios to occur. However, even without mandatory labeling, Charles (2016) shows that cane sugar has been trading at a \$0.03 to \$0.05 premium over beet sugar. If the labeling of GM sugar becomes US law, it is possible that the beet sugar price and cane sugar price could diverge even further. In a situation where the GM beet sugar price falls below the loan rate while the cane sugar price stays above the loan rate, there could be a circumstance for policy intervention by the USDA to modify the domestic marketing allotments and/or beet sugar loan rate to operate the sugar program at no cost to the government.

Quantitative Example of Increased Beet Sugar Yields

We now explore the impact of GM sugar beets on yields and compare GM sugar beet with non-GM sugarcane yields from 1980 to 2018 (Figure 6). During this period sugarcane yields are more variable than sugar beet yields, but sugar beets have demonstrated a greater rate of growth, particularly from the mid-1990s to 2018. GM sugar beets accounted for approximately 95% of beet sugar production by 2010 (McGinnis et al., 2010).

5. *Our analysis precludes the possibility that imported sugar could come from genetically modified sugarcane. Additional issues will need to be examined if foreign countries begin using GM cane sugar to fill their tariff-rate quotas.*

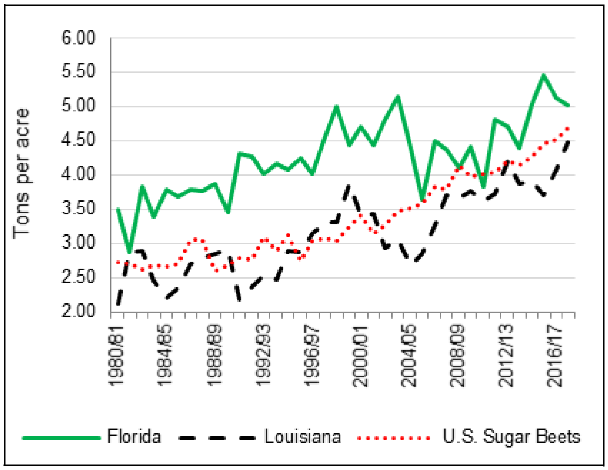

Figure 6. Sugar yields for US sugar beets and sugarcane, 1980/81 to 2017/18.
Source: USDA ERS (2018b).

We examine the impact of increased yields with fixed acreage and with fixed output to show the potential impact of biotechnology adoption through increased beet sugar production as well as through the increased production of alternative crops. Table 1 presents sugar beet area, yield, and production data from the 1980/81 market year through 2017/18 (USDA Economic Research Service [ERS], 2018b). Given that 95% of US sugar beets have used GM seed since the 2009/10 crop year (Dillen et al., 2013; McGinnis et al., 2010), the 2009/10 through 2017/18 period (the GM period) is compared with the 2000/01 through 2008/09 period (the pre-GM period).

The pre-GM period had a beet sugar yield per harvested acre averaging 3.58 tons compared to 4.26 tons in the GM period, an increase of 19.20%. Average annual harvested acres were 1.27 million in the pre-GM period, decreasing by 8.94% to 1.16 million in the GM period. Annual production averaged 4.52 million tons of beet sugar in the pre-GM period and increased by 8.95% to 4.92 million tons in the GM period.

Fixed Sugar Beet Acreage versus Fixed Production

In examining the implications of GM sugar beet adoption, we consider the case of fixed sugar beet acreage and the resulting increased production versus the case of fixed production levels and the accompanying decrease in land use. To determine the impact of increased yields with fixed sugar beet area, the average harvested area from the pre-GM period (1.27 million acres) is multiplied by the sugar yield per harvested acre from the GM period (4.26 tons of sugar per acre) to derive total production of 5.42 million tons. This indicates that, had acreage remained the same in the GM period as it was in the pre-GM period, beet sugar production would have increased by 19.20%. As it was, beet production increased by only 8.95% as harvested acres decreased by 8.94% (USDA ERS, 2018b).

To determine the impact of increased yields with fixed beet sugar production, the pre-GM average beet sugar production (4.52 million tons) is divided by the GM period yield (4.26 tons per acre), which yields 1.06 million acres. This indicates that 209,462 less acres are required in the GM period to attain the same amount of sugar produced in the pre-GM period, which can be compared to the actual decrease in acreage of 113,478 acres from the pre-GM to GM period (USDA ERS, 2018b).

During the period from 2009/10 to 2017/18, the average corn yield per harvested acre was 159.51 bushels per acre (USDA ERS, 2018a). If the displaced 209,462 acres were to shift into corn production, total annual corn production would increase by 32.45 million bushels. Given average annual US corn production of 13.33 billion bushels during this period, the addition to corn acreage would account for a 0.243% increase in US corn production. Although this increase in US corn production is less than 1%, its impact on the world food supply could be quite important considering that the United States accounts for roughly 40% of the world's corn production (USDA ERS, 2018a).

The Interface between GM Crop Adoption and Demand

Upon conducting an environmental assessment, USDA/APHIS unconditionally approved the GM glyphosate-tolerant sugar beet event H7-1 and found there to be no significant impact on the environment from its unconfined cultivation (Smith, 2005). In addition, and prior to the USDA/APHIS approval of this GM sugar beet variety, it had been shown that the sugar obtained from conventional and transgenic beets was indistinguishable or substantially equivalent with respect to purity (Klein et al., 1998).

Given these findings combined with the yield increases achieved through GM sugar beets, it appeared at first glance that the adoption of GM sugar beets would be a win-win situation (Pollack, 2007). However, according to a recent National Public Radio broadcast, public pressure is causing candy makers to begin label-

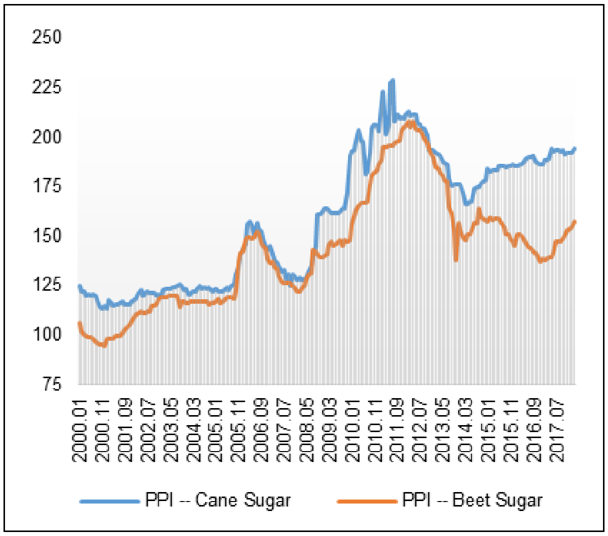

Figure 7. Refined sugar prices, monthly producer price indices for US cane and beet sugar, January 2001 to March 2018. Producer price indices: 1982=100.
Source: USDA ERS (2018b).

ing their products as non-GM. As a result, the demand for beet sugar has declined while the demand for cane sugar (both domestic and imported) has increased (Charles, 2016). This increasing distinction between beet sugar and cane sugar has occurred even without mandatory labeling. If demand for GM is affected by consumer aversion, to what extent could the potential adoption and impact of GM be affected?

This perceived dissimilarity between cane and beet sugar may be manifested through refined wholesale sugar prices. The refined beet sugar wholesale price in 2015/16 averaged \$0.3055 per pound, a \$0.0235 or 7.14% discount to the comparable cane price of \$0.3291 per pound (McConnell, 2016). The difference in these prices was only \$0.0023 or 0.65% in 2014/15 (McConnell, 2016). This can also be seen through the respective producer price indices. As shown in Figure 7, the producer price indices for refined cane and beet sugar followed each other closely prior to 2009. The two indices began to diverge after 2009, with the refined cane sugar receiving an increased premium starting in 2015. This can be compared with the findings of Carter and Schaefer (2018), who identify a 13% discount to beet sugar and a 1% premium to cane sugar resulting from mandatory labeling.

The market fundamentals for cane and beet sugar appear to have shifted, differing from those of the aggregate US sugar market. According to McConnell (2016), several significant developments in the US sweetener market have contributed to this shift. Among these are the "purported consumer preferences toward GMO ingredients and food manufacturers' labeling requirements for their food products" (McConnell, 2016). Examinations of mandatory labeling have shown that mandatory labels can improve consumer attitudes toward GM product (Kolodinsky & Lusk, 2018), while in the case of sugar (Carter & Schaefer, 2018) it has been shown that mandatory labeling resulted in a price discount for GM product.

Although the mandatory labeling of GM products had not yet gone into effect in the United States, the previous example indicates that, even so, there was sufficient product distinction to result in a price differential between beet sugar and cane sugar. However, the National Bioengineered Food Disclosure Law, which is set to go into effect in 2019, will create a mandatory national system for disclosing bioengineered material (USDA Agricultural Marketing Service, 2018).

The question remains as to how voluntary and mandatory GM labeling could influence GM food prices and the adoption of biotechnology in agriculture. In exploring the role of consumer confidence in the ability of institutions to safeguard the food supply in determining their desire for mandatory GM beet sugar labeling, DeLong and Grebitus (2018) found that consumers who had greater trust in food manufacturers and the government to ensure the safety of food were less likely to desire GM labeling of beet sugar. The meta-analysis by Lusk, Jamal, Kurlander, Roucan, and Taulman (2005) revealed that consumers discounted GM labeled food by 23% to 42% compared to non-GM food. Globally, GM-labeling research indicates that mandatory GM labeling can act as a market barrier, which prevents GM products from even appearing on supermarket shelves (Carter & Gruère, 2003). This finding was similar to the decision of Hershey's to stop purchasing sugar from GM sugar beet producers (Charles, 2016).

While food processors, such as Hershey's, could choose to discontinue or reduce their use of sugar from GM sugar beets, the issue of mandatory labeling is more complicated. Although research has been conducted to determine the impact of mandatory labels for sugar from GM sugar beets (Carter & Schaefer, 2018; Lewis, Grebitus, & Nayga, 2016), sugar is not a GM product (Klein et al., 1998). At the extreme, sugar from GM sugar beets could be labeled as a product produced from a GM crop.

The reality of a situation, however, does not always correspond with what theory predicts. In the case of the impact of GM sugar beet adoption, our four scenarios reveal that there are several outcomes that may exist based on the US sugar policy. In particular, it is possible that there will be more opportunity for domestic US sugar within the bounds of the US sugar policy, especially after the antidumping/countervailing lawsuit between Mexico and the United States over sugar. If the outcome of this suspension agreement results in less Mexican sugar entering into the United States, then the price of sugar should be above the loan rate and will allow US sugar beet growers to market their additional sugar.

This issue becomes more complicated as other countries adopt GM technology to produce sugar for export to the United States. Suppose Brazil were to begin planting GM sugarcane. Would the resulting cane sugar be free to enter the United States as part of Brazil's TRQ? On the one hand, if foreign GM products could enter freely, then both sources of sugar in the United States (cane and beet) would be GM, and it is likely the price differential between cane and beet sugar would diminish. On the other hand, if imports of GM sugar were limited or subject to mandatory labeling requirements, then the price differential between GM and non-GM product could become even greater.

A Quantitative Examination of GM Crop Adoption and Decreased Demand

To determine the producer impact of GM technology adoption, consider Figure 8. Adoption of GM technologies shifts the supply curve from S_1 to S_2, given demand D_1. This could occur from either increased yields or cost savings. Assuming no change in consumer demand, the new equilibrium occurs at a price of P_2, lower than the initial price of P_1. Producers experience a welfare loss shown as area A+B. Concurrently, the shift in supply increases producer welfare by D+E+F, resulting in an overall producer welfare gain represented by area D+E+F-A-B.

Suppose now that demand for the GM product decreases. This is reflected in Figure 8 by a shift in demand from D_1 to D_2. Combined with the previous shift in supply from S_1 to S_2, the resulting equilibrium price falls to P_3. The overall producer welfare loss from the price decrease is shown as area A+B+C, while the producer gain from the supply shift is area F. This results in a producer welfare gain of F-A-B-C, which is less than the producer welfare gain of D+E+F-A-B that resulted from increased productivity alone.

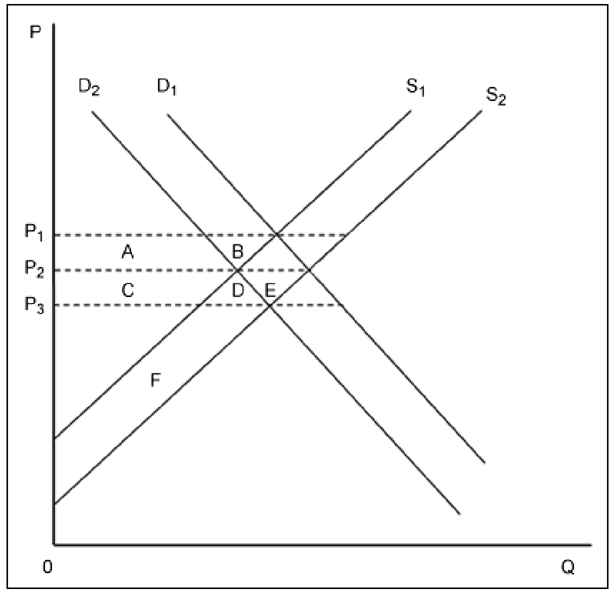

Figure 8. Producer welfare implications of productivity gains and decreased demand.
Source: Authors.

These impacts can be categorized as those stemming from either productivity gains or palatability losses. The *Gains from Productivity* are producer welfare gains that occur due to the technology-induced shift in the supply curve, shown as area D+E+F-A-B. The *Loss from Palatability* are producer welfare losses that occur due to the decrease in demand for the product, shown as area C+D+E. As before, this results in a net producer gain of F-A-B-C. If F-A-B-C > 0, then the GM technology adoption is successful for the producer.

To quantify these producer welfare impacts, we utilize a partial equilibrium framework based on the 2005/06 crop year (prior to GM adoption). Price elasticities of 0.50 and -0.24 of supply and demand, respectively, are obtained from the Trade Liberalization Database (Gardiner, Roningen, & Liu, 1989). Using linear supply and demand and holding quantities of cane sugar supply and imports constant, the market-clearing equilibrium is determined following shifts in supply and demand.

Given an increase in beet sugar yields of 31.17% from the 2005/06 to 2016/17 crop years, we simulate a positive 10%, 20%, and 30% shift in supply while holding demand constant. The corresponding shift in demand that exactly negates producer welfare gains is then calculated.

Table 2 illustrates the results of this analysis. Our results show that the producer welfare gains resulting from a 10% increase in productivity could be negated by

Table 2. Change in equilibrium quantities, prices, and producer welfare given alternative shifts in supply and demand.

	Equilibrium quantity	Equilibrium price	Producer surplus losses (million dollars)	Producer surplus gains (million dollars)	Producer surplus change (million dollars)
Status quo: 2005/06	4,444.00	36.007			
Supply shift: +10%	4,516.06	33.574	$212.582	$317.216	$104.634
w/-1.935% demand shift	4,444.00	32.406	$312.027	$312.027	$0.000
Supply shift: +20%	4,516.06	31.141	$417.859	$628.810	$210,951
w/-3.871% demand shift	4,444.00	28.805	$608.052	$608.052	$0.000
Supply shift: +30%	4,516.06	28.708	$615.830	$934.782	$318,952
w/-5.806% demand shift	4,444.00	25.205	$888.076	$888.076	$0.000

Note: quantities are in 1,000 tons, prices are in cents/lb

a 2% decrease in demand. Similarly, a 20% and 30% increase in productivity could be negated by 4% and 6% decreases in demand, respectively.

It is important to note that our analysis does not account for the rents extracted from producers by the owners of the GM technology. While farmers may experience decreased input costs through lowered herbicide usage or increased revenue through yield gains, biotech firms will consider these impacts in determining the price of GM seed. From this perspective, this analysis likely overestimates the shift in demand necessary to negate producer gains.

However, our analysis estimates the shift in supply based only on yield gains. The resulting decrease in herbicide usage from this technology decreases production costs, thereby resulting in an additional outward shift in supply. Further, Schmitz and Zhu (2017) demonstrate that the return to research and development may be underestimated given that the adoption of technology not only allows producers to increase yields, but also provides for yield maintenance. Additionally, given the variety of crops that could be grown on the acres shifted from sugar beet production, this analysis does not account for the benefits to producers resulting from that additional production. From these perspectives, this analysis may underestimate the producer gains from adoption of this technology as well as the shift in demand necessary to negate producer gains.

Conclusions

At first glance, one might assume that the adoption of productivity-enhancing biotechnology in agriculture would benefit producers. Based on the analysis presented here, this result is not a foregone conclusion. The adoption of GM varieties has the potential to increase the efficiency of producers and yield greater productive capacity. However, if consumers consider a GM product to be inferior, their aversion could erode producer benefits from GM adoption. A similar case involved the adoption of hardy tomato varieties suited to mechanical harvesters. Adoption of these varieties allowed for efficiency gains in production, but the quality of the resulting produce was viewed to be inferior to existing varieties (Schmitz & Seckler, 1970). The resulting product differentiation often results in decreased demand for the product considered inferior. The eventual equilibrium may occur at some level of decreased prices or quantities that leave the producer worse off than prior to adoption of the new technology.

The USDA suggests (McConnell, 2016) that consumers have started to differentiate between beet sugar and cane sugar. From a product perspective, beet sugar is not different from cane sugar. The sweetener that results from both plants following the extraction process is sucrose. Klein et al. (1998) notes the homogeneity of beet and cane sugar given that proteins are absent in refined sugar; the only difference is the source.

Regardless of the preferences of the consumer, some food retailers and processors may avoid products and inputs that are GM. For example, a grocer who wishes to retain the patronage of GM-wary consumers may refrain from carrying GM products. As a result, the pro-GM consumers' demand for GM products could decrease through lack of availability rather than preferences. As a result, there can be direct and indirect demand effects. This *direct effect* occurs because some consumers do care. They decrease or cease their consumption of GM products. The *indirect effect* occurs because some food manufacturers and/or retailers may reduce or halt use of GM products to retain GM-averse customers. That portion of the population decreases consumption of GM products due to lack of availability.

The ultimate outcome of GM sugar beet adoption will be influenced by factors such as labeling requirements and marketing strategies. Requirements to label GM beet sugar could reduce the demand for beet sugar and negate production efficiency gains. Likewise, adoption of a program by the US cane sugar industry to voluntarily label their product as non-GM could have the same impact. The questions that remain to be answered are whether consumers will view sugar from GM beets as inferior to sugar from non-GM cane and the impact of consumers' concerns on demand.

The recent contrast between GM beet sugar and non-GM cane sugar creates the potential for market segmentation. However, producers adopt new technologies not only to increase yields, but also for maintenance purposes. Given the relatively stagnant yields since 2000 (Schmitz & Zhu, 2017), genetic modification may provide the best opportunity for sugarcane producers to increase and maintain efficiency, but at what cost? Just as the sugar beet industry must evaluate the gains and losses from their adoption of GM technology, the US sugarcane industry should weigh the production and efficiency gains of new technologies, including GM, with potential losses stemming from consumer concerns.

Sugar provides an interesting case to consider given the current US sugar program. The US Secretary of Agriculture is charged with operating the US sugar program at zero net cost to the government. This has been accomplished using a non-recourse loan program in combination with an import quota and marketing allotments for all domestic beet sugar and cane sugar, which were viewed as near-perfect substitutes when both were non-GM. Despite knowledge that sucrose is a homogeneous product (Klein et al., 1998), the categorization of sugar as GM and non-GM results in a differentiated product. Interestingly, according to long-standing FDA policy, since sugar from GM beets has not been deemed to be unsafe or materially different from conventional sugar, labeling would not be required (Kalaitzandonakes, Lusk, & Magnier, 2018). The existence of differentiated sugar products (sugar from non-GM cane and sugar from GM beets) may require the government to rethink its operation of the program. Should demand for sugar from GM beets be dramatically reduced, market allotments may need adjustment and loan rates reevaluated and differentiated to avoid GM beet prices falling below the loan rate.

The structure of this market and nature of the government support also has implications for the distribution of benefits from GM adoption. Our analysis shows that, given constant demand, sugar beet producers stand to benefit from biotechnology adoption while sugarcane producers may experience depressed prices. Consumer aversion to the biotech product could alter this outcome. If demand for the GM product (beet sugar) decreases while demand for the non-GM product (cane sugar) increases, then scenarios could exist in which sugar beet producers are worse off while sugarcane producers benefit from the sugar beet industry's adoption of GM product. With respect to GM adoption decisions, this has implications as to whether the early adopter will regret these decisions and whether the late adopter will ever choose to adopt GM technology.

Even though sucrose from sugarcane and sugar beets is identical (Klein et al., 1998), the categorization of sugar as GM and non-GM has implications for industry with respect to distribution and product segregation. Given the homogeneity of cane and beet sugar, the cost of segregating these products could be difficult and come at a significant cost. These increased costs could negatively affect overall sugar demand and the size of this market.

The adoption of GM technology in sugar beet production has provided a breakthrough to allow for productivity gains. Yet with these productivity gains come questions as to consumer perception of the desirability of the resulting product. This scenario highlights the interdependence of productivity and palatability. While productivity gains are certainly a desirable objective, they come at a cost if decreased demand negates technological gains.

The producer impacts resulting from the adoption of GM crops hinge on whether consumers decrease their demand for the resulting products. Although consumer tastes and preferences may vary over time, one way that consumer perception can be influenced is through labeling. While mandatory labeling could influence the consumption of sugar from GM sugar beets, this is not likely to come about given the recent adoption of the National Bioengineered Food Disclosure Standard (NBFDS). The NBFDS states that refined foods or ingredients that do not contain detectable modified genetic materials are not bioengineered foods and are not required to be labeled as bioengineered foods. When interpreting our findings, the above new GMO labeling requirement should be kept firmly in mind.

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