Welfare Effects of Identity Preservation and Labelling of Genetically Modified Food

Bob Lindner, Michael Burton, Sallie James and Jo Pluske[*]

Abstract

Using a simple model of the world canola market, this paper explores the consequences of the introduction of GM canola on prices, production and consumer welfare. In particular, the model contains heterogeneous consumers who differentiate between GM and non-GM canola, but who can be captured by the GM market if the price discount for GM is sufficiently large. This leads to market segmentation, with the size of price differentials determined by identity preservation costs. A particular feature of the model is the appropriate measurement of consumer welfare changes when the novel good is seen as inferior. The ability of the technology provider to extract rents through the use of technology fees is also explored, and the implications for market equilibrium and social welfare identified.

---

[*] Agricultural and Resource Economics, The University of Western Australia, 35 Stirling Hwy, Crawley, Western Australia 6009.

1. Introduction

A little over a year ago, the future for genetically modified organisms (GMOs) looked bright. Plantings of transgenic soybean, corn, cotton, and canola by American, Argentine, and Canadian farmers set new benchmarks for the rate of adoption of a new agricultural technology. Virtually the only cloud on the horizon was widespread consumer resistance to GMOs in Europe. Industry assumed that this was a *temporary* problem that could be overcome by an "educational program" that provided more information about the benefits of GMOs (Marshall, 1998).

One year later, the outlook has changed. Consumer resistance to GMOs has intensified rather than waned in Europe. Furthermore, it has now spread to many other countries as well. Even in Canada and the US, there are press reports of supermarkets chains stocking items labelled as GM free[1]. Moreover, the effect of education programs may be questionable given findings by Zechendorf (1998) that suggest consumer acceptance depends on people's socio-cultural attitudes as well as their knowledge about the benefits of biotechnology.

Despite the uncertainty surrounding consumer acceptance of GMOs, there are lessons to be learnt from studies of innovation adoption. First and foremost, for an innovation to be adopted enduringly, it must not only create value but also must deliver meaningful net benefits to all potential adopters. That is, the benefits of adoption must be distributed all along the supply chain, including to consumers.

Genetically engineered crops that are already being grown commercially include tobacco, cotton, soybean, corn/maize, canola/rapeseed, tomato and potato. In a review, James (1999) noted that seven transgenic crops were grown commercially by 1996 on approximately 2.8 million hectares, mostly in the United States and Canada. Between 1996 and 1998, there was a further increase in the global area of transgenic crops to 27.8 million hectares (James 1999). As James (1999) points out adoption rates have been some of the highest ever for new agricultural technologies, and reflect grower satisfaction with significant benefits ranging from more flexible crop management, higher productivity and a safer environment through decreased use of conventional pesticides and herbicides.

---

[1] As reported by Thomas Walkom, The Toronto Star, Editorial, 'GMO folks have a little surprise from Alberta', May 2, 2000 (retrieved 2nd May 2000 from the Agnet at http://www.plant.uoguelph.ca/safefood).

To date, the overwhelming majority of GM foods are the products of first generation GM crops. The principal transgenic traits in 1999 were herbicide tolerance, insect and viral resistance, and hybrid technology (James, 1999). As explained by Fulton and Keyowski (1999a), these “input traits” lower average costs of production through some combination of reduced costs of control of, and/or smaller losses from weed, pest, and disease infestation, and through increased yields. Because these beneficial traits can be introduced into a plant without disturbing the rest of the plants’ genetic code, the resulting varieties are potentially much more profitable for growers. Realised profitability will fall short of potential profitability to the extent that a product price discount applies to the GM crop, and/or to the extent that growers have to pay a premium to grow the GM crop relative to comparable “conventional” crop varieties. Even though these crops may deliver lower costs of production to farmers, they typically deliver no or least negligible benefits to consumers[2] unless some of the lower production costs are passed on as lower retail prices for GM food relative to non-GM food. This has not happened to date, and will not happen until the necessary preconditions of retail labelling underpinned by a credible and verifiable system of identity preserved production and marketing are implemented.

Second generation or quality enhanced GM crops, most of which are still under development, incorporate crop attributes that provide direct benefits to the consumer, or in some cases to intermediate producers. Delayed ripening tomatoes, oilseed rape with modified fatty acid, high oleic acid soybean, and carnations with extended shelf life and modified colour, are examples of second generation crops that are already in commercial production. Some companies are predicting that the third generation of GM crops will be nutraceuticals. Nutraceuticals are foods that prevent or treat diseases or otherwise provide medical or health benefits. GMOs that include genes coding for pharmaceutical drugs are touted as GM crops of the future. In contrast to first generation crops, quality enhanced crops have not been widely adopted so far (James, 1999).

---

[2] There may be indirect benefits to consumers by knowing farmers benefit from lower on-farm costs or by valuing reduced environmental costs.

Alerted by activists, consumers are increasingly aware of public health concerns about GMOs and this appears to be the most important consideration regarding their development and use. Within the scientific community, there also are worries about the long-term effects on human health (for example, through the use of antibiotic resistant marker genes and the risk of allergen transfer) and the environment from widespread use of genetically engineered crops. Other concerns about GM crops include the influence of multinational seed companies on countries' economies; and the possible demise of the small-scale farmer. While various special interest groups share these concerns, it is a growing reluctance to eat GM food by the general public that is limiting the size of the market for GMOs, threatening the realisation of substantial value creation from genetic manipulation technologies and perhaps even threatening the financial viability of some life science companies.

Some advocates of GM foods point out that consumer reactions to real price differentiated choices (as opposed to hypothetical choices) between conventional (i.e. non-GM) and GM foods have yet to be observed (see, e.g., Caulder, 1998) for a significant number of foodstuffs. They anticipate that when consumers are more regularly exposed to GM foods, and compare them favourably (or at least neutrally) to conventional foods, the anticipated price differential between GM and non-GM foods will create a viable market for GM foods (Caulder, 1998). If correct, such a response will belie the survey results that suggest such a market is likely to be small at best.

Work completed by Gamble, *et al.* (2000) indicates that when second generation foods become available, the market for these foods may be larger than for first generation foods as consumers appreciate the extra direct benefits they offer (such as longer shelf life, or enhanced nutritional value). It is possible, depending on the extent of extra benefits and the willingness of consumers to accept any perceived risk associated with the technology, that these products might command a price *premium* over conventional foods.

That is, for now, a hypothetical scenario. The immediate challenge facing producers and advocates of GM foods is to convince consumer and environmental groups that regardless of its generation, any food produced using recombinant gene technology is safe to consume and to produce. General acceptance of second and third generation crops will not be realised if the market potential of first generation crops is thwarted by health and environmental fears, regardless of their legitimacy.

For the biotechnology industry, there is a clear lesson about how to solve the consumer "problem" and current lack of demand for GMOs. Trying to allay consumer concerns about the health risk from eating GMOs by relying on scientific argument has not, and will not succeed. Consumers want to be assured about the origins of their food, and ways must be found to allow them to knowingly choose between GM and non-GM foods. Moreover, products from first generation GM crops will have to sell at a discount (relative to the GM free equivalents) to induce significant numbers of consumers to buy them.

The technology component of GM foods is, for our purposes here, a credence attribute. This means that the technology used to produce a (first generation) food is indistinguishable to the consumer both before and after purchase (Caswell and Mojduszka, 1996; Caswell, 2000). Thus the only way a non-GM food producer is able to elicit a price premium for his product is by indicating the status of his product by the use of a label supported by a credible testing and assurance program.

So long as identity preservation remains haphazard and labelling regulations ambiguous, price premiums for any type of good – GM or non-GM, first, second or third generation – are likely to be small.[3] That is, so long as there is no way of differentiating between types of good, consumers have no certain or reliable way of knowing whether the food they eat is GM-free. Producers of GM-free products are unable to advertise (with any integrity) the status of their product and, as such, rational consumers will be unwilling to pay more than the "non-segmented" market price. This is especially true for first generation GM foods since there are no enhanced attributes from which consumers could derive extra (direct) benefit. Consumer rejection of GM foods is rational if they are not offered it at a lower price. After all, what rational consumer would accept a "bad" characteristic in the absence of no offsetting benefits such as a lower price?[4]

---

[3] Price premiums for non-GM food will, of course, be market determined, and depend on the proportion of supply that is non-GM. Recent market reports for corn and soybean have, however, reported premiums of between 10-15 per cent and 5-35 per cent, respectively (Miranowski *et al*, 1999).

[4] This clearly ignores the possibility of consumers buying GM food because they derive utility from knowing it has been produced using techniques beneficial to the environment.

To deliver a price premium for non-transgenic food, industry must provide verifiable labelling and maintain credible identity preserved production and marketing (IPPM) systems, thus facilitating choice by consumers of food products that align with their preferences. However, work completed by KPMG (1999) indicated that the introduction of an IPPM system could prove to be prohibitively expensive. This conclusion, however, is difficult to sustain given the current widespread practice of segregating different grades of non-GM crops to separate higher added value products from other commodities in order to exploit niche markets. In the case of GM crops, it is the absence of genetic engineering in food that is the key “attribute” being demanded, so only non-transgenic food would need to be segregated in the marketing chain, labelled and subject to some form of verification. A particularly apposite case is marketing systems for organic food.

Buckwell *et al.* (1999) estimated that the increased cost of segregating GM products could range between 5-15 per cent of the usual farm gate price. Despite this cost, the same authors explain that there could be benefits both to consumers and to farmers as long as consumers are willing to pay the added cost of separating GM from non-GM crops. Labelling is likely to be the most efficient alternative because market forces would determine the acceptance of the new technology. So long as most people demand food that is GM free, the advantage of labelling may be minimal, and arguably even unnecessarily expensive if IPPM costs exceed cost savings from growing first generation GM crops. If and when demand for non-transgenic food declines in the longer run to the point where it becomes a specialty product, then requiring compulsory labelling of GMOs is likely to prove unduly costly. Ultimately, the magnitude and cost structure of an IPPM system will determine, *inter alia*, the market determined equilibrium level of the price differential between GM and non-GM foods at farm gate, and at retail level.

The rest of this paper reports the findings from some preliminary analysis of the impact on prices at farm gate and at retail of introducing a system of retail labelling of non-GM food. Estimated price differentials obviously depend on the likely costs of introducing and maintaining a credible system of identity preserved production and marketing. Of interest here is the nature of market segmentation and price differentiation after a first generation GM crop (canola, in this example) is produced and marketed. The simple model that follows explores some possible scenarios for future prices for GM and non-GM canola under a few key assumptions. Firstly, the GM crop is of the first generation such that consumers will not purchase food produced using GM canola unless it is sold at a lower price than conventional canola. Clearly the model would need to be adjusted to allow for any positive attributes associated with GM foods, such as those in second or third generation GM foods. Secondly, the production function for both types of foods is assumed to be constant returns to scale with a constant elasticity of substitution. The market is characterised by perfect competition. Identity preservation costs are presented as simple fixed costs in each market.[5]

2. Model Specification

Formal modelling of the market with segregated production/consumption will be presented in two parts. In the first, a simplified model is developed which allows for an analytical solution, but is restrictive. In the second, a more general model is presented which can be solved numerically, but not analytically. These models are similar in structure to those developed by Fulton and Keyowski (1999b), and Falck-Zepeda *et al.* (1999) but provide a number of extensions. There is a more formal representation of the technology than used in either. Our models also remove the restriction of a fixed output level used by the former, and do not assume that all consumers accept the product, as assumed by the latter.

---

[5] Market forces (specifically the relative elasticities of supply and demand) will determine the incidence of IPPM costs. The likely scenario is that farmers will have to bear part of the cost of segregating, testing and marketing of non-GM crops and consumers will bear the rest through higher prices.

2.1 The simple model

Representative demand functions for the two types of good, non-GM (subscript, *n*) and GM (subscript, *g*) are assumed to be simple linear functions of (normalised) own price. It is assumed that at the individual level, consumers make a decision to purchase either one or the other, but not both. Hence, the price of the alternative form of the product is not an argument to the representative demand functions:

$$d_n=a_{0+}a_1P_n \tag{1}$$

$$d_g=a_0+a_1P_g \tag{2}$$

However, the relative price of the two goods does determine which form of the product is selected. As the good under consideration is a first generation GM crop, there are no intrinsic benefits in consumption. Hence we assume there will be no demand for the GM version if the prices of the two forms are equal. This is consistent with the argument above that even the slightest residual perception of risk from consuming the product, or concern about potential non-consumptive issues (on farm ecological effects for example) will lead consumers to reject GMO's unless there is price differential.

Assume that there is some latent index of concern, *c*, and some underlying discrete choice process which means consumer *i* will consume the GM product if

$$f(P_g/P_n) < c_i \tag{3}$$

i.e. if the price differential is large enough they will be induced to change. Assuming the function f(•) is linear in the price ratio, and that *c* is distributed across the population as a uniform variable from 0-1, the share of the population that consumes non-GM is determined by:

$$S_n=P_g/P_n \tag{4}$$

With no loss if generality, normalising the consumer population size to unity gives aggregate demands of:

$$D_n=(a_0+a_1P_n)P_g/P_n \tag{5}$$

$$D_g=(a_0+a_1P_g)(1-P_g/P_n) \tag{6}$$

The supply side of the model is represented by the marginal cost of production:

$$MC_n=b_0+b_1(Q_n+Q_g) \tag{7}$$

$$MC_g=b_0-b_t+b_1(Q_n+Q_g) \tag{8}$$

where b_t is the cost advantage enjoyed by the GM crop,

Assuming b_1 is positive implies a rising marginal cost, determined by the aggregate production of both crops. Given the similarity in the two goods, it would be expected that there will be interactions between the two goods in production, leading either to joint decreasing marginal productivity of resources, or common impacts on costs through the input markets.

Assuming profit maximization and perfect competition allows one to equate the marginal cost with the product price, and the market clearing condition of $D_j=Q_j$ allows a solution to be identified.

Defining Q as aggregate quantity (i.e., $D_n + D_g$) of both crops leads to:

$$Q=(a_0+a_1P_n)P_g/P_n+(a_0+a_1P_g)(1-P_g/P_n) \tag{9}$$

$$P_n=b_0+b_1Q+IP_n \tag{10}$$

$$P_g=b_0-b_t+b_1Q+IP_g \tag{11}$$

where P_n and P_g are prices at retail, and IP_j is the marginal cost of identity preservation of crop *j* when the GM crop is introduced.

Substituting (10) and (11) into (9) leads to a single equation which can be solved for *Q* (see Appendix I), which can then be used to identify prices and quantities of the individual commodities.

The model leads to a number of intuitive conclusions. So long as there are no identity preservation (IP) costs, the extent of market penetration of the GM crop will be directly related to the degree of cost advantage it enjoys. Furthermore, there will be an increase in the aggregate market for the commodity as the average cost of producing GMO's falls because the increase in the GM segment of the market will be larger than the non-GM segment it displaces. Since marginal cost is specified to rise with increasing aggregate output, the marginal cost and hence price of the non-GM commodity must rise following the introduction of the GM crop. In turn, this will cause a movement along the representative non-GM demand curve, which will compound the reduction in non-GM demand due to the segmentation of the market. The greater the cost advantage enjoyed by the GM crop, the greater the size of these effects. Introduction of an IP cost on the non-GM product widens the gap between GM and non-GM prices, although the rise in non-GM prices will depend on the elasticities of non-GM demand and supply curves: the standard incidence argument. However, that widening will cause further restructuring of the market between the two crops. The introduction of IP costs on the GM product alone can simply be seen as an offset for the technological cost reduction. If the IP cost is sufficiently large, the GM product may not be able to penetrate the market.

If the IP costs fall on both sectors, and they are large enough, it is possible for both consumer prices to rise relative to the pre-GM situation, and for aggregate consumption/production to be less. This would lead to the interesting situation that aggregate welfare would be reduced, and yet all markets would be in equilibrium, and there would be no competitive pressure for production of GM to cease.

The model structure used here is rather restrictive. In particular, the segmentation of the market is a linear function of the ratio of prices, and one might expect that the expansion of the GM sector would accelerate as the price differential expanded. Secondly, the production side of the market is very simplified, with no differentiation of technical change and input market effects on the marginal cost of production.

2.2 The extended model

Attempts to derive analytical solutions from more elaborate models were not successful. Consequently, it was decided to resort to numerical methods to obtain solutions from a somewhat more realistic model outlined below. Dropping the requirement for the model be solved analytically allowed a number of changes to be made, including explicit introduction of production functions utilizing two inputs, characterized respectively as a seed and herbicide complex on the one hand, and on the other a composite factor for all other inputs, including land. Nevertheless, it should be noted that the model is still very simplified. In particular, the model does not explicitly include trade; processing and marketing activities are subsumed into supply/demand functions; and it is assumed that there is a single consumer good generated from the farm product (i.e. joint or by-products are not considered).

The representative demand functions are expressed as a constant elasticity form:

$$d_n=a_0P_n^{a1} \tag{12}$$

$$d_g=a_0P_g^{a1} \tag{13}$$

The function determining the share of the market allocated to non-GM is extended, as the proportion of the people consuming the GM product may rise non-linearly as the price differential increases:

$$S_n=(P_g/P_n)^{\lambda} \qquad \lambda>1 \tag{14}$$

This gives aggregate demands of:

$$D_n=a_0P_n^{a1}(P_g/P_n)^{\lambda} \tag{15}$$

$$D_g=a_0P_g^{a1}(1-(P_g/P_n)^{\lambda}) \tag{16}$$

The production functions are given by a two-input constant returns to scale (CRTS), constant elasticity of substitution (CES) production function:

$$Q_n=\gamma\left[\delta k_{1n}^{-\theta}+(1-\delta)k_{2n}^{-\theta}\right]^{1/-\theta} \tag{17}$$

$$Q_g = \gamma\, t_\gamma \left[\delta\left(t_1 k_{1g}\right)^{-\theta} + (1-\delta)\left(t_2 k_{2g}\right)^{-\theta}\right]^{1/-\theta} \tag{18}$$

where k_{1n} is the amount of input 1 used by the non-GM sector, k_{2n}, the amount of input 2 and so on.

In the GM sector t_1 and t_2 are the input augmenting technical change associated with the new innovation. Setting t_1>1 implies that k_{1g} is becoming more effective. Hicks neutral technical change can be represented by setting t_γ >1.

The other parameters in the function can be interpreted as follows:

γ is a general scaling factor;
δ determines (in part) the slope of the isoquant and must lie between 0 and 1 for it to be downward sloping, while
θ determines the elasticity of substitution (σ) between the two inputs ($\sigma=1/(1+\theta)$).

For this CRTS, CES the marginal costs of production are given by:

$$MC_n = \frac{P_1}{\gamma}\delta^{1/\theta}\left(\left(\frac{1-\delta}{\delta}\right)^{\sigma}\left(\frac{P_2}{P_1}\right)^{\theta\sigma}+1\right)^{1/\theta} + \frac{P_2}{\gamma}(1-\delta)^{1/\theta}\left(\left(\frac{\delta}{1-\delta}\right)^{\sigma}\left(\frac{P_1}{P_2}\right)^{\theta\sigma}+1\right)^{1/\theta} \tag{19}$$

$$MC_g = \frac{P_1}{\gamma\, t_\gamma t_1}\delta^{1/\theta}\left(\left(\frac{1-\delta}{\delta}\right)^{\sigma}\left(\frac{P_2}{P_1}\right)^{\theta\sigma}+1\right)^{1/\theta} + \frac{P_2+tf}{\gamma\, t_\gamma\, t_2}(1-\delta)^{1/\theta}\left(\left(\frac{\delta}{1-\delta}\right)^{\sigma}\left(\frac{P_1}{P_2}\right)^{\theta\sigma}+1\right)^{1/\theta} \tag{20}$$

where P_1 and P_2 are the prices of k_1 and k_2 respectively, and t_f is the technology fee charged by the provider of the improved inputs. The form of this fee will be described later, when the model is parameterised.

Assuming profit maximizing, perfectly competitive behavior one can directly infer that at equilibrium the product price and marginal cost will be equal, allowing for any identity preservation costs that may arise:

$$P_n=MC_n+IP_n \tag{21}$$

$$P_g=MC_g+IP_g \tag{22}$$

With fixed input prices (P_1, P_2), marginal costs are not dependent on the scale of production, and equations (19) to (22) will define the product price for the two commodities, and hence the resulting demands. However, things are more interesting if one makes the input markets endogenous.

The optimal input demand, for a given level of output, is given by:

$$K_{1n} = \frac{Q_n \delta^{1/\theta}}{\gamma}\left(\left(\frac{1-\delta}{\delta}\right)^{\sigma}\left(\frac{P_2}{P_1}\right)^{\theta\sigma}+1\right)^{1/\theta} \tag{23}$$

$$K_{2n} = \frac{Q_n (1-\delta)^{1/\theta}}{\gamma}\left(\left(\frac{\delta}{1-\delta}\right)^{\sigma}\left(\frac{P_1}{P_2}\right)^{\theta\sigma}+1\right)^{1/\theta} \tag{24}$$

$$K_{1g} = \frac{Q_g \delta^{1/\theta}}{\gamma t_\gamma\, t_1}\left(\left(\frac{1-\delta}{\delta}\right)^{\sigma}\left(\frac{P_2}{P_1}\right)^{\theta\sigma}+1\right)^{1/\theta} \tag{25}$$

$$K_{2g} = \frac{Q_g (1-\delta)^{1/\theta}}{\gamma\, t_\gamma\, t_2}\left(\left(\frac{\delta}{1-\delta}\right)^{\sigma}\left(\frac{P_1}{P_2}\right)^{\theta\sigma}+1\right)^{1/\theta} \tag{26}$$

The (inverse) supply curve associated with each input is assumed to be linear, and be a function of aggregate input demand:

$$P_1=b_0+b_1(K_{1n}+K_{1g}) \tag{27}$$

$$P_2=b_2+b_3(K_{2n}+K_{2g}) \tag{28}$$

So, although there are no direct interactions between the two types of goods on the cost of production as a result of changing output levels, there are indirect effects through the input markets.

3. Parameterization of the model

Numerical solutions to models require some foundation in specific data, or the results are little more than curiosities. The simplified nature of the model, and the unknowable aspects of the consumer response to GM products when they enter the market, means that the linkage between parameters and data is not exact. In the following sections, the method of parameter identification and the relevant baseline data are outlined. A summary of parameter values is reported in Tables 3.1 and 3.2.

3.1 Production and price data

As this study is based on a world market scenario, it is not country specific and therefore there are no ramifications associated with trade. The basic model is parameterized to give a stylized representation of a canola market. In the model the aggregate quantity of canola grain is set at 35.87million tonnes and is based on FAO data for world production of canola grain in 1998 (FAOSTAT, 2000). The price for canola grain is assumed to be \$296/tonne which, according to the USDA's Foreign Agricultural Service, was the canola grain price for 1998 (FAS Online, 2000).

3.2 Farm input costs and benefits

3.2.1 Without GM inputs

The two inputs in the production function are characterized as k_1, the canola complex (seed and herbicide) and k_2, all other inputs. Fulton and Keyowski (1999a) suggest that the share of the canola complex is some 16 per cent in total cost, and the parameters of the production function are selected to generate this result at the pre-GM equilibrium. Given an elasticity of substitution (σ) set exogenously at 1/3, and normalizing the input prices to unity allows the input ratio to be determined (the ratio of equations (23) and (24)) to be a function of a single parameter, δ.

The scale parameter γ is then identified by equating marginal cost (equation 19) with canola price.

As an alternative, the original share of 16 per cent is increased to 40 per cent, which may be closer to the value for Australia. This leads to alternative values for δ and γ (see Table 3.2).

Having identified all parameters of the production function, the equilibrium input quantities are identified (equations (23), (24)). The units in which these are measured cannot be interpreted, as the input prices have been normalized to unity, and they will change with the differing assumption about the input share (or σ, if it were altered). However, once the input quantities have been established at equilibrium, the parameters of their (inverse) supply functions can be obtained.

3.2.2 With GM inputs

Fulton and Keyowski (1999b) suggest that farmers who have adopted some form of reduced tillage system are more likely to profit from using HR (herbicide resistant) seed. Production of GM canola requires a one-pass chemical operation (as opposed to two passes required by non GM Canola) so eliminates the cost of additional machine operations over the field, enables control of the entire spectrum of weeds so giving farmers much more flexibility in terms of the timing and type of weed control and has the potential to improve the crop yield by removing competition for moisture and nutrients (Fulton and Keyowski, 1999a). Even so, the benefits of the new technology will only be recognised if returns increase through reduced weed control costs and/or increased yields (CCGA, 2000). Therefore, where weed control is not a major concern farmers are unlikely to benefit and may be better off to use conventional varieties (CCGA, 2000). Ballenger *et al.* (2000) state that producers in different countries will consider the relative prices for biotech and non-biotech crops in relation to their local farming conditions when deciding what to plant. For the purpose of this study, this statement is extended further to assume that producers will use GMO technology only if it is beneficial to their production method thereby capturing benefits associated with herbicide reduction and yield increase. Therefore, while acknowledging the argument by Fulton and Keyowski (1999a) that total benefits derived from GMO technology will depend on agronomic, management, and technology factors facing individual farmers, we assume here that farmers included in this study are alike.

The GM innovation is assumed to have two potential modes of action in the production function that may occur separately or together. The first is a change in the effectiveness of the canola complex inputs. This is represented by assuming that the effectiveness of this input rises by some 87 per cent (t_1=1.87), a figure derived using results found by Fulton and Keyowski (1999a). The implied reduction in marginal costs (before allowing for substitution and input price effects) is approximately 8.5 per cent if the input share is 16 per cent.

The second mode of action is a Hicks neutral shift in the production function. Fulton & Keyowski (1999a) found a yield decrease of around 7 per cent[6] with the introduction of Round-up Ready™ canola; James (1998) found that the average canola yield in Canada increased by 7.5 per cent between 1996 and 1997[7]. Here we set this value at 8.5 per cent, so that the change in marginal cost due to this change is equivalent to that induced by the input-specific shift.

It should be noted that when the input share of k_1 is raised to 40 per cent, the economic impact of the innovation is significantly increased for the same increase in effectiveness: equivalent to a 22 per cent reduction in marginal cost. In the simulations with this higher share the yield effect is retained at 8.5 per cent.

---

[6] As Fulton & Keyowski (1999a) note, farmers were not differentiated in the study and those who have not adopted conservation practices are unlikely to receive the same benefits as those who have.

[7] From Fulton & Keyowski (1999a) almost 4 per cent of canola grown in Canada was GM canola in 1996 compared to 33 per cent in 1997 and therefore is could be assumed that part of the overall yield increase could be contributed to production of GM canola.

3.3 Elasticities of supply and demand

The elasticity of supply of the canola complex (k_1) is assumed to be infinite. Given constant returns to scale, imposing an elasticity of supply on the other inputs effectively determines the long run equilibrium response of output to changes in the canola price. While Johnson *et al.* (1996) found elasticity of supply to be up to 0.85, for the purpose of this project it was deemed that the long run supply elasticity would be set at 1.5. If the input share of k_2 is set at 84 per cent (because the share of k_1 has been set at 16 per cent as described above), this implies an elasticity of supply of k_2 of 1.25. If the input share is 60 per cent, then the elasticity of supply of k_2 is set at 0.9. In both cases the parameters of the linear marginal supply function for the input can subsequently be identified.

Johnson *et al.* (1996) indicate the elasticity of demand of canola oil to be -0.6 for Canada, -0.69 for the US and for the EU, -0.56. Goddard and Glance (1989) quote elasticity of demand for canola oil ranging from -1.17 to -0.31 with a mean and median of -0.78. Here, we simply specify a single derived demand for oilseed, with no differentiation by end-use, and an elasticity of demand of either –0.75 or –0.5. This, combined with the base quantity/price data allows the parameters of the representative demand functions to be identified.

3.4 Market share

Phillips (1999) and Buckwell *et al.* (1999) argue that for non-GM products to enter the market, the market would have to segment and the cost that this segmentation could bear would depend on the willingness of consumers to pay extra for non-GM products. In the long run consumers around the world will decide on the premiums they will pay for non-biotech products (Ballenger *et al.*, 2000). Miranowski, *et al.* (1999) adds that the price-premium for a non-GMO crop will depend on the supply of that crop, and costs of identity preservation. The size of these premiums is unknown and any market intelligence concerning GM food is scarce. Differences in regional attitudes towards GM foodstuffs complicate the picture, as does the fact that canola generates two products, oil and meal, with human and animal feed end-markets. If public concerns about GM products do not extend to products from animals raised on GM feeds, then the derived demand for meal will not segment.

In the face of uncertainty about possible responses, λ is set at an arbitrary value of 3, a value which leads to significant segmentation at relatively low price differentials (e.g., for a GM product priced at 10 per cent less than non-GM product, the market share for the GM product would be 27 per cent of individuals).

3.5 Identity preservation costs

Smyth and Phillips (1999) found the cost of an identity preservation and marketing system for canola in Canada to be between 12 and 15 per cent of the farm gate price. This cost is assumed to impose a wedge between farm and retail price by raising the effective marginal cost of supply at retail level. In the simulations that follow, the cost is set at $44 per tonne, or approximately 15 per cent of the pre-GM farm gate price.

Farmers must pay for GM canola seed as it is assumed that they are not able to retain any seed for planting from the previous year. From Fulton & Keyowski (1999a) the increase in GM canola seed price over non-GM was found to be 2 per cent of the total return. To acquire Round-up Ready™ canola seed, farmers must attend a sign-up meeting and agree to a Technology Use Agreement, pay $15/acre technology fee and buy a package of seed and Round-up™ herbicide (Phillips, 1999). In this study, these costs are referred to as “the technology fee that is associated with the GM technology” and is applied to the ‘other’ input (k_2), leading to an effective increase in its price. This is emerging as a common practice in the industry, with the technology fee applied to land area planted, rather than output levels or seed. In an initial simulation the technology fee is set at 7 per cent of total revenue (at pre-GM equilibrium input quantities and output price).

3.6 Summary of data

Tables 3.1 and 3.2 summarize the data used in the model. Table 3.1 generates the production parameters on the assumption that the input share for k_1 is 16.7 per cent, and reports alternative values for the demand elasticity. The lower half reports the values for the technological change parameters, identity preservation costs and technology fee for seven scenarios. Table 3.2 is generated on the basis of an input share of 40 per cent.

The scenarios explore the response of the model to:

- Different forms of technical change

- Different incidence of Identity Preservation costs
- The impact of a technology fee

Scenarios 1-3 introduce a factor saving innovation, a Hicks neutral innovation, and a combination of both, but no identity preservation costs. The most likely outcome from adoption of herbicide resistant GM canola is assumed to be significant savings in the cost of the canola complex input, as well as an additional factor neutral yield increase.

Scenarios 4-6 build on Scenario 3 by introducing identity preservation costs that respectively impact on the cost of retail supply of the GM commodity alone, on both commodities, and finally on the non-GM commodity alone. Again for reasons outlined above, it is thought that the latter is the most likely outcome in the market. Finally, a technology fee is added to the system and is fixed exogenously at the rate suggested by Phillips (1999) (Scenario 7).

Table 3.1 Baseline and scenario parameter values: k_1 *input share =16.7%*

Baseline parameters and values										
Parameter	Canola price (US$/mt)	Canola Prod. (million mt)	θ	σ	δ	γ	b_0	b_1	b_2	b_3^{f}
Value	296	35.87	2	1/3	$7.936\ 10^{-3}$	$4.42\ 10^{-3}$	1	0	0.2	$9.04\ 10^{-5}$

With elasticity of demand set at –0.75 and used for Table 4.1	a_1	-0.75	a_0	2560
With elasticity of demand set at –0.5 and used for Table A1	a_1	-0.50	a_0	617

Technology, yield, identity preservation and technology fees used in Scenarios 1 to 7								
	Baseline	S1	S2	S3	S4	S5	S6	S7
t_1	1	1.87^{ff}	1	1.87	1.87	1.87	1.87	1.87
t_γ	1	1	1.0845	1.0845	1.0845	1.0845	1.0845	1.0845
IP_n	0	0	0	0	0	44	44	44
IP_g	0	0	0	0	44	44	0	0
t_f	0	0	0	0	0	0	0	0.085

[f] Implied elasticity of supply of k_2=1.25, implied elasticity of supply of output=1.5, share of k_1 in total costs=16.66%

[ff] The assumption is that the technology increases the effect of k_1 by a factor of 87%, i.e. generates a 47% savings in cost of that factor. With this input ratio that is equivalent to a “neutral” 8.45% increase in yield

Table 3.2 Baseline and scenario parameter values: k_1 *input share =40%*

Baseline parameters and values										
Parameter	World Canola price (US$/mt)	Tot world prod (million mt)	θ	σ	δ	γ	b_0	b_1	b_2	b_3[f]
Value	296	35.87	2	1/3	0.2286	$6.384\ 10^{-3}$	1	0	-0.111	$1.74\ 10^{-4}$

With elasticity of demand set at –0.75 and used for Table A2	a_1	-0.75	a_0	2560
With elasticity of demand set at –0.5 and used for Table A3	a_1	-0.50	a_0	617

Technology, yield, identity preservation and technology fees used in Scenarios 1 to 7								
	Baseline	S1	S2	S3	S4	S5	S6	S7
t_1	1	1.87[ff]	1	1.87	1.87	1.87	1.87	1.87
t_γ	1	1	1.0845	1.0845	1.0845	1.0845	1.0845	1.0845
IP_n	0	0	0	0	0	44	44	44
IP_g	0	0	0	0	44	44	0	0
t_f	0	0	0	0	0	0	0	0.118

[f] Implied elasticity of supply of k_2=0.9, implied elasticity of supply of output=1.5, share of k_1 in total costs=40%

[ff] The assumption is that the technology increases the effect of k_1 by a factor of 87%, ie. generates a 47% savings in cost of that factor. With this input ratio that is equivalent to a "neutral" 22% increase in yield

4. Results

The full set of simulation results are reported in Appendix II. For simplicity, the discussion results will focus on one set of results that are presented in Table 4.1 based on an input share for the canola complex of 16 per cent and an elasticity of demand of -0.75 (i.e. based on parameter values drawn from Table 3.1).

Table 4.1 Simulated values for canola price and quantity, input quantities and welfare impacts.

	baseline	S1	S2	S3	S4	S5	S6	S7
P_n	296	298	296	298	296	328	338	333
P_g	na	275	273	254	296	285	250	265
Q_n	35.8	28.0	28.1	22.0	35.8	21.8	13.1	16.5
Q_g	na	8.1	8.2	15.5	0.1	12.7	24.2	19.4
Q	***35.8***	***36.1***	***36.3***	***37.5***	***35.9***	***34.5***	***37.3***	***35.9***
P_2	1	1.01	0.99	1.01	1	0.95	0.99	0.97
k_{1n}	1770	1388	1389	1087	1765	1061	647	809
k_{1g}	0	215	375	377	2.3	305	588	468
k_1	***1770***	***1603***	***1764***	***1464***	***1366***	***1366***	***1235***	***1277***
k_{2n}	8850	6921	6949	5423	8828	5395	3244	4088
k_{2g}	0	2005	1876	3517	21	2900	5517	4423
k_2	***8850***	***8926***	***8825***	***8940***	***8849***	***8295***	***8761***	***8511***
Δcs_n		-48	16	-44	0	-715	-579	-629
(share)		*(0.78)*	*(0.78)*	*(0.85)*	*(1.0)*	*(0.65)*	*(0.40)*	*(0.50)*
Δcs_g		81	100	319	0	-94	253	62
Δps_1		0	0	0	0	0	0	376
Δps_2		61	-20	72	0	-430	-71	-266
ΔW		***94***	***96***	***347***	***0***	***-1239***	***-397***	***-457***

Note: The bottom six rows of the table above contain estimates of changes in consumer and producer welfare relative to the baseline scenario representing no production of GM food. The estimate of share is the proportion of the consumers consuming the non-GM food.

Δcs_j is the change in consumer surplus for those consuming good *j*,
Δps_l the change in producer surplus for supplier of input 1(k_1), and
ΔW the aggregate effect.
See Appendix III for further details on the method of calculation.

The first column reports the baseline simulation, with the equilibrium price and quantity as initially set. In scenario 1, the GM technology is depicted as a factor saving technical change with an impact on k_1 alone. The market segments, with the GM crop taking some of the market, with the non-GM price rising slightly, and a substantial fall in the GM price compared to the initial equilibrium. The expansion in demand by those who switch to GM product leads to an expansion in aggregate output. While this increased output is produced using less of k_1 (due to the technical change), an expansion in k_2 is necessary due to the scale effect. The latter causes the price of k_2 to be bid up, which is the cause of the increased cost (and hence price) of non-GM output. Note that the reduction in demand for k_1 gives no compensating relief, as its price does not vary with output.

In the reported estimates of welfare effects, it should be noted that the changes in consumer surplus are reported for the sub-populations of consumers. The proportion of the market that remains with non-GM food is reported. Per capita estimates of welfare changes could be obtained by multiplying the aggregate change in welfare by the share. Those who remain with non-GM product are worse off due to the increased price, while those who switch to the GM alternative are better off due to the lower price. Net, there is an increase in welfare, which is increased when the increase in producer surplus of those supplying k_2 is included[8]. Parenthetically, comparison of changes in consumer welfare between scenarios should be conducted with care, because the size of the sub-populations involved varies.

Under scenario 2, the input specific technical change is replaced with a Hicks neutral effect, which, at initial quantities and prices, leads to the same reduction in marginal cost. However, the distributional effects on the input side differ. Demand for both inputs falls, despite a slight increase in output and hence input price P_2 falls. This reduces the marginal cost of producing the non-GM product, leading to welfare gains for both sets of consumers (the price P_n declines be less than the rounding factor used in Table 4.1).

---

[8] Details of how the change in consumer surplus is calculated are reported in Appendix III.

Scenario 3 combines both forms of technical change. The increased cost advantage allows the GM market to expand significantly, leading to gains in consumer surplus of that group. However, due to the scale effect, adoption of the GM crop again results in increased demand for k_2, and consequential increased cost (and hence price) of non-GM food. Thus consumers who continue to purchase the non-GM product despite the price differential are worse off than they were prior to the introduction of the GM crop, even though there are no identity preservation costs under this scenario.

Under Scenario 4, the incidence of the cost of identity preservation is assumed to fall exclusively on the GM crop. In this case, these costs almost outweigh the benefits of the technical change, and although GM enters the market, it does so only marginally.

In Scenario 5, the incidence of IP costs falls on both commodities. As a result, there is a net reduction in welfare even for those who switch to GM crop, despite the fact that the price of GM lies below the baseline level of 296 (see Appendix III for an explanation of this). Combined with the losses felt by both the consumers of non-GM product, and producers of k_2, who suffer from the reduction in aggregate supply, aggregate welfare also declines as a result of the innovation.

Scenario 6 also maintains both forms of technical change, while introducing an identity preservation cost for the non-GM product only. This increases the price of the non-GM product, but not by the full $44 (the incidence is about 90 per cent). The GM market expands further, but aggregate output falls. This, combined with a greater concentration in the lower input GM sector leads to reduced input demands, and hence lower input prices. The marginal cost and hence price of GM product falls. Consumers of non-GM product and suppliers of k_2 lose, while GM consumers gain.

As noted above, Scenario 7 presents the “best guess” for possible configurations of a technology innovation fee and identity preservation costs. In fact, the level of the technology fee will depend on the behavior of the technology provider, and they may be expected to set this fee so as to maximise rents. This is an area of research that will be explored at a later date.

In Scenario 7, a technology fee is introduced which allows the supplier of the new seed/herbicide complex to extract part of the rent associated with the innovation. IP costs are only placed upon the non-GM crop. Compared to Scenario 6 (which has the equivalent IP cost, but no technology fee), the non-GM market recovers some ground, as its lower cost competitor is now facing the technology fee. The rent earned by the fee is reported as the change in producer surplus of input 1 (Δps_1).

Increasing the share of k_1 in production increases the significance of the technological innovation: it is clearly more valuable. The results for this simulation are reported in Table A2 in Appendix II. As the marginal cost of producing the GM product drops further, the price differential widens and it absorbs more of the market. As a result, the IP and technology fees used here are no longer sufficient to outweigh the benefits of the innovation, and net welfare increases in all scenarios when comparing Tables 4.1 and A2.

Comparing Table 4.1 with Table A1 and Table A2 with Table A3 reveals that changing the elasticity of demand from -0.75 to -0.5 does little to either the qualitative or quantitative results from the model. In general, both sets of consumers are better off when the elasticity of demand is set at -0.5 as compared to -0.75, and producers of input 2 are worse off except when input share is 16.7%.

5. Conclusions

The simulation results presented here are predicated on a consumer market that can differentiate between the production technology used to produce the good, with a heterogeneity of preferences within the population which mean that the consumer cares about the technology used to produce the good[9]. The former requires segregation and credible labelling of the product.

---

[9] This heterogeneity is represented by the preferences that lead to the choice between the two. An alternative specification that extends that heterogeneity to the individuals demand function is reported in Appendix IV, but the additional complexity does little to change the basic story told here.

When this occurs, the market segments. The aggregate and distributional effects of that segmentation will depend on the economic and technical parameters of the underlying system, and in particular the degree to which the market segments. The latter is the great unknown in the GM debate: if presented with genuine choices, how resilient would the consumer concerns that are expressed in surveys be to price discounts? This paper does not attempt to answer that question, but derives some implications conditional upon an imposed response.

In general the price of conventional, non-GM product is increased, due to the requirement that it bear identity preservation costs. In the case where there is either zero cost, or the cost is borne solely by the GM crop, it may be the case that the price of non-GM product falls, due to changes in the input markets induced by the innovation, but these are small.

The key distributional impacts are between consumers. Those for whom the new technology holds no qualms in general benefit from access to cheaper commodity, while those who remain with the non-GM product can suffer significant losses: typically greater than the gains to the industry supplying the innovation. There are also losses to the suppliers of other inputs to the industry, as long as the innovation is input enhancing rather than Hicks neutral. These losses are extended where a technology fee is associated with these other inputs: the quantity demanded is being adversely affected by the increase in effective price, without its benefits.

Net welfare effects can be positive or negative. If the identify preservation costs are sufficiently high relative to the cost savings, and in particular if they fall on both commodities, aggregate welfare may fall, but with no competitive incentives for the innovation to be dis-adopted. Furthermore, the possibility of monopoly rent seeking on the part of the supplier of innovation increases that likelihood.

The range of conditions under which the later holds true seems a particularly fruitful area of further development in the model.

6. References

Ballenger, N., Bohman, M. and Gehlhar, M. (2000). Biotechnology: Implications for U.S. Corn & Soybean Trade. Agricultural Outlook/April 2000: pp24-28. Economic Research Service/USDA. Retrieved June 8, 2000 from the World Wide Web: http://www.ERS.USDA.gov/epubs/pdf/agout/apr2000/ao270g.pdf

Buckwell, A., Brookes, G., and Bradley, D. (1999). Economics of Identity Preservation for Genetically Modified Crops. Final Report of a Study for Food Biotechnology Communications Initiative (FBCI).

Caswell, J. (2000), "Labelling Policy for GMOs: To Each His Own?", mimeo, June (forthcoming, AgBioForum)

Caswell, J. and E. Mojduszka (1996), "Using Informational Labelling to Influence the Market for Quality in Food Products", *American Journal of Agricultural Economics*, 78(5): 1248-1253

Caulder, J. (1998). Agricultural biotechnology and public perceptions. AgBioForum, 1(1), 38-39. Retrieved May 1, 2000 from the World Wide Web: http://www.agbioforum.missouri.edu.

CCGA. (2000). Canadian Canola Growers Association - The canola producers' perspective on biotechnology. December 1999. Retrieved on 5th June 2000, from the Web - http://www.canola-council.org/biotechweb.htm

Falck-Zepeda, J.B., Traxler, G., and Nelson, R.G. (1999). Rent creation and distribution from the first three years of planting *Bt* cotton. ISAAA Briefs No.13. ISAAA: Ithaca, NY.

FAOSTAT (2000) Agriculture data. Retrieved June 19, 2000 from the World Wide Web: http://apps.fao.org/cgi-bin/nph-db?subset=agriculture

FAS Online (2000) Oilseed prices. Retrieved June 19, 2000 from the World Wide Web: http://www.fas.usda.gov/oilseeds/circular/2000/00-06/Prices.pdf

Fulton, M. & Keyowski, L. (1999a). The producer benefits of herbicide-resistant canola. AgBioForum,2(2), 85-93. Retrieved May 1, 2000 from the World Wide Web:http://www.agbioforum.missouri.edu.

Fulton, M. & Keyowski, L. (1999b). The Impact of Technological Innovation on Producer Returns: The Case of Genetically Modified Canola. Paper presented at the Transitions in Agbiotech: Economics of Strategy and Policy Conference. 24-25 June 1999, Washington DC.

Gamble, J., Muggleston, S., Hedderley, D., Parminter, T. and Richardson-Harman, N. (2000). Genetic engineering: the public's point of view. Report to Stakeholders. The Horticulture and Food Research Institute of New Zealand Ltd. Retrieved on 5th June 2000, from the Web – www.hort.cri.nz/media/gm_report.pdf.

Goddard, E.W. and Glance, S. (1989). Demand for fats and oils in Canada, United States and Japan. Canadian Journal of Agricultural Economics 37(3):421-43.

Hayenga, Marvin. (1998). Structural change in the biotech seed and chemical industrial complex. AgBioForum, 1(2), 43-55. Retrieved May 1, 2000 from the World Wide Web: http://www.agbioforum.missouri.edu.

James, C (1999), Global Review of Commercialised Transgenic Crops: 1999. ISAAA Briefs No. 12. ISAAA: Ithaca, NY

James, C. (1998). Global Review of Commercialised Transgenic Crops: 1998. ISAAA Briefs No. 8. ISAAA: Ithaca, NY.

Johnson, D.D, Satyanarayana, V, Dahl, B.L. and Dooley, F.J. (1996). Trade in minor oilseeds: A spatial equilibrium analysis of sunflower and canola. Agricultural Economics Report No. 353. Department of Agricultural Economics, North Dakota State University, Fargo, ND 58105.

KPMG (1999). Report on the compliance costs facing industry and government regulators in relation to labeling genetically modified foods. October 1999, Canberra.

Lin, W.W., Chambers, W. and Harwood, J. (2000). Biotechnology: U.S. Grain Handlers Look Ahead. Agricultural Outlook/April 2000:pp29-34. Economic Research Service/USDA. Retrieved June 8, 2000 from the World Wide Web: http://www.ERS.USDA.gov/epubs/pdf/agout/apr2000/ao270g.pdf

Lindner, B. (2000). The future of Frankenstein Foods. Invited paper presented to the 44th Annual Conference of the Australian Agricultural and Resource Economics Society, Sydney, January 23-25.

Marshall, K. (1998), “What’s in a label?”, *AgBioForum*, 1(1): 35-37, Summer. Retrieved March 2000 from the World Wide Web: http://www.agbioforum.org.

Miranowski, J.A., Moschini, G., Babcock, B., Duffy, M., Wisner, R., Beghin, J., Hayes, D., Lence, S., Baumel, C.P. and Harl, N.E. (1999). Economic perspectives on GMO market segregation. Staff Paper No. 298, October.

Phillips, P.W.B. (1999). IPRs, canola and public research in Canada. (Mimeo).

Smith, N. (2000). Seeds of opportunity: An assessment of the benefits, safety and oversight of plant genomics and agricultural biotechnology. Report transmitted to the Committee on Science for the One Hundredth Sixth Congress Second Session, April 13. Retrieved from Web site: www.house.gov/science on 8th May 2000.

Smyth, S. and Phillips, P. (1999). Competitors co-operating: Establishing a supply change to manage genetically modified canola. Paper presented at the The Economics of Quality Control in Agriculture meeting, Saskatoon, 2nd to 4th December 1999.

Thompson, G.D. and Kidwell, J. (1998). Explaining the choice of organic produce: Cosmetic defects, prices and consumer preferences. American Journal of Agricultural Economics 80(May 1998): 277-287.

Walkom, T. (2000), ‘GMO folks have a little surprise from Alberta’, *The Toronto Star*, Editorial, May 2, 2000 (retrieved 2nd May 2000 from the Agnet at http://www.plant.uoguelph.ca/safefood).

Zechendorf, B. (1998), “Agricultural biotechnology: Why do Europeans have difficulty accepting it?”, *AgBioForum*, 1(1): 8-13, Summer. Retrieved March 2000 from the World Wide Web: http://www.agbioforum.org

Appendix I Solution for aggregate output for the simple model

$$Q = \frac{\begin{array}{c}[a_0^2\, b_1^2 + 2a_0\, b_1\, (b_0 + IP_n) + 4\, a_1^2\, b_1^2\, (b_t^2 + 2\, b_t\, (IP_n - IP_g) + (IP_g - IP_n)^2\,) \\ -\, 4\, a_1\, b_1\, (b_t^2 + 2\, b_t\, (IP_n - IP_g) + (IP_g - IP_n)^2\,) + (b_0 + IP_n)^2\,]^{0.5} \\ +\, a_0\, b_1 + (b_0 + IP_n)\, (2\, a_1\, b_1 - 1)\end{array}}{2b_1(1 - a_1\, b_1)}$$

Appendix II Alternate simulation results

Table A1. Simulated values for canola price and quantity, input quantities and welfare impacts, for parameters described in Table 3.1, with elasticity of demand = -0.5.

	baseline	S1	S2	S3	S4	S5	S6	S7
P_n	296	297	295	296	296	330	336	333
P_g	na	274	272	252	296	286	248	265
Q_n	35.8	28.1	28.2	22.1	35.8	22.3	13.5	17.0
Q_g	na	8	8.1	14.9	0.1	12.5	23.4	18.8
Q	***35.8***	***36.1***	***36.3***	***37***	***35.9***	***34.8***	***36.9***	***35.8***
P_2	1	1.01	1	0.99	1	0.96	0.98	0.97
k_{1n}	1770	1389	1388	1089	1765	1088	667	833
k_{1g}	0	211	367	364	2	301	566	455
k_1	***1770***	***1600***	***1755***	***1453***	***1767***	***1389***	***1233***	***1288***
k_{2n}	8849	6935	6954	5446	8827	5518	3349	4209
k_{2g}	0	1971	1840	3403	18	2859	5322	4299
k_2	***8849***	***8906***	***8794***	***8849***	***8845***	***8377***	***8671***	***8508***
Δcs_n		-35	35	0	1	-766	-561	-636
(share)		*(0.78)*	*(0.78)*	*(0.62)*	*(1.0)*	*(0.65)*	*(0.40)*	*(0.50)*
Δcs_g		83	103	338	0	-113	287	64
Δps_1		0	0	0	0	0	0	365
Δps_2		43	-46	-2	-2	-369	-140	-270
ΔW		***91***	***92***	***336***	***-1***	***-1268***	***-414***	***-477***

Note: Δcs_j is the change in consumer surplus for those consuming good *j*, Δps_k the change in producer surplus for supplier of input *k*, and ΔW the aggregate effect.

Table A2. Simulated values for canola price and quantity, input quantities and welfare impacts, for parameters described in Table 3.2, with elasticity of demand = -0.75.

	baseline	S1	S2	S3	S4	S5	S6	S7
P_n	296	305	295	305	296	334	348	341
P_g	296	249	272	230	266	261	229	243
Q_n	35.8	19.2	28.2	15	26.1	15.6	9.1	11.6
Q_g	0	18.5	8.2	24.7	10.6	20.6	31	26.6
Q	***35.8***	***37.7***	***36.4***	***39.7***	***36.7***	***36.2***	***40.1***	***38.2***
P_2	1	1.05	0.99	1.06	1	0.97	1.05	1.01
k_{1n}	4246	2292	3333	1797	3088	1838	1083	1373
k_{1g}	0	1185	900	1460	619	1196	1828	1560
k_1	***4246***	***3477***	***4233***	***3257***	***3707***	***3034***	***2911***	***2933***
k_{2n}	6370	3384	5004	2650	4633	2788	1600	2054
k_{2g}	0	3270	1351	4026	1738	3393	5049	4363
k_2	***6370***	***6654***	***6355***	***6676***	***6371***	***6181***	***6649***	***6417***
Δcs_n		-169	13	-143	0	-623	-506	-555
(share)		*(0.54)*	*(0.78)*	*(0.43)*	*(0.72)*	*(0.48)*	*(0.28)*	*(0.36)*
Δcs_g		383	99	755	159	97	644	375
Δps_1		0	0	0	0	0	0	515
Δps_2		317	-21	343	-4	-212	310	49
ΔW		***531***	***91***	***955***	***155***	***-738***	***448***	***384***

See note to Table A1

Table A3. Simulated values for canola price and quantity, input quantities and welfare impacts, for parameters described in Table 3.2, with elasticity of demand = -0.5.

	baseline	S1	S2	S3	S4	S5	S6	S7
P_n	296	302	295	301	295	334	343	339
P_g	296	247	272	226	265	261	225	240
Q_n	35.9	19.3	28.2	15.1	26.1	16.1	9.4	11.9
Q_g	0	17.9	8.1	23.6	10.3	19.9	29.5	25.6
$\boldsymbol{Q}$	***35.9***	***37.2***	***36.3***	***38.7***	***36.4***	***36***	***38.9***	***37.5***
P_2	1	1.04	0.99	1.03	0.99	0.96	1.02	0.99
k_{1n}	4246	2303	3331	1803	3090	1893	1115	1417
k_{1g}	0	1141	881	1383	603	1159	1731	1491
$\boldsymbol{k_1}$	***4246***	***3444***	***4212***	***3186***	***3693***	***3052***	***2846***	***2908***
k_{2n}	6371	3415	5009	2681	4644	2875	1661	2131
k_{2g}	0	3164	1325	3845	1694	3292	4825	4193
$\boldsymbol{k_2}$	***6371***	***6579***	***6334***	***6526***	***6338***	***6167***	***6486***	***6324***
Δcs_n		-125	32	-73	26	-625	-463	-527
(share)		*(0.55)*	*(0.78)*	*(0.42)*	*(0.72)*	*(0.48)*	*(0.28)*	*(0.35)*
Δcs_g		411	102	818	165	105	745	426
Δps_1		0	0	0	0	0	0	495
Δps_2		230	-45	170	-40	-227	125	-54
$\boldsymbol{\Delta W}$		***516***	***89***	***915***	***151***	***-747***	***407***	***340***

See note to Table A1

Appendix III Calculation of the change in consumer surplus, following introduction of the GM alternative.

Estimation of the aggregate change in consumer surplus is based initially on changes for the individual consumers, which are then aggregated according to whether the consumer has switched from non-GM product to GM product.

For those that do not switch, the conventional approach can be applied: for a demand function of the form

$$d_{ni}=a_0P_n^{a1} \qquad \text{(A1)}$$

leads to the standard measure for the change in consumer surplus of:

$$\Delta cs_i = \int_{P_{n2}}^{P_{n1}} d_{ni} \; dp \qquad \text{(A2)}$$

where P_{n1} is the price of non-GM canola before the introduction of GM, and P_{n2} the new market price, *ex post*. (Note the introduction of a further subscript: 1 denotes the initial period, 2 the post-GM period). This gives

$$\Delta cs_i = \frac{a_0\left(P_{n1}{}^{a_1+1} - P_{n2}{}^{a_1+1}\right)}{a_1+1} \qquad \text{(A3)}$$

As all individuals who remain consuming non-GM product are identical, the aggregate change in welfare for that group is obtained by multiplying equation (A3) by the proportion who remain with non-GM:

$$\Delta cs = \frac{a_0\left(P_{n1}{}^{a_1+1} - P_{n2}{}^{a_1+1}\right)}{a_1+1} . \left(\frac{P_{g2}}{P_{n2}}\right)^{\lambda} \quad \text{(A4)}$$

The groups who switch to GM product present more of a problem, because by definition, they do not have a 'base line' GM price, from which the change in consumer surplus can be identified. However, such a price can be inferred.

Recall that c_i is defined as an index of concern, and is the basis on which the decision to switch consumption is made i.e. *i* will consume the GM product if

$$c_i > \left(\frac{P_g}{P_n}\right)^{\lambda} \quad \text{(A5)}$$

We now introduce the notion of an *equivalent price* for GM. This is the price at which consumer *i* is indifferent between consuming GM and non-GM product

$$EP_g = c_i^{1/\lambda} P_{n1} \quad \text{(A6)}$$

That is, if the consumer switches to GM canola, and can purchase it at EP_g there will be no change in their welfare, as compared with their pre-GM consumption of non-GM product. If they switch to GM product, and can pay a price less than EP_g then their welfare will be increased, by the conventional amount, defined as the wedge below the GM demand curve and between the effective price and the market price of GM:

$$\Delta cs_i = \frac{a_0\left(\left(c_i^{1/\lambda} P_{n1}\right)^{a_1+1} - P_{g2}{}^{a_1+1}\right)}{a_1+1} \quad \text{(A7)}$$

Given the distribution of *c* there will be a range of welfare impacts, ranging from large (for those individuals who are effectively indifferent between the two products, and hence need very little price differential to switch) to negligible for those who are more concerned, and whose equivalent price of GM coincides with the market price.

Note that it is the post-GM price of non-GM that governs the decision to switch, while it is the pre-GM price of non-GM canola which determines the welfare impact. As a result it is possible for consumer surplus for the individual to fall.

Assume that the initial price of non-GM canola is 296, and the equivalent price for individual *i* is 266 i.e., they require a 10% discount before they will switch. Let the post-GM price of non-GM canola rise to 320 (due to IP costs), and the GM price be 266. This individual will certainly switch (there is now a 15% price differential), but the change in welfare will be zero, by definition. Furthermore, if the GM price were 270, they would still switch (the price differential still exceeds 10%) but they would be at a lower level of welfare ***compared to the pre-GM position.*** Indeed, they would be prepared to switch at prices of GM up to 288. The decision to switch is still rational, in that it minimizes the losses associated with the new price regime, after the introduction of the GM crop.

The aggregate change in welfare for all those who switch is given by integrating across the population who switch:

$$\int_{\left(\frac{P_{g2}}{P_{n2}}\right)^{\lambda}}^{1} \Delta cs_i = \frac{a_0\left(\left(c_i^{1/\lambda} P_{n1}\right)^{a_1+1} - P_{g2}{}^{a_1+1}\right)}{a_1+1} dc_i \qquad \text{(A8)}$$

Appendix IV Heterogeneity of demand.

The demand decision has been treated as a two-stage process: consumers first decide which type of commodity they will consume (depending on relative prices of GM and non-GM), and then the quantity of commodity. So far the representative demand curve for the two commodities has been identical: there is heterogeneity in preferences between the two commodities, but homogeneity with respect to the actual demand function. This restriction will now be relaxed.

We assume that those who willing to convert at a relatively low price differential are consumers who are more price responsive in general. Thus we model the elasticity of demand of individual *i* within the population as a function of their latent 'concern' variable *c*.

$$d_{ni} = a_0 P_n^{a1+a2c_i} \tag{A9}$$

$$d_{gi} = a_0 P_g^{a1+a2c_i} \tag{A10}$$

If $a_2<0$ then those most likely to switch from non-GM to GM product (see (3) above) are those in the population that have the highest price elasticity of demand.

Identifying aggregate market demand in the two segments will now require aggregation over the individual demands within the two. Defining c^* as the level of the *c* held by the marginal consumer (i.e. who is indifferent between non-GM and GM) then aggregate demands are given by:

$$D_n = \int_0^{c^*} a_0 P_n^{a1+a2c} dc \tag{A11}$$

$$D_g = \int_{c^*}^{1} a_0 P_g^{a1+a2c} dc \tag{A12}$$

Given the assumption that *c* is distributed as a uniform variable, and maintaining $a_2 \neq 0$ then

$$D_n = P_n^{a_1}\left(\frac{a_0 P_n^{a_2 c^*}}{a_2 \ln(P_n)} - \frac{a_0}{a_2 \ln(P_n)}\right) \tag{A13}$$

$$D_g = P_g^{a_1}\left(\frac{a_0 P_g^{a_2}}{a_2 \ln(P_g)} - \frac{a_0 P_g^{a_2 c^*}}{a_2 \ln(P_g)}\right) \tag{A14}$$

and noting that

$c^* = (P_g/P_n)^{\lambda}$

allows the identification of aggregate demand as a function of the two product prices.