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Will consumers lose or gain from the environmental impacts of transgenic crops?

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Abstract

Opposition to genetically modified food encompasses environmental concerns, food-safety concerns and ethical objections. Potential environmental benefits from transgenic crops are not well accepted. Genetic modification is a credence attribute that cannot be detected by consumers without labelling. In the absence of labelling a pooling equilibrium results in an adverse quality effect for those consumers who prefer not to consume genetically modified (GM) food for environmental or food-safety reasons, but may result in a beneficial price effect for all consumers if the innovation is drastic. Labelling enables consumers to express their environmental preferences through the marketplace and can mitigate the adverse quality effect, but only in the absence of cheating. Both mandatory GM and voluntary non-GM labelling will impose segregation costs on the non-GM sector, leading to an increase in prices. The challenge will be to allow technological advances in agriculture that increase yields, reduce costs and improve product quality, while respecting consumer preferences. Future research could assist by improving our understanding of the consumer decision-making process, including how consumers react to new information and how consumers would respond to future GM products with direct consumption or environmental benefits.
Keywords: consumer welfare; labelling; transgenic crops

Introduction

Transgenic crops have been adopted rapidly in some countries in response to their perceived agronomic and economic benefits to producers. Herbicide-tolerant varieties and crops genetically engineered to be resistant to targeted pests offer the potential for reduced agricultural-chemical use, lower input costs and higher yields. Where approved for release, the relatively rapid adoption of transgenic varieties of soybean, corn and canola means that food derived from genetically modified crops quickly found its way onto retail shelves. Many processed foods contain soy protein or soy derivatives, and the majority of soybean crops grown in the US and Canada are now transgenic varieties. Consumer reaction to food derived from transgenic crops has been decidedly mixed, ranging from vocal opposition among some consumers and interest groups, to confusion or puzzled indifference among others. This paper examines the consumer reaction to genetically modified (GM)[1] food, focusing on the

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potential consumer benefits and costs from the perceived environmental impacts of transgenic crops.

Consumer reaction to GM food is complex and multi-faceted. Broadly speaking, consumer concerns can be split into four groups: specific food-safety concerns, fear of the 'unknown' consequences of consumption, ethical concerns and environmental concerns. Although the primary focus of this paper is on environmental concerns, it is useful to outline the other issues briefly. Specific food-safety concerns relate to allergens and the use of antibiotic-resistant marker genes. Some consumer groups have expressed concerns that transgenics could result in the transference of allergens into foods in which they were not previously present. This risk is explicitly recognized in the European and North-American regulatory systems and the use of potentially allergenic genes is strictly regulated. The use of antibiotic-resistance marker genes to track the presence of a modified gene also raised concerns that this practice could contribute to the growth of antibiotic resistance in humans and animals (Gaisford et al. 2001).

Specific food-safety concerns relate to known risks that can be addressed through the regulatory system. In contrast, food-safety concerns over the potential long-run, unknown consequences of ingesting GM food present a more difficult problem. These concerns are not based on clear scientific evidence; instead they reflect a lack of confidence in the ability of scientific analysis to identify long-run risks. An element of uncertainty is introduced into the consumer decision-making process. For the most part, consumer unease over the long-run consequences of consuming GM food has been exacerbated by a series of high-profile food-safety scares, including Bovine Spongiform Encephalopathy (BSE) in beef. Lack of trust in the regulatory system and weakened confidence in the ability of science to determine long-run food-safety risks were consequences of high-profile food-safety problems.

The third group of concerns can be classed as ethical objections to transgenic technology and the patenting of genetic material. For some consumers, mixed with this is often a suspicion of or hostility towards the large multinational firms that are seen to dominate the agricultural biotechnology sector. Finally, some consumers and environmental groups have expressed concerns over the potential environmental consequences of introducing transgenic crops into cropping systems. While the purpose of this paper is to examine the environmental aspect of consumer responses, it is important to recognize that consumer unease over transgenics is multi-faceted. As a result, 'genetic modification' of food has become a lightening rod for a powerful coalition of interest groups.

Examining the potential environmental impacts of transgenic crops

Concerns over the potential environmental impacts of transgenic crops include fears about evolutionary resistance in target organisms, potential outcrossing with weedy relatives, the use of 'terminator' genes, reduction in biodiversity and damage to non-target organisms[2] (Gaisford et al. 2001). Evolutionary resistance in target organisms as a result of continuous use of specific herbicides or pesticides is an ongoing concern in cropping systems and is not limited to transgenic crops. The possibility of outcrossing between the transgenic variety and wild weed relatives through cross-pollination is a paramount concern for many environmentalists who fear the transference of herbicide resistance to weeds could make them harder to control, disrupting ecosystem balances. The use of so-called 'terminator' genes to prevent seed germination in transgenic crops has raised fears that this gene could contaminate other crops; however, sterile seeds cannot contaminate the gene pool as the trait cannot be passed on. Environmental groups have raised concerns that transgenic crops with a clear agronomic advantage could increase monoculture production and reduce biodiversity. As with the development of resistance, however, this concern is not unique to transgenic crops and could occur with the development of superior conventional varieties. Finally, potential negative effects on non-target organisms such as butterflies or beneficial insects and fungi from transgenic crops designed to target a different specific pest have been raised. Intense media attention and conflicting scientific studies, for example, related to Monarch butterflies[3], have fuelled these fears (Gaisford et al. 2001).

While the potential negative environmental impacts of transgenic crops have garnered most of the media and public attention, there is also a range of potential environmental benefits, which have a lower profile in terms of public awareness. The most important environmental benefit is the potential to reduce the application of chemical pesticides and herbicides. The transfer of genes from *Bacillus thuringiensis (Bt)* into crops such as corn and cotton produces toxins that kill target pests, reducing the need to use chemical pesticides. Through transgenics, herbicide-tolerant crops such as corn, soybeans and canola have been developed that are resistant to broad-spectrum herbicides. In theory this should enable farmers to kill weeds with fewer chemical applications and facilitate the use of 'zero-till' production systems. Transgenic technology offers the promise of future plants engineered to be resistant to major diseases and tolerant of environmental stresses; in turn this could reduce the use of fungicides and chemical fertilizers or reduce the need to irrigate (Gaisford et al. 2001). Reduced soil erosion is another potential agronomic benefit if fewer pre-emergent chemical applications are required, since this practice can result in higher moisture conservation and can reduce impacted soil problems from heavy machinery.

Clearly, there are a range of potential environmental problems and environmental benefits from transgenic crops. The extent to which consumers perceive the costs to outweigh the benefits, or vice versa, will influence their reaction to food identified as genetically modified. The next section explores the potential impacts on consumers.

Impacts on consumers

Consumers are affected in two ways by transgenic crops: direct (tangible) consumption effects and indirect (intangible) existence-value effects. Direct consumption benefits result from the physical purchase and consumption of GM food. Reduced use of agricultural chemicals may lead to lower pesticide-residue levels in food, with health benefits (or reduced health risks) for consumers. This is a positive quality effect. There may also be beneficial price effects for consumers. If transgenic technology reduces production costs, assuming competitive markets, these cost savings should be passed through to consumers in the form of lower food prices. While competitive markets is a strong assumption with respect to downstream food processing and retailing markets in most developed countries, technological advances in agriculture have tended to result in falling real food prices over the long run.

Counteracting these direct consumption benefits, are negative consumption effects for some consumers. For those consumers with specific food-safety concerns, or uncertainty over the long-run health effects of consuming GM food, there is an adverse quality effect, as these consumers will perceive GM food as lower quality.

Indirect existence benefits and costs also arise from transgenic crops. A positive existence value implies that some consumers value the potential environmental benefits from transgenic crops. A negative existence value represents the opposite situation; consumers who believe that transgenic crops are harmful to the environment perceive that there is a market failure resulting in the over-production of a negative externality. Consumers receive disutility or utility from the consumption of GM food derived from transgenic crops believed to be harmful or beneficial to the environment, respectively. These are additional adverse and beneficial quality effects. Thus, an 'eco-unfriendly/-friendly' discount or premium may apply to foods identifiable as GM. Whether consumers gain or lose from transgenic crops depends on the extent to which the market accurately reflects their preferences and if information asymmetry is present. If GM foods are labelled, consumers can express their environmental preferences through the market.

Credence attributes and the role of quality signals

With the exception of beneficial price effects, the impacts of GM food on consumers are credence attributes. Unlike search attributes, which consumers can evaluate prior to purchase – for example the colour of an apple – or experience attributes, which consumers can evaluate after consumption – for example the juiciness of an orange – consumers cannot detect the presence of credence attributes even after consumption (Nelson 1970). The presence of a genetically modified organism is a credence attribute.

Credence attributes create an information-asymmetry problem for the consumer unless the attribute is transformed into a search attribute through labelling. In the absence of labelling, adverse selection leads to over-supply of 'low-quality' (as perceived by consumers) goods in the marketplace in the classic 'lemons' effect (Akerlof 1970). Consumer uncertainty over product quality reduces average willingness to pay, thereby reducing the incentive for producers of high-quality goods to supply these goods to the marketplace. Low-quality goods (lemons) dominate the market. In this context, quality is 'in the eye of the beholder', such that low quality for some consumers may equate to food derived from transgenic crops.

As the previous discussion indicated, there exist potential positive and negative quality reactions to GM food among consumers. Most consumer research suggests that consumers are either indifferent or would choose to avoid GM food if given the choice. A recent stated-preference survey in Canada indicated that some consumers would choose GM over non-GM food, perhaps as a novelty, although these consumers were in the minority with a larger proportion of consumers stating a preference for non-GM food (Hünnemeyer et al. 2003). It is reasonable to assume that firms would expect a negative (rather than positive) reaction to a GM label. However, it is interesting to note initial evidence that the introduction and subsequent removal of a GM-content label from food in The Netherlands did not significantly change consumption patterns for those foods (Marks, Kalaitzandonakes and Vickner 2003). In general, if firms believe that consumers will react negatively to a 'GM content' label, they will not voluntarily label their food as genetically modified as this would signal low quality. Grossman (1981) shows that firms will not voluntarily disclose low quality if quality verification is difficult. The following analysis presents scenarios for the impact of transgenic crops on consumers with and without labelling.

Consumer impacts in the absence of labelling

In the absence of labelling, a pooling equilibrium exists, as consumers cannot distinguish between GM and non-GM food[4]. While some consumers are indifferent, others will suffer an 'adverse quality effect' if they perceive GM food as being of lower quality. This may be for any of the food-safety, environmental or ethical reasons identified earlier. The 'lemons effect' ensues, and *ceteris paribus*, we expect demand for the product to fall, reflecting consumer uncertainty over quality. The extent to which demand falls will depend on consumers' subjective probabilities of consuming GM food. Thus, if the transgenic innovation is drastic and it completely displaces the non-transgenic crop, we can expect a relatively large shift in consumer demand for that specific product. If the innovation was non-drastic and it does not completely displace the non-GM crop, the two crops exist simultaneously, and the fall in consumer demand is smaller.

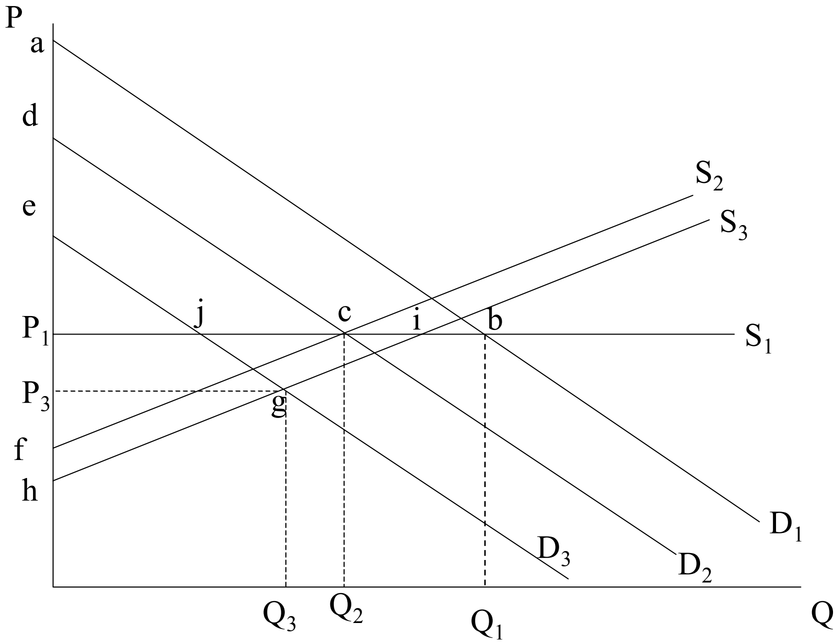

Figure 1. GM-food market effects in the absence of labelling

Figure 1 illustrates these two cases for the GM-food market. The initial equilibrium is represented by point *b* at the intersection of D_1 and S_1, giving equilibrium price and quantity of P_1, Q_1 respectively. A drastic innovation that completely displaces the conventional crop, leading to a consumer expectation that 100% of the food derived from that crop will be GM, is represented by D_3. A non-drastic innovation that only partially displaces the conventional crop results in demand curve D_2. Following Gaisford et al. (2001), initial supply of non-GM output is assumed to be perfectly elastic, reflecting uniform technology and costs across all farms, and for simplicity it is assumed that the farm sector is vertically integrated forwards into the food market. Unequal abilities among farms to adopt transgenic crops (and produce GM food) result in upward-sloping supply functions for GM food given by S_2 and S_3 for a non-drastic and drastic GM innovation respectively.

A number of potential effects from transgenic crops are apparent from Figure 1. In the case of a non-drastic innovation, supply of GM food shifts to S_2, price remains at P_1 and GM and non-GM food co-exist in the product market. Demand shifts to D_2, given consumer uncertainty about the quality of the product, giving a new equilibrium at point *c*. Consumers who are indifferent between GM and non-GM food are unaffected. However, consumers who regard GM food as lower quality, suffer an adverse quality effect equal to area *a-b-c-d* in Figure 1. It is assumed that there are no consumers who actually prefer the GM product. There is a gain in producer surplus for those farms able to adopt the transgenic technology equal to area *P_1-c-f*. Consumers, on aggregate, are unambiguously worse off; however, the net effect on economic welfare depends on the relative size of the loss in consumer surplus and gain in producer surplus.

If the GM innovation is drastic and if transgenic crops completely displace the conventional version of the crop we move to equilibrium point *g*, at the intersection of S_3, D_3. Price falls to P_3 and quantity falls to Q_3.The complete displacement of the non-GM food product leads to a larger adverse quality effect for consumers with strong anti-GM preferences, equal to *a-b-j-e*. Consumers who are indifferent between GM and non-GM food do not experience a quality effect. However, there is an offsetting beneficial price effect that benefits all consumers. The drop in price from P_1 to P_3 yields a gain in consumer surplus relative to the pre-innovation equilibrium of *P_1-j-g-P_3*. The producer surplus gain is larger at *P_3-g-h*. If there are beneficial price effects, consumers who are indifferent about GM food are better off, while the effect on those with negative quality perceptions is now ambiguous.

Labelling as a quality signal

Labelling the presence or absence of GM-food content provides a quality signal to consumers. An important policy debate surrounds the labelling of GM food. A number of countries (e.g. member states of the European Union, New Zealand, Japan) favour mandatory labelling of GM content, with various threshold proposed from 0.9% to 5% of allowable GM content before a ‘GM’ label must be applied. Other countries, notably the US and Canada, prefer voluntary labelling by firms wishing to differentiate their food as not genetically modified. Proponents of mandatory labelling argue that it enshrines in law consumers’ right-to-know whether they are consuming GM food. They fear that, left to its own devices, the market will under-identify and over-provide GM food relative to consumer preferences. Opponents of mandatory labelling argue that it is misleading, implying a safety or quality difference that has not been substantiated by scientific evidence and as such is inconsistent with a regulatory trajectory that has approved GM foods as safe for consumption. They argue that the market will self-identify non-GM foods if there is a sufficient demand for a non-GM assurance. However, there is a clear incentive for cheating and the mislabelling of GM food as non-GM, so in either case, monitoring and enforcement costs will arise. The following analysis examines voluntary labelling of non-GM food, followed by a discussion of a mandatory GM-labelling policy.

Voluntary labelling of non-GM food

Labelling leads to a separating equilibrium, wherein we can identify separate markets for non-GM and GM food. In the absence of cheating, consumers can accurately and costlessly distinguish between the two types of food. This enables those consumers with quality concerns about GM food – either for food-safety or environmental reasons – to avoid GM products. Thus, labelling enables consumers to express their existence values, or environmental preferences, through the marketplace. For now we will assume that these are negative preferences, i.e. that consumers perceive transgenic crops to be a potential cause of environmental harm and wish to signal this through their food purchases. In this case voluntary labelling will be undertaken by the non-GM rather than the GM food-producing sector.

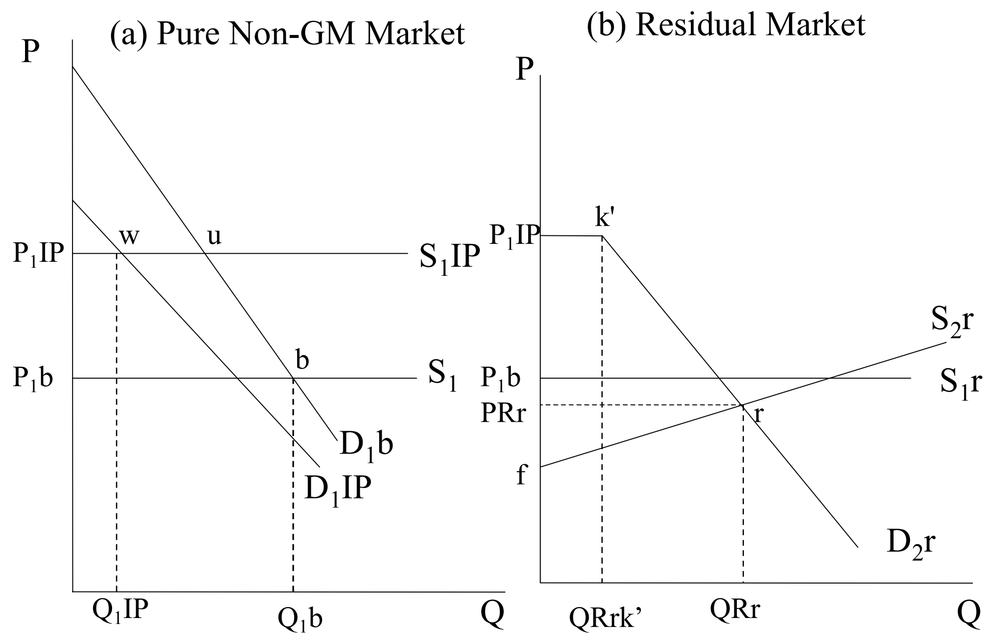

Figure 2. Non-GM identity preservation and labelling

The separating equilibrium under voluntary non-GM labelling is illustrated in Figure 2. Abstracting from the problem of cheating, a voluntary identity preservation and labelling system for non-GM food emerges, as depicted in panel (a) (Gaisford et al. 2001). A second 'residual' market emerges, consisting of GM food and any non-GM food that does not participate in identity preservation and labelling. Equilibrium in the non-GM food market begins at point *b*, with price P_{1b} and quantity Q_{1b}. With the introduction of transgenic crops, a voluntary non-GM identity-preservation and labelling system emerges in response to consumer demand for non-GM assurances based on consumers' environmental and food-safety preferences. The costs of the identity-preservation system are borne by the non-GM food sector, shifting the supply curve in panel (a) to S_1IP. The labelling of non-GM food gives rise to the residual market in panel (b), where S_2r is the supply of GM foods and S_1r is the supply of non-GM food to that market. Following Gaisford et al. (2001), the demand curve D_2r is drawn conditional on a price of P_1IP for the non-GM food. If the prices of the two foods are identical, consumers who are indifferent between GM and non-GM foods will consume in either market, up to quantity QRrk'. At prices below P_1IP, the indifferent consumers and some of those who only weakly prefer non-GM food will switch to the cheaper residual market, giving rise to the downward portion of demand curve D_2r. Given the non-GM price of P_1IP, the residual market is in equilibrium at r, with price of PRr and quantity at QRr. The introduction of substitute GM food at a price of PRr shifts the non-GM market demand curve in panel (a) to D_1IP. This is a pure substitution effect, rather than an adverse quality effect. The new equilibrium on the non-GM market is at *w*, with a price of P_1IP and a quantity of Q_1IP.

In the situation depicted in Figure 2, there is a loss of consumer surplus in panel (a) equal to *P_1IP-u-b-P_1b* resulting from the increase in the price of non-GM food 'before' consumers switch to the residual market[5]. With the adjusted non-GM price, there is a gain in consumer surplus on the residual market of *P_1IP-k'-r-PRr*. Some of the consumers who only weakly prefer non-GM food will be better off, while those who remain in the non-GM market will be worse off than prior to the innovation. Consumers who are indifferent between GM and non-GM food are better off due to the beneficial price effect in the residual market. There is a gain in producer surplus in the residual market of *PRr-r-f.* Overall economic welfare will increase if and only if the gain in producer and consumer surplus on the residual (GM) food market outweighs the loss in consumer surplus due to the incidence of identity-preservation and labelling costs on the non-GM market[6].

If there is a price premium for GM food, and if the probability of being caught and/or the penalties from cheating are low, cheating is likely to become a problem. There is an incentive for producers of GM food to mislabel their products as non-GM, particularly if these firms have not incurred identity-preservation costs, unlike 'honest' non-GM supplying firms. In this situation, panel (a) in Figure 2 no longer represents a 'pure' non-GM market. If cheating is suspected to be present, the demand curve in panel (a) will shift further to the left representing an adverse quality effect and resulting in a loss in welfare for consumers who do not want to consume GM food (not shown in graph). The economic rents from cheating are in the form of a gain in producer surplus for GM producers who mislabel their products. In the long run, rampant cheating would weaken the credibility of a non-GM labelling system, rendering it unsustainable.

Mandatory labelling of GM food

If policymakers believe that a significant market failure exists in enabling consumers to express their environmental (food-safety or ethical) preferences for avoiding GM food, they may mandate GM-content labelling. Mandatory GM-content labelling results in a separating equilibrium consisting of an identified GM market and a market for non-GM food identified by default. However, cheating or non-compliance can still be a problem, so that the default 'non-GM' market may contain food that is genetically modified but that has not been labelled. Figure 3 illustrates a mandatory GM-food identity-preservation and labelling system with non-compliance, resulting in an impure non-GM market.

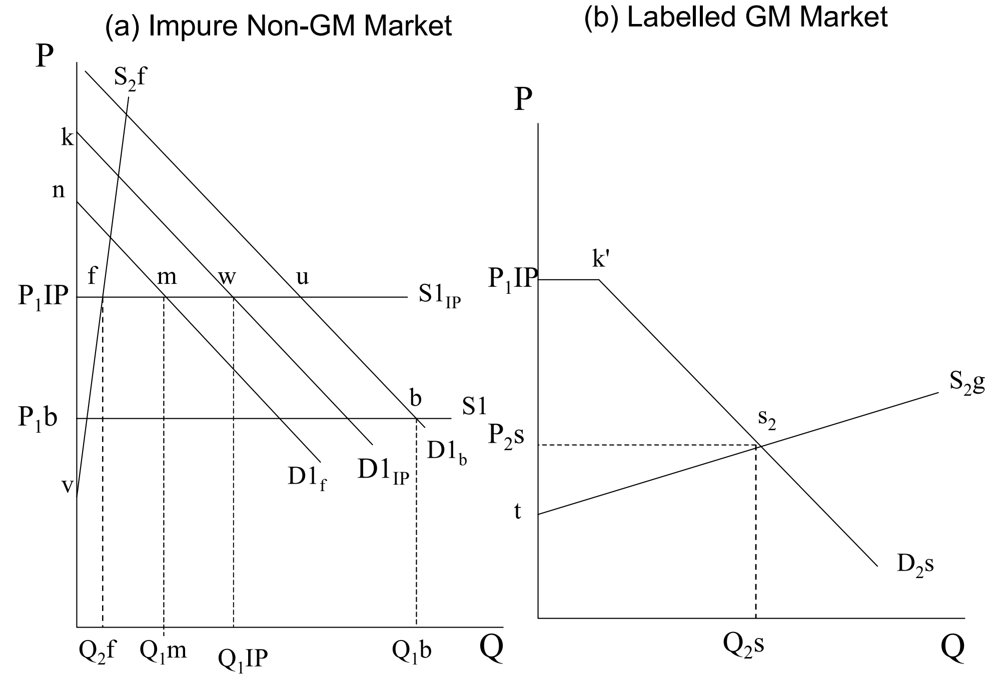

Figure 3. Mandatory GM labelling with non-compliance problem

From the initial equilibrium at point *b*, a GM innovation with mandatory labelling has two effects. First it imposes segregation and identity-preservation costs on non-GM supply chains that wish to continue to market their products as non-GM. It is expected that it will be much more costly to substantiate the absence of GMOs than to acknowledge their possible presence with a 'may contain GMOs' type label. As consumers who choose to purchase GM food will not care if their food is 'contaminated' with non-GM food, it will not be necessary for supply chains providing GM products to segregate their products and incur the costs associated with segregation. This will not be the case for those wishing to sell non-GM food because their consumers will care if their purchases are 'contaminated' with GMOs, hence these supply chains will bear the cost of segregation. Thus, the non-GM supply curve shifts from S_1 to S_1IP reflecting the higher costs segregation indirectly imposed on the non-GM sector. The demand curve for labelled GM food is represented by D_2S in panel (b) and is conditional on the price of P_1IP in the non-GM market. The supply curve of labelled GM food is given by S_2g, yielding an equilibrium price and quantity in the labelled GM market of P_2s, Q_2s[7]. As in the previous case, the cheaper GM-food price entices those consumers who are indifferent toward GM content, and any consumers with only weak preferences for non-GM food, to shift to the labelled-GM market. The departure of these consumers from the non-GM market causes the demand curve to shift to D_1IP in a pure substitution effect.

To this point, the story is similar to that outlined for voluntary labelling with no cheating. However, we now acknowledge the incentive for GM-producing firms to avoid labelling their products in order to take advantage of the relative price differential between unlabelled (assumed GM-free) and labelled GM products. The supply curve for the GM content 'fraudulently' supplied in the (now impure) non-GM market is given by S_2f. At a price of P_1IP, quantity Q_2f of GM food is fraudulently supplied into the non-GM market. Recognition, or even suspicion, among consumers that this is occurring causes the demand curve in the non-GM market to shift left to D_1f, with the result that the equilibrium quantity of food transacted in the (impure) non-GM market falls to Q_1m, with Q_1m-Q_2f supplied by the non-GM sector.

The adverse quality effect on the impure non-GM market leads to a loss in consumer surplus for those consumers with strong anti-GM preferences of *k-w-m-n*. Furthermore, all consumers remaining in the non-GM market suffer a loss in consumer surplus due to the increase in price of P_1IP-u-b-P_1b. There is a gain in consumer surplus of P_1IP-k'-s_2-P_2s, however, for those consumers who shift to the labelled-GM market. GM-producing firms receive economic rents of P_2s-s_2-t in the labelled-GM market given their abilities to adopt the new technology. GM producers who successfully sell GM food fraudulently in the non-GM market receive additional producer surplus o f P_1IP-f-v[8].

The magnitude of the effects on consumers will depend on the increase in food costs as a result of the industry's need to segregate and label products; this will affect the size of the adverse price effect on consumers in the non-GM market. The effectiveness of monitoring and enforcement and the size of the penalties for cheating will determine the propensity of GM firms to avoid complying with a mandatory labelling policy. If enforcement is rigorous, the adverse quality effect may be quite small. If, however, a mandatory GM-labelling policy proves difficult to enforce due to the complexity of testing foods (particularly further processed foods) for GM content, then widespread cheating is likely, and the adverse quality effect for non-GM consumers will be much higher.

An alternative to a performance-based standard for GM-content labelling based on end-product testing is a process-based approach involving supply-chain audits and documentation to verify GM presence or absence. Since the onus is likely to be on non-GM supply chains to verify the purity of their products, this will magnify their identity-preservation and segregation costs. The intention of a mandatory GM-labelling policy may be to increase the economic welfare of consumers who wish to avoid GM food for food-safety, environmental or ethical reasons. Paradoxically however, the outcome could be a reduction in consumer welfare if negative price effects are substantial and an adverse quality effect remains.

Reactions to environmental benefits

The preceding analysis was predicated on the assumption that the identification of non-GM or GM food through either voluntary or mandatory labelling would provide consumers with the ability to express their environmental (or food-safety, ethical) preferences for non-GM food. As the earlier discussion indicated, however, there are potential environmental benefits from transgenic crops. Thus it is conceivable that some consumers, if aware of these potential benefits, might choose to consume GM food. This introduces counteracting pressures on the demand curves for both non-GM and GM food products. In the absence of labelling, the adverse quality effect on a pooled GM/non-GM market (Figure 1) would be mitigated if a third group of consumers existed that preferred GM products for environmental reasons. With labelling (Figures 2 and 3), positive environmental attributes of GM products could result in both a price *and* a quality substitution effect out of the non-GM market into the GM market. If positive environmental preferences for GM food were sufficiently strong, there would be an incentive for a voluntary labelled-GM market. While the balance of consumer research to date suggests that consumers are either indifferent or prefer non-GM food, the case of positive attitudes towards GM food products should not be discounted.

Risk, uncertainty and the consumer decision-making problem

The potential environmental benefits of transgenic crops have not been convincingly communicated to consumers. This may be because the life-science companies who have developed the crops are not credible sources of objective information about the potential environmental impacts. Also, consumers may perceive the potential downside environmental risks to outweigh any potential environmental benefits. Events with a low probability of occurring but with large negative impacts may be weighted more heavily than events with a higher probability of occurring but with smaller impacts.

Uncertainty over the ability of scientific analysis to assess accurately the long-run implications of a new technology makes some consumers sceptical of the risk-analysis process. The regulatory approval process for new varieties includes an assessment of the risk of outcrossing between GM varieties and other plants and other environmental risks. As with food safety, there remains an element of uncertainty over long-run impacts on the ecosystem and on biodiversity, and for some consumers a lingering concern that science can never have all the answers. Widely publicized contradictions in scientific evidence serve to increase the uncertainty and make it difficult for the general public to discern between sound science and sensationalist science. There has been intense media focus on scientific studies that claim to have found evidence of health or environmental harm from genetically modified organisms. For example, the apparent finding that *Bt* corn harmed monarch butterflies, and the apparent evidence of harm caused to rats fed genetically modified potatoes from a study conducted at the Rowatt Institute in Scotland. In both cases a subsequent review of the research by other independent scientists called into question the validity of the initial reported findings. Media coverage of scientific repudiation, however, tends to be less intense. There is some evidence that negative media coverage has a disproportionately larger impact on public opinion than positive coverage. Liu, Huang and Brown (1998) found that negative news about a food-safety incident related to milk in Hawaii in 1982 had a more immediate effect on consumption than positive news.

Even if consumers are aware that a food is genetically modified, their decision-making process is complicated by the presence of uncertainty. The distinction between decision-making under risk versus under uncertainty is important. A situation involves risk if statistical probabilities can be attached to the randomness facing an economic agent. If it is not possible to attach statistical probabilities to the likelihood of an event occurring, the situation is characterized by uncertainty (Knight 1921; Eatwell, Milgate and Newman 1987). Isaac (2002) distinguishes between recognizable risks, hypothetical risks and speculative risks. Recognizable risks are those where there is sufficient information to attach probabilities. This describes consumer concerns about specific food-safety risks from GM food, and may describe some of the more tangible environmental risks that can be evaluated through short-term field trials. Hypothetical risks yield sufficient information upon which to base a testable hypothesis, but the research to evaluate the risks has not been done. Some concerns over the long-run health or environmental consequences of transgenic crops can be characterized as hypothetical risks. Speculative risks involve uncertainty, and it is not possible to devise a testable hypothesis to evaluate these risks based on current science. Speculative risks represent a fear of the 'unknown' and by definition, we cannot attach statistical probabilities to the unknown occurring. For a portion of consumers, uncertainty over the long-run environmental impacts of transgenic crops prevails and a risk-analysis framework for approving new transgenic crops based on risk assessment, risk management and risk communication will not reduce that uncertainty.

If consumers can form subjective probabilities regarding the recognizable risk they may choose to purchase the product if the perceived benefits from consuming the food outweigh the costs, including the costs of a negative outcome occurring with some probability, *p*. In cases for which the recognizable risks outweigh the potential benefits for an individual consumer, or for which environmental or food-safety risks are hypothetical or even speculative, consumers may respond by avoiding the product. In the case of environmental risks, which do not have a direct consumption effect on individual consumers, they may choose to boycott genetically modified products, thereby sending a market signal through product avoidance. Additionally, consumers may lobby for removal of the product from the market. In both cases, product avoidance requires that a food be identifiable as genetically modified through an effective and enforceable labelling system.

Conclusions

Consumer response to genetically modified food and transgenic crops is multi-faceted and complex. Initially consumers have either been indifferent or have expressed concerns about agricultural biotechnology related to perceived food-safety or environmental outcomes, or ethical objections to the technology or the technology provider. While this paper has focused on reactions to environmental attributes of transgenic crops, it is extremely difficult to disentangle these reactions from the other consumer concerns. It is difficult to determine the extent to which a negative consumer reaction is due to environmental reasons versus other concerns. Labelling of GM food, if effective, enables consumers to avoid foods about which they have food-safety concerns. It also allows consumers to signal their environmental preferences through food-consumption decisions. However, labelling alone does not remove the environmental ‘threat’ that may be perceived. This has led some groups to lobby for stronger measures such as a ban on the production or importation of transgenic crops.

New biotechnology innovations that offer direct consumer health benefits through genetic modification of functional traits in food may have interesting implications for consumer acceptance. Similarly, proven (and credible) environmental benefits from transgenic crops could also lead to an interesting dichotomy in consumer markets where different groups of consumers have positive or negative perceptions of the environmental impacts of transgenic crops. The ability of scientific analysis to verify the environmental benefit or damage from transgenic crops will become even more critical, as will the acceptance of that scientific evidence by an often-sceptical public.

Regardless of whether there are perceived environmental benefits or costs from transgenic crops, the credence nature of the GMO attribute means that without labelling a pooling equilibrium emerges. The aggregate effects on consumers are determined by the extent to which adverse quality effects for some consumers are mitigated by a beneficial drop in food prices, or by a counter-acting positive quality effect among other consumers who believe that transgenic crops have environmental benefits. While labelling is often posited as a solution to the consumer information problem with respect to GM food, it is not a simple solution. Segregation and identity preservation costs are likely to have a disproportionate effect on the non-GM producing sector, with potential pass-through of cost increases to consumers. Both a voluntary non-GM label and a mandatory GM-labelling policy will only be effective if the label is credible and backed by sufficient monitoring and enforcement to deter cheating. If substantial mislabelling occurs, consumer benefits are weakened and information asymmetry is not mitigated.

The debate over labelling of GM food and the regulatory approval of existing or new transgenic varieties across jurisdictions is likely to continue for some time. Different regulatory processes have resulted in different rules for labelling and product approval, inevitably leading to international trade tensions. Consumer (and public) concerns over long-run environmental and food-safety implications are often the justification for more restrictive rules with respect to product approval or labelling requirements. It is important to note that in most countries (including the European Union, the US and Canada) the regulatory approval process for new transgenic crops or new foods derived from transgenic crops includes the three-tier scientific risk-analysis approach, including risk assessment, risk management and risk communication. This approach has apparently failed to reassure many consumers. In part this reflects a lack of confidence in the regulatory approval process and in the ability of science to predict the potential extent of environmental or food safety hazards accurately.

The challenge will be to allow technological advances in agriculture that increase yields, reduce costs and improve product quality, while respecting consumer preferences. Regulatory oversight to ensure product safety and environmental soundness remains critically important. Improved communication with respect to proven environmental and quality benefits is also important. Future research could assist in this process in a number of ways. First, by improving our understanding of the consumer decision-making process. Second, by evaluating how consumers react to new information and to different sources of information about transgenic crops or GM food. Finally, by assessing how consumers will trade-off GM content with positive attributes such as improved quality or environmental benefits.

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1 Definitions of genetic modification, genetic engineering and transgenics often differ. For simplicity, food derived from transgenic crops will be referred to as "genetically modified" food throughout this paper.

2 The authors make no claim as to the scientific merit of these concerns; they are presented as a backdrop to an economic analysis of how they affect consumer decisions.

3 Intense media attention arose following a scientific study that appeared to show harmful effects on monarch butterflies from *Bt* corn. Subsequent scientific analysis called into question the conclusions of the first study.

4 The following analysis draws on Gaisford et al. 2001.

5 There may be special equilibrium circumstances where a pooling equilibrium exists in the residual market if the S_2r GM supply curve intersects the D_2r demand curve above the S_1r non-GM supply curve. Alternatively, if the intercept of D_1IP in the non-GM market lies below P_1IP no consumers would be willing to pay the costs of the identity-preservation system. These cases are discussed in more detail in Gaisford et al. (2001).

6 This abstracts from any gains to technology providers. See Gaisford et al. (2001) for a more complete discussion of impacts on input markets.

7 S_2g is drawn conditional on the price of P_1IP in the non-GM market. Technically this means that S_2g represents the supply of GM food in the GM-labelled market, net of any amount fraudulently supplied in the non-GM market.

8 This surplus gain is net of any loss in producer surplus from shifting out of the labelled GM market, given the specification of S_2g as outlined in the previous note.