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# **Estimates of the Welfare Impact of Intragenic and Transgenic GM Labeling Policies**

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## **Introduction**

In little more than a decade since the first commercially available genetically modified (GM) crops were introduced, GM crops have been adopted globally by farmers at an extraordinary rate, surmounting the one billionth planted acre in 2005. Since their commercialization, a diverse set of interested parties including environmental groups, biotechnology companies, and government and health organizations have disseminated to the public and policymakers conflicting information on the benefits and risks of GM. A central issue in the larger debate between critics and advocates of GM has been if and how GM foods should be labeled. Given that genetic modification is a product attribute not directly observable by consumers pre- or post-purchase/consumption, a market with GM and non-GM products will result in a pooled equilibrium ala Akerlof's (1970) lemons model with too great a proportion of the weakly inferior GM product. In markets characterized by this form of information asymmetry, labeling requirements and credible certification schemes can alleviate the undesirable welfare properties of the lemons problem.

While there are numerous potential labeling policies that facilitate informed product purchases by consumers (see Caswell 1998, 2000 and Sheldon 2001 for discussions), globally two divergent policies have primarily been implemented. Countries including the EU, Australia, and Japan have adopted a "mandatory" labeling policy that requires all GM foods to be clearly labeled as such. In the United States and Canada (among other countries), a "voluntary" labeling policy has been adopted where producers in most circumstances may label their products as GM on a voluntary basis. From a welfare perspective, the optimal choice of labeling policy by a governmental regulatory body depends in part upon the balance between compliance and labeling costs and consumer preferences towards genetically engineered foods. Several analyses, including Berwald, Carter, and Gruere (2006), Crespi and Marette (2003), Kirchhoff and Zago (2001), and Lapan and Moschini (2004), have considered the implications resulting from the imposition of these two disparate labeling policies in a variety of contexts.

While the debate over labeling policies for GM foods continues, a new feature is beginning to be introduced. GM food products have relied upon "transgenic" engineering techniques in which genes from a different organism (typically soil bacteria) are transferred into a commercial crop variety in order to yield a new product with a desired trait. Yet, a new line of varieties have been developed using so-called "intragenic" engineering techniques in which genes from an alternative variety of the same species are transferred into a commercial crop variety. These new intragenic engineering techniques have the potential for genomic and metabolic pathway discoveries to be rapidly introduced into established commercial varieties to fast-track the breeding processes without introducing foreign DNA or antibiotic markers and to deliver new varieties that were previously impossible through conventional cross-breeding techniques. For a more technical overview of intragenic versus transgenic engineering see Rommens et al. (2004).

While consumers' view of non-GM as being weakly superior to GM has been well documented, little research has addressed exactly what aspect of the production of GM food products results in this inferiority. Namely, is it the use of genetic techniques for producing a product that would otherwise not appear in nature, the presence of foreign genetic content, or a combination of both factors? The answer to this question manifests in whether consumers place a different value on intragenic foods when compared to otherwise equivalent transgenic foods (i.e., to what extent is intragenics weakly/strictly superior to transgenics). Furthermore, if consumers do have non-equivalent preferences towards intragenic and transgenic food products, the debate over mandatory versus voluntary labeling policies is augmented with a new question: is it socially optimal to impose a labeling regime that differentiates between intragenic and transgenic GM?

This paper serves to address these questions, but takes a distinctly different approach from previous works studying the provision of quality in agricultural markets. In this paper a model is developed where GM Free, intragenic GM, transgenic GM, and generically labeled GM foods are modeled as "vertically differentiated" goods ala Mussa and Rosen (1978). In the model, consumers

differ with respect to two taste parameters - dislike for genetic modification and dislike for foreign genetic content - as opposed to the typical assumption of a single taste parameter.<sup>1</sup> In models of vertically differentiated goods, the typical approach for arriving at a tractable solution is to assume that consumer tastes are uniformly distributed along some interval.<sup>2,3</sup> While this assumption may be appropriate in some contexts, this is highly questionable when considering tastes involving GM foods because, by construction, uniformity implies that the fraction of individuals who are indifferent between GM Free and GM alternatives is relatively minor.

This paper strives to move in the opposite direction away from an emphasis on tractability towards a more realistic characterization of consumer preferences. To that end, the actual distributions of consumers' taste preferences are estimated using data from a series of multiple-round random  $n$ th-price experimental auctions with randomly chosen adult consumers in two geographically separated cities. In addition to randomized labeling treatments, biased and verifiable information on GM are injected into the experiment. Using the estimated taste distributions and numerical methods it is possible to derive and evaluate a set of complex welfare functions under mandatory/voluntary labeling policies with/without labeling of intragenic and transgenic products. Finally, these welfare estimates are compared to those found under the typical assumption in the literature of uniformly distributed consumer tastes.

The paper is organized as follows. In the following section a model with a vertically differentiated market structure for GM food products is developed. Section 3 derives consumer surplus functions under different government policies. Section 4 provides a brief overview of the conducted

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<sup>1</sup> The authors are unaware of previous studies addressing the provision of quality in agricultural markets where consumers in a vertically differentiated product setup are modeled using more than one continuously distributed taste parameter.

<sup>2</sup> An exhaustive list of papers utilizing the assumption of uniformly distributed consumers within a vertically differentiated product model is extensive. A sampling of relevant papers addressing product quality or labeling include: Berwald, Carter, and Gruere (2006), Crespi and Marette(2003), Giannakas (2002), Giannakas and Fulton (2002), Hamilton and Zilberman (2006), Hollander, Monier-Dilhan, and Ossard (1999), Moschini, Bulut, and Cembalo (2005), Scarpa (1998), Stivers (2003), and Valletti (2000).

<sup>3</sup> A notable exception is Lapan and Moschini (2007) where the assumption of uniformly distributed consumer tastes is only used in order to derive unambiguous comparative statics. The authors show analytically that the reduced modeling burden from assuming uniform tastes does not come without a cost.

experimental auctions. Section 5 develops and estimates a model of consumer taste distributions. Section 6 evaluates welfare under different government labeling policies under the assumption of uniformly distributed tastes and using the distributions estimated in section 5. Finally, section 7 concludes the paper.

### **Model of the market for GM foods**

In this section a theoretical model of the market for genetically modified food products is developed. Firms are assumed to be able to produce three different products: GM Free (GMF), Intragenic GM (IGM), and Transgenic (TGM) with marginal costs  $C^{GMF}$ ,  $C^{IGM}$ ,  $C^{TGM}$  (where  $C^{GMF} > C^{IGM} > C^{TGM} > 0$ ) respectively.<sup>4</sup> Firms act competitively. Depending upon the imposed government policy, food products may bear one of the following labels: *GM Free*, *Intragenic GM*, *Transgenic GM*, or *GM* (note, the generic *GM* label arises when intragenic/transgenic is not allowed to be included on the label).

#### *Compliance Costs*

Depending upon the government labeling policy imposed on the market, producers incur a number of compliance costs related to “identity preservation” activities (e.g. segregation, testing, and labeling costs). We assume that compliance costs per unit of production (if they are incurred under the considered government policy) are  $t^{IGM}$ ,  $t^{TGM}$ , and  $t^{GMF}$  for intragenic, transgenic, and GM Free products respectively (where  $t^{GMF} \geq t^{TGM} \geq t^{IGM} \geq 0$ ). While intragenic foods may face lower compliance costs compared to transgenic foods, it is assumed that  $C^{IGM} + t^{IGM} > C^{TGM} + t^{TGM}$ , else transgenic foods would completely exit the market.

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<sup>4</sup> Implicitly in this specification it is assumed that a product cannot be intragenically and transgenically modified. Relaxing this assumption is trivial, and would only modify the later described assumed setup for compliance costs.

### *Government Labeling Policies*

This paper considers four alternative labeling policies. *Mandatory Policy 1*, which corresponds to a modified<sup>5</sup> version of the current policy of the EU (among other nations), mandates that all GM products must be labeled as GM. No labeling of intragenic or transgenic is allowed. Hence, the only GM product produced will be transgenic since  $C^{IGM} + t^{IGM} > C^{TGM} + t^{TGM}$ . Under this policy, GM Free products incur a compliance cost of  $t^{GMF}$  and transgenic products incur a compliance cost of  $t^{TGM}$ . Under *Mandatory Policy 2*, again all products must be labeled, but now labeling of intragenic GM and transgenic GM is permitted. Compliance costs for GM Free, intragenic GM, and transgenic GM are  $t^{GMF}$ ,  $t^{IGM}$ , and  $t^{TGM}$  respectively. Under *Voluntary Policy 1*, which corresponds to a modified version of the current policy in the US (among other nations), only products that seek the GM Free label incur a compliance cost of  $t^{GMF}$ . No labeling of intragenic or transgenic is allowed. Hence no intragenic products will be produced.<sup>6</sup> Finally, under *Voluntary Policy 2*, only products seeking the GM Free or intragenic GM labels incur compliance costs of  $t^{GMF}$  and  $t^{IGM}$  respectively. In the perfectly competitive setting, equilibrium prices under each policy are given by table 1.

### *Consumers*

The impetus for labeling of food products derives from consumers' preferences towards GM food products. As previously discussed, it is assumed that the preference relation GM Free  $\succeq$  intragenic GM  $\succeq$  transgenic GM holds across consumers. Consumer preferences are modeled using a vertically differentiated demand structure. Typically in a model of this nature, consumers are differentiated according to a single "taste parameter". In order to address the market at hand, it is necessary to partition the taste parameter into two components. Let  $\theta^{GM}$  denote a consumer's type with regards to

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<sup>5</sup> This policy is "modified" because no current governmental policy explicitly considers intragenics.

<sup>6</sup> Note that since  $C^{GMF} > C^{IGM} > C^{TGM}$ , no producer would produce GM Free products and attempt to sell them under the "inferior" label.

"dislike" for genetic modification and let  $\theta^F$  denote a consumer's type with regards to "dislike" for foreign genetic content in food. The first type parameter,  $\theta^{GM}$ , applies to preferences for both intragenic GM and transgenic GM products since both involve some form of "unnatural" genetic production methods. The second type parameter,  $\theta^F$ , applies only for the transgenic GM product since it is the only product that is produced with the additional negative attribute of containing foreign genetic material. This specification of consumer types allows for differentiating the two components that make up "dislike" for transgenic food products. Without loss of generality, consumer types are normalized to the unit interval,  $\theta^{GM}, \theta^F \in [0,1]$ .

Consumers are assumed to purchase at most one unit of one type of product depending upon those available under the imposed regulatory policy. The indirect utility for a consumer of type  $\{\theta^{GM}, \theta^F\}$  is

$$\begin{aligned}
 U^{GMF} &= U - P^{GMF} \\
 U^{IGM} &= U - P^{IGM} - \alpha\theta^{GM} \\
 U^{TGM} &= U - P^{TGM} - \alpha\theta^{GM} - \delta\theta^F \\
 U^{GM} &= U - P^{GM} - \alpha\theta^{GM} - \gamma\delta\theta^F
 \end{aligned}
 \tag{1}$$

where  $U$  denotes the fixed utility from consuming a food product,  $P$  denotes price,  $\alpha$  and  $\delta$  are non-negative intensity parameters, and  $\gamma \in [0,1]$  is a parameter capturing consumers' expectation that a generically labeled GM product is transgenic.<sup>7</sup>

## Welfare

In this section, consumer surplus functions under policies allowing and not allowing labeling of intragenic GM and transgenic GM are setup, but not explicitly solved. Due to the complexity of

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<sup>7</sup> Technically, under full information of labeling policies consumers should infer that a generically labeled GM product is in fact a transgenic product (i.e.  $\gamma = 1$ ). However, this is a source of contention and a feature of the argument by GM opponents for mandatory labeling. To keep the model as general as possible and to facilitate later discussion this expectation parameter is included throughout the derivations. Later analysis is considered under both the full information setting in which  $\gamma = 1$  and a partial information setting where  $\gamma \in [0,1]$ .

modeling two taste parameters with generic distributions, the explicit solution is quite lengthy, intractable, and uninformative. In a later section, where the distributions of  $\theta^{GM}$  and  $\theta^F$  are empirically estimated using data collected through experimental auctions, it is feasible to numerically solve for welfare under different government policies. Before solving for the consumer surplus functions it is necessary to specify notationally the taste parameter distributions. Let  $k^{GM}(\theta^{GM})$  and  $k^F(\theta^F)$  denote the probability distribution functions and  $K^{GM}(\theta^{GM})$  and  $K^F(\theta^F)$  denote the cumulative distribution functions.

#### *Welfare when labeling of intragenic GM and transgenic GM is not allowed*

In this section, welfare is considered under *Mandatory Policy 1* and *Voluntary Policy 1* where labeling of intragenic GM and transgenic GM is not allowed. Given the specification of consumer preferences, the GM Free product will be strictly preferred if  $\alpha\theta^{GM} + \gamma\delta\theta^F > P^{GMF} - P^{GM}$  and vice versa for the GM product. Given this preference structure, the ranges of  $\theta^{GM}$  and  $\theta^F$  under which the GM Free product (or GM product) are strictly preferred is not uniquely defined. Figure 1 provides a graphical representation of the four possible cases that may arise. The area above each line represents the set  $\{\theta^{GM}, \theta^F\}$  under which the GM Free product is strictly preferred and below the line is where the GM product is strictly preferred. For the four possible cases, the conditions under which they may occur can be characterized by

$$(2) \quad \begin{aligned} \text{Case A: } & P^{GMF} - P^{GM} \leq \alpha \text{ and } P^{GMF} - P^{GM} \leq \gamma\delta \\ \text{Case B: } & P^{GMF} - P^{GM} \leq \alpha \text{ and } P^{GMF} - P^{GM} \geq \gamma\delta \\ \text{Case C: } & P^{GMF} - P^{GM} \geq \alpha \text{ and } P^{GMF} - P^{GM} \geq \gamma\delta \\ \text{Case D: } & P^{GMF} - P^{GM} \geq \alpha \text{ and } P^{GMF} - P^{GM} \leq \gamma\delta \end{aligned}$$

The consumer surplus functions under each of the four possible cases can be expressed as:

$$(3) \quad \begin{aligned} CS^{GMF} &= \int_{\max\{0,H\}G}^{\min\{J,1\}} \int_0^1 \{\bullet^{GMF}\} d\theta^{GM} d\theta^F + \int_{\min\{J,1\}0}^1 \int_0^1 \{\bullet^{GMF}\} d\theta^{GM} d\theta^F \\ CS^{GM} &= \int_{\max\{0,H\}G}^{\min\{J,1\}} \int_0^1 \{\bullet^{GM}\} d\theta^{GM} d\theta^F + \int_0^{\max\{0,H\}} \int_0^1 \{\bullet^{GM}\} d\theta^{GM} d\theta^F \end{aligned}$$

where  $\bullet^{GMF} = U^{GMF} k^{GM}(\theta^{GM}) k^F(\theta^F)$ ,  $\bullet^{GM} = U^{GM} k^{GM}(\theta^{GM}) k^F(\theta^F)$ ,  $G = \frac{1}{\alpha}(P^{GMF} - P^{GM} - \gamma\delta\theta^F)$ ,

$H = \frac{1}{\gamma\delta}(P^{GMF} - P^{GM} - \alpha)$ , and  $J = \frac{1}{\gamma\delta}(P^{GMF} - P^{GM})$ .

As is evident from these consumer surplus functions, given the general specification of the model there is little intuition to be gained. As well, it can be seen that in order to solve for an explicit solution would require a distributional assumption over tastes that the CDF is twice integrable with a closed form, severely restricting the class of distributions which could be utilized.

#### *Welfare when labeling of intragenic GM, and transgenic GM is allowed*

In this section, welfare is considered under *Mandatory Policy 2* and *Voluntary Policy 2* where labeling of intragenic GM and transgenic GM is allowed. Given the specification of consumer preferences, the following are the sufficient conditions on the taste parameters for each product to be strictly preferred.

$$(4) \quad \begin{aligned} GMF : \theta^{GM} &> \frac{P^{GMF} - P^{IGM}}{\alpha} & \text{and} & \quad \alpha\theta^{GM} + \delta\theta^F > P^{GMF} - P^{TGM} \\ IGM : \theta^{GM} &< \frac{P^{GMF} - P^{IGM}}{\alpha} & \text{and} & \quad \theta^F > \frac{P^{IGM} - P^{TGM}}{\delta} \\ TGM : \alpha\theta^{GM} + \delta\theta^F &< P^{GMF} - P^{TGM} & \text{and} & \quad \theta^F < \frac{P^{IGM} - P^{TGM}}{\delta} \end{aligned}$$

To this point, given the assumed competitive market setting, the only assumption built-up for prices is  $P^{GMF} > P^{IGM} > P^{TGM}$ . Without further restrictions, the ranges of  $\theta^{GM}$  and  $\theta^F$  under which each product is strictly preferred are not characterized by a single set of conditions. This significantly increases the complexity at hand, but allows for more generality. To illustrate, figure 2 provides a graphical representation of the sets of  $\{\theta^{GM}, \theta^F\}$  under which each product is strictly preferred assuming that

$\frac{P^{GMF} - P^{TGM}}{\alpha} < 1$  and  $\frac{P^{IGM} - P^{TGM}}{\delta} < 1$ . Without placing price or parameter restrictions six feasible cases may occur. Figure 3 presents each of the possible cases. In this graph, depending upon the parameters, the point at which the preference lines "cut the axis at 1" changes.

While the presence of six possible cases increases the complexity in deriving expressions for consumer surplus, they can be expressed as

$$\begin{aligned}
 CS^{GMF} &= \int_{\max\{R,X\}}^{\max\{R,X,\min\{1,Q\}\}} \int_L^1 \{\bullet^{GMF}\} d\theta^{GM} d\theta^F + \int_{\min\{Q,1\}}^1 \int_0^1 \{\bullet^{GMF}\} d\theta^{GM} d\theta^F \\
 (5) \quad CS^{IGM} &= \int_0^{\min\{1,X\}} \int_{\min\{1,Y\}}^1 \{\bullet^{IGM}\} d\theta^{GM} d\theta^F \\
 CS^{TGM} &= \int_0^{\min\{1,\max\{R,X\}\}} \int_0^{\min\{1,Y\}} \{\bullet^{TGM}\} d\theta^{GM} d\theta^F + \int_{\min\{1,\max\{R,X\}\}}^{\min\{1,Q\}} \int_L^1 \{\bullet^{TGM}\} d\theta^{GM} d\theta^F
 \end{aligned}$$

where  $\bullet^{GMF} = U^{GMF} k^{GM}(\theta^{GM}) k^F(\theta^F)$ ,  $\bullet^{IGM} = U^{IGM} k^{GM}(\theta^{GM}) k^F(\theta^F)$ ,  $\bullet^{TGM} = U^{TGM} k^{GM}(\theta^{GM}) k^F(\theta^F)$ ,

$$L = \frac{P^{GMF} - P^{TGM} - \alpha\theta^{GM}}{\delta}, \quad Q = \frac{P^{GMF} - P^{TGM}}{\alpha}, \quad R = \frac{P^{GMF} - P^{TGM} - \delta}{\alpha}, \quad X = \frac{P^{GMF} - P^{IGM}}{\alpha} \text{ and } Y = \frac{P^{IGM} - P^{TGM}}{\delta}.$$

Again, as in the case of the welfare functions under policies without labeling of intragenic GM and transgenic GM, tractability is certainly not present in this model design. Even under the assumption of uniform distributions, as opposed to the utilized generic setup, little intuition is to be gained due to the dual taste parameters. But, as will be shown in later sections, the generality of the presented market design yields a much richer characterization of the welfare impact of different government labeling policies.

## Experimental design

To elicit the necessary information for characterizing the distribution of consumer tastes ( $\theta^{GM}$  and  $\theta^F$ ), we conducted experimental auctions in the spring of 2007. Our experiments integrate recognized experimental procedures (e.g., Shogren et al. 1994, Lusk et al. 2001, Alfnes and Rickertsen 2003) and the advances of Rousu et al. (2007). Experiments were conducted in two cities, Des Moines, Iowa and

Harrisburg, Pennsylvania. These cities were chosen in order to prevent results from being driven based on preferences from individuals in one geographic area. A total of seven sessions (four in Des Moines and three in Harrisburg) were conducted consisting of between nine and seventeen participants each, for a total of 92 individuals and 1104 observations. Individuals for the study were randomly solicited by the Iowa State University Center for Survey Statistics and Methods (CSSM) and invited to participate in a university study for \$45 in compensation, but were not told beforehand the nature of the project.

### *The information treatments*

Prior to the bidding rounds participants in each session were randomly provided one of five information treatments. This contrasts previous studies (e.g., Rousu et al. 2007) that assign all participants in a given session the same information treatment (i.e., treatment A in session 1, treatment B in session 2, etc.). By assigning multiple treatments within a session our approach ensures that the treatment effect is not confounded with a session effect. The information treatments included: 1) *no information* - as a control group, 2) *the industry (pro-biotech) perspective* - a collection of mainly positive or optimistic statements and information on genetic modification provided by a group of leading biotechnology companies, 3) *the environmental (anti-biotech) perspective* - a collection of mainly negative statements and information on genetic modification from leading environmental groups, 4) *industry and environmental perspectives* - both information statements 2 and 3, and 4) *industry, environmental, and third-party (verifiable information) perspectives* - this treatment included statements 2 and 3 as well as an objective statement on genetic modification approved by a third-party group consisting of a variety of individuals knowledgeable about GM goods, including scientists, professionals, religious leaders, and academics, none of whom have a financial stake in GM foods. To ensure that the volume of information contained in these statements was not overwhelming for participants, each statement was limited to a single standard page size and clearly organized. For information treatments consisting of more than one perspective, the order in which they were presented was randomized across participants.

### *The auction mechanism and rounds of bidding*

Most experimental auctions use one of three demand revealing auction mechanisms: the Vickrey 2nd price auction (Vickrey 1961) (e.g. Fox, Hayes, and Shogren 2002), the BDM mechanism (Becker, Degroot, and Marshak 1964) (e.g. Lusk et al. 2001 and Monchuk et al. 2007), or the random  $n$ th-price auction (e.g. Shogren et al. 2001, Huffman et al. 2007). We chose the random  $n$ th-price auction because it is demand revealing in theory and the auction attempts to engage bidders at all locations along the demand curve. The random  $n$ th-price auction works as follows: each of  $k$  bidders submits a bid for one unit of a good, then each of the bids is rank-ordered from highest to lowest. The auction monitor then selects a random number drawn from a uniform distribution between 2 and  $k$ . The monitor sells one unit of the good to each of the  $(n-1)$  highest bidders at the  $n$ th-price. For instance, if the monitor randomly selects  $n = 5$ , the four highest bidders would each purchase one unit of the good priced at the fifth-highest bid. Ex ante, bidders who have low or moderate valuations now have a nontrivial chance to buy the good because the price is determined randomly. This auction increases the odds that insincere bidding will lead to a loss. Participants were given detailed instructions and examples about the random  $n$ th-price auction, and were trained in a multi-round practice auction.

### *The products and labels*

During the sessions, each participant bid in an  $n$ th-price auction consisting of four rounds where in each round bids were placed on three products (broccoli, beefsteak tomatoes, and russet potatoes). We chose these products for two reasons. First, these are different from each other, so even if participants disliked one of the products, we would be able to assess their preferences for genetic modification based on the other products. Second, these products are neither, or at least weak, complements nor substitutes for each other. This is important because research has shown when participants can win multiple products that are complements or substitutes that their bids can be affected (Rousu, Beach, and Corrigan 2008).

In each round, the three food products were presented in packaging as one would find in a grocery store and were affixed with one of four labels: GM Free, Intragenic GM, Transgenic GM, or a plain label. All three products within the round had the same label and the order in which the labels were presented was randomized across sessions. Examples of the labels are presented in figure 4.

## Empirical Model

Utilizing the bids from the experimental auctions, it is possible to estimate the distribution of the taste parameters  $\theta^{GM}$  and  $\theta^F$ . Let  $B_i^{L,f}$  denote the bid by an individual  $i=1,2,\dots,I$  for a food product  $f \in \{Broccoli, Tomato, Potato\}$  with label  $\ell \in \{GMF, IGM, TGM, GM\}$ .<sup>8</sup> Using these conventions and following from the theoretical model, consumer utility can be restated as

$$\begin{aligned}
 U_i^{GMF,f} &= U_i^f - P^{GMF,f} \\
 U_i^{IGM,f} &= U_i^f - P^{IGM,f} - \alpha^f \theta_i^{GM,f} \\
 U_i^{TGM,f} &= U_i^f - P^{TGM,f} - \alpha^f \theta_i^{GM,f} - \delta^f \theta_i^{F,f} \\
 U_i^{GM,f} &= U_i^f - P^{GM,f} - \alpha^f \theta_i^{GM,f} - \gamma^f \delta^f \theta_i^{F,f}.
 \end{aligned}
 \tag{6}$$

In the experimental auction, consumers were not faced with a choice based upon market prices, but instead submitted bids for what they are willing to pay for a product. The utilized auction mechanism, the  $n$ th-price auction, is incentive compatible meaning that an individual's optimal strategy is to submit a bid for a product equal to their willingness to pay (i.e. the price at which they would be indifferent between consuming the product or not). Given the specification of preferences, the bid submitted by an individual is the price at which purchase would yield a utility equal to zero. Thus we can express utility in terms of bids as

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<sup>8</sup> In the series of experimental auctions used for this paper, participants did not bid on products labeled as GM (instead they were faced with a no label case). The absence of this information prevents explicit calculation of the expectation parameter  $\gamma$  at the individual level. In a second set of similar but modified experimental auctions also conducted in 2007, consumers did bid on products with a GM label. Using this data, an average value of  $\gamma$  across individuals was calculated and found to be equal to approximately 0.68. While this estimate is not as robust as the estimates for  $\theta^{GM}$  and  $\theta^F$  it is evidence that consumers are not characterized by the full information case ( $\gamma = 1$ ).

$$\begin{aligned}
(7) \quad & B_i^{GMF,f} = U_i^f \\
& B_i^{IGM,f} = U_i^f - \alpha^f \theta_i^{GM,f} \\
& B_i^{TGM,f} = U_i^f - \alpha^f \theta_i^{GM,f} - \delta^f \theta_i^{F,f} \\
& B_i^{GM,f} = U_i^f - \alpha^f \theta_i^{GM,f} - \gamma_i^f \delta^f \theta_i^{F,f}.
\end{aligned}$$

Rearranging these expressions we can solve for the relationship between bids and taste parameters

$$\begin{aligned}
(8) \quad & \theta_i^{GM,f} = \frac{1}{\alpha^f} (B_i^{GMF,f} - B_i^{IGM,f}) \\
& \theta_i^{F,f} = \frac{1}{\delta^f} (B_i^{IGM,f} - B_i^{TGM,f}) \\
& \gamma_i^f = \frac{1}{\delta^f \theta_i^{F,f}} (B_i^{IGM,f} - B_i^{GM,f})
\end{aligned}$$

As can be seen in the above expression, given the information available from the experimental auction it is not possible to individually identify  $\alpha^f$ ,  $\delta^f$ ,  $\gamma_i^f$ ,  $\theta_i^{GM,f}$ , and  $\theta_i^{F,f}$ . But, given the generic space over which  $\theta_i^{GM,f}$  and  $\theta_i^{F,f}$  are defined, if we assume these parameters are constrained to the unit interval [0,1] it must hold that

$$\begin{aligned}
(9) \quad & \alpha^f \geq \max_i \{B_i^{GMF,f} - B_i^{IGM,f}\} \\
& \delta^f \geq \max_i \{B_i^{IGM,f} - B_i^{TGM,f}\}
\end{aligned}$$

in order to ensure that tastes are properly mapped to the dollar space. Thus, while we cannot explicitly solve for the parameters  $\alpha^f$  and  $\delta^f$ , we can place a lower bound on their values, which, as will be shown, is sufficient and revealing for subsequent analysis.<sup>9</sup>

Finally, while given the data available it is possible to consider each food product  $f$  separately, to simplify the analysis and concentrate the results reducing potential noise across products, consumer

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<sup>9</sup> Please note that clearly, given the information contained in bid differences, we could simply reformulate the model by combining intensity and type parameters into a single variable (for example  $\tilde{\theta}_i^{GM,f} \equiv \alpha^f \theta_i^{GM,f} = B_i^{GMF,f} - B_i^{IGM,f}$ ) thereby dropping the normalization of consumer types to the unit interval. We purposely choose not to in order to keep our model consistent with the structure typically used in theoretical and empirical applications and to facilitate comparisons.

types are averaged across the three products ( $\bar{\theta}_i^{GM} = \frac{1}{3} \sum_f \theta_i^{GM,f}$  and  $\bar{\theta}_i^F = \frac{1}{3} \sum_f \theta_i^{F,f}$ ).<sup>10</sup> This yields a composite calculation of each consumer's aversion to genetic modification and foreign genetic content.

### *Distribution of taste parameters*

In both the theoretical and empirical models it was assumed that  $\bar{\theta}_i^{GM}, \bar{\theta}_i^F \in [0,1]$ , but no assumption was made regarding the specific distribution governing these parameters. Given the data provided by the experimental auction, we can actually estimate the governing distributions, but we require a distributional form to fit. One potential flexible form candidate would be the beta distribution which can characterize a wide variety of potential forms, but suffers from not having a closed form CDF. An alternative, but less frequently utilized distribution which mimics the beta distribution but with a closed form PDF and CDF, is the Kumaraswamy distribution. The PDF for the Kumaraswamy distribution is  $f = abx^{a-1}(1-x^a)^{b-1}$  and the CDF is  $F = 1 - (1-x^a)^b$  where  $a, b > 0$ .

One of the drawbacks of the Kumaraswamy distribution (and similarly the beta distribution) is that it, by construction, has zero probability at the endpoints 0 and 1 ( $f(0) = f(1) = 0$ ). Hence, while the distribution is flexible over the internal interval (0,1) it does not allow for potential masses of individuals at 0 or 1. This is highly unsatisfactory in that it does not allow for individuals to have preferences such that products are weakly superior (i.e. it forces strict superiority). To remedy this shortcoming, a piecewise distribution is defined. Let  $\Psi = \{GM, F\}$ ,  $0_\Psi$  denote the fraction of individuals with  $\bar{\theta}_i^\Psi = 0$ , and  $1_\Psi$  denote the fraction of individuals with  $\bar{\theta}_i^\Psi = 1$ . Define the piecewise Kumaraswamy CDF as

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<sup>10</sup> Conducted sensitivity analysis showed that averaging across types did not qualitatively change the results of the model and had a minor impact on quantitative estimates.

$$(10) \quad K^\Psi(\bar{\theta}_i^\Psi) = \begin{cases} K^\Psi(\bar{\theta}_i^\Psi = 0) = 0_\Psi \\ K^\Psi(0 < \bar{\theta}_i^\Psi < 1) = (1 - 0_\Psi - 1_\Psi) F^\Psi(\bar{\theta}_i^\Psi) \\ K^\Psi(\bar{\theta}_i^\Psi = 1) = 1_\Psi \end{cases}$$

where  $F^\Psi(\bar{\theta}_i^\Psi)$  denotes the standard Kumaraswamy CDF. With this piecewise modified version of the Kumaraswamy distribution we have an extremely flexible distribution over the interval (0,1) that will allow for nontrivial positive masses at the endpoints.

### *Estimates of taste parameter distributions*

For estimating the distribution of individuals with  $0 < \bar{\theta}_i^\Psi < 1$  the likelihood function is

$$(11) \quad L = \max_{a^\Psi, b^\Psi > 0} \left\{ \prod_{i \in \{0 < \bar{\theta}_i^\Psi < 1\}} a^\Psi b^\Psi (\bar{\theta}_i^\Psi)^{a^\Psi - 1} \left( 1 - (\bar{\theta}_i^\Psi)^{a^\Psi} \right)^{b^\Psi - 1} \right\}.$$

Since there is no closed form solution to the likelihood function, the parameters  $a^\Psi$  and  $b^\Psi$  are estimated using numerical simulations. Table 2 presents the estimated parameters of the piecewise defined Kumaraswamy distribution for participants receiving different information treatments (“All” denotes all participants and all information treatments).

As can be seen from table 2, for each information treatment a significant percentage of individuals are of type  $\bar{\theta}^{GM} = 0$  or  $\bar{\theta}^F = 0$  meaning that these individuals are indifferent between GM Free and the intragenic or transgenic alternatives. This is the first clear indication that by assuming uniformly distributed tastes the impact of GM on utility is overstated. To gain a clearer picture of the estimated taste distributions, figure 5 presents the estimated PDFs over the interval  $0 < \bar{\theta}_i^\Psi < 1$  and figure 6 presents the estimated CDFs over the interval  $0 \leq \bar{\theta}_i^\Psi \leq 1$ .

From figures 5 and 6 it is clear that a uniform distribution does not appropriately characterize individuals' tastes for either genetic modification or foreign genetic content. A uniform distribution

drastically overestimates the fraction of individuals of non-zero type as well as the percentage of individuals of higher order types (i.e. types approaching one). This arises even though the parameter  $\alpha$  used for estimating these distributions is potentially less than the "true"  $\alpha$  that characterizes the population.<sup>11</sup> These results raise the question as to whether previous analyses addressing the impact of labeling (or other quality market applications) are potentially significantly overestimating the impact of consumer types on welfare.

Comparing across information treatments, we can see that both dislike for genetic modification of food and foreign genetic content in food play a role in the weakly inferior nature of intragenic and transgenic food products. Neither attribute can be characterized as being the dominant factor. We see that consumers do view intragenic food products differently and weakly superior to transgenic food products. The effect of the information treatments on the fraction of individuals with  $\bar{\theta}^{GM} = 0$  or  $\bar{\theta}^F = 0$  falls in line with expectations. Seventeen percent more individuals who received the *pro-biotech perspective* are of type  $\bar{\theta}^{GM} = 0$  as compared to those receiving the *no information treatment*. As well, the distribution of those with  $\bar{\theta}^{GM} > 0$  is more heavily massed towards zero. For those receiving the *anti-biotech perspective* the result is reversed, with 14% fewer individuals being of type  $\bar{\theta}^{GM} = 0$  and the distribution being more heavily weighted towards one over the range  $\bar{\theta}^{GM} > 0$ . An interesting, but not unexpected result arises for the distribution of  $\bar{\theta}^F$  by those individuals who received the *pro-biotech perspective*. The fraction of those individuals with  $\bar{\theta}^F = 0$  is actually 14% less than the *no information treatment* and the estimated distribution is fairly diffuse over the unit interval. While seeming surprising, since the *pro-biotech* and the *verifiable information perspectives* were the only information treatments that contained specifics regarding intragenic and transgenic processes, it is apparent that the emphasis on foreign genetic material increased participants' concerns regarding this content.

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<sup>11</sup> Note that from the derivation of the taste parameters that  $\bar{\theta}^{GM}$  and  $\bar{\theta}^F$  are monotonically decreasing in  $\alpha$ .

Finally, when comparing the distributions of the *pro- and anti-biotech perspectives* with and without *verifiable information* we can see that the 3rd party information has an augmenting effect on the fraction of individuals that have  $\bar{\theta}^{GM} = 0$  or  $\bar{\theta}^F = 0$  (17% and 36% respectively). This implies that the *verifiable information* acts to dampen the effect of the *anti-biotech perspective*.

## Welfare estimates

Using the estimated distributions from the empirical model and experimental auction data, it is now possible to evaluate welfare under the four considered government labeling policies. Since the welfare functions are largely intractable and the assumed piecewise Kumaraswamy distribution does not have a closed form single or double integral over the CDF, it is necessary to evaluate welfare using numerical methods. To estimate welfare under each government policy, the consumer surplus functions detailed in the model section are evaluated via numerical integration using an adaptive Simpson quadrature algorithm.

For brevity, results are presented using parameter estimates across all of the information treatments (i.e. the entire auction sample), but the accompanying discussion relates the alternative information treatments with the presented results. Figure 7 compares welfare between policies that do and do not allow for labeling of intragenic products (i.e. *mandatory or voluntary policy 2 vs. mandatory or voluntary 1*). Here, the price of the transgenic GM product is normalized to one and the relative prices of the intragenic GM and GM Free products are considered over the intervals [1,1.2] and [1,1.4] respectively. Figure 8 compares welfare between voluntary and mandatory policies that do not allow labeling of intragenic foods (*voluntary policy 1 vs. mandatory policy 1*). Here, the production cost of the transgenic GM product is normalized to one and the transgenic compliance cost ( $\iota^{GM}$ ) and price of the GM Free are considered over the intervals [0,0.05] and [1,1.4] respectively. Finally, figure 9 compares welfare under *voluntary policy 2* using the empirically estimated taste distributions with those that arise under the assumption of uniformly distributed tastes. All results in the figures are presented as a

percentage difference in aggregate welfare under the considered policies and distributional assumptions and estimated assuming full consumer information ( $\gamma = 1$ ).

As can be seen by figure 7, there are small welfare gains under mandatory and voluntary policies with the introduction of intragenic labeling. These welfare gains are substantial only when the production and compliance costs for the intragenic product are nearly equivalent to the transgenic, but 25% (or more) lower than for the GM Free. Only then is the price differential sufficiently great to induce a large percentage of consumers to switch to the intragenic product and yield large welfare gains. For example, if the price of the intragenic product is 5% greater than for the transgenic product and 25% less than the GM Free there is approximately a 5% increase in welfare. The welfare gains from introducing intragenic labeling is lower than one might potentially expect (or find under the assumption of uniform tastes) because the experimental auction revealed that a significant percentage of individuals are indifferent between the GM Free and GM alternatives. Under information treatments that increase aversion to foreign genetic content in food the difference in welfare between the two policies increases.

Comparing voluntary and mandatory policies that do not allow labeling of intragenic foods (figure 8) we find that, depending upon the cost for transgenic products to comply with a mandatory policy, that there is small difference in welfare. For example, if the compliance cost is \$0.02 for the transgenic product (i.e. 2% of the production cost) a voluntary policy translates into a welfare gain of over 3% when compared to a mandatory policy. The welfare gain under a voluntary policy is monotonically increasing in the price of the GM Free product and the transgenic compliance cost. Under information treatments that reduce aversion to the transgenic product the welfare gains are even larger. For brevity, results comparing mandatory and voluntary policies that do allow labeling of intragenic foods are not shown, but the welfare differences are very similar to those shown in figure 8.

Comparing welfare under the estimated distributions with the typical literature assumption of uniformly distributed tastes, figure 9, it can be seen that uniformity drastically under estimates welfare because it fails to appropriately model the significant fraction of individuals who are indifferent between

the alternatives and the skewed characterizing distribution of consumers. Similar results are found under different labeling policies. Under information treatments where the share of type zero consumers increases or the distribution of tastes is massed towards zero, the mischaracterization of welfare under uniformity is greater.

Finally, while all of the results presented here assume full consumer information regarding the type of genetic modification used in the production of a generically labeled GM food product ( $\gamma = 1$ ), relaxing this assumption (i.e.  $\gamma < 1$ ) has an interesting effect in that it actually increases welfare under policies without labeling of intragenic and transgenic products (*mandatory and voluntary policies 1*). Given the model setup, welfare from consumption of GM products is monotonically increasing in  $\gamma$ . This is an interesting case where ignorance or misinformation increases welfare.

## **Concluding remarks**

As new intragenic biotechnology engineering techniques improve and these products begin to enter worldwide food markets, the GM labeling and compliance policies of governments internationally will be forced to adapt. In this paper a model of consumer demand for GM Free, Intragenic GM, and Transgenic GM food products is developed where consumers are characterized based upon two distinct taste parameters. Using experimental auction bid-price data the distribution of consumer tastes is estimated in order facilitate an analysis of consumer welfare under alternative labeling regimes. Additionally, by injecting biased and verifiable information into the experimental auctions allows evaluation of the shifts in the distributions of tastes resulting from these new perspectives. The estimated distributions of consumer tastes unequivocally reveal that a uniform distribution fails to properly characterize consumers. The welfare estimates clearly show that policies that differentiate between intragenic and transgenic food products yield greater aggregate welfare for consumers. Furthermore, it is shown that a voluntary policy is superior from a welfare perspective to a comparable mandatory policy.

Finally, the results of this paper show that while assuming uniformly distributed consumer tastes may not qualitatively change models of demand for quality, this assumption is clearly inappropriate for empirical endeavors. At a minimum, if tractability is of concern, the presented results suggest that it would be prudent to model consumers utilizing a piecewise uniform distribution, as opposed to a standard uniform distribution, allowing for a significant mass of individuals to be indifferent between products of different qualities.

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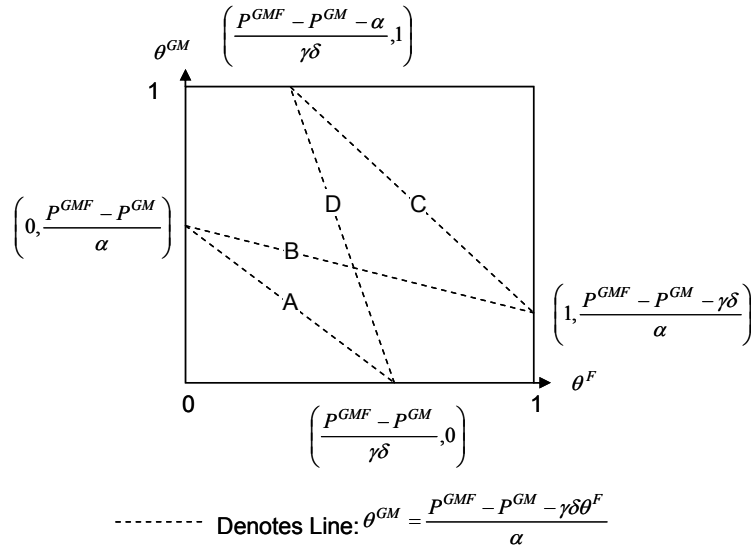
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**Table 1. Product Prices Under Different Government Policies**

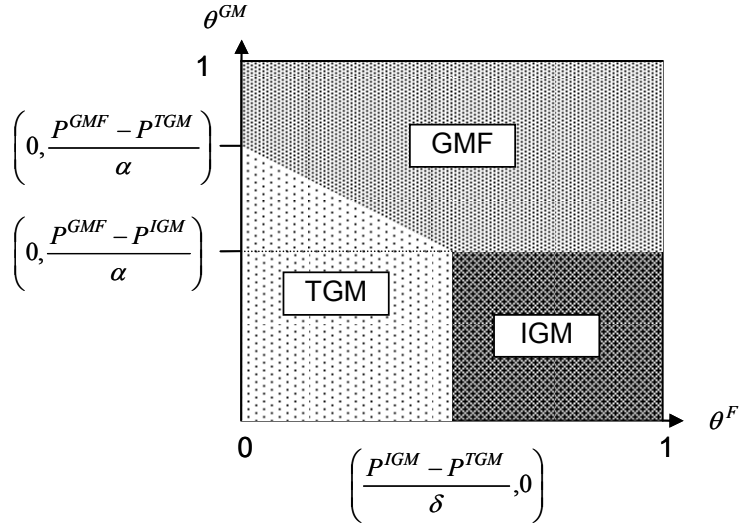
	$P^{GMF}$	$P^{IGM}$	$P^{TGM}$	$P^{GM}$
Mandatory Policy 1	$C^{GMF} + t^{GMF}$	-	-	$C^{TGM} + t^{TGM}$
Mandatory Policy 2	$C^{GMF} + t^{GMF}$	$C^{IGM} + t^{IGM}$	$C^{TGM} + t^{TGM}$	-
Voluntary Policy 1	$C^{GMF} + t^{GMF}$	-	-	$C^{TGM}$
Voluntary Policy 2	$C^{GMF} + t^{GMF}$	$C^{IGM} + t^{IGM}$	$C^{TGM}$	-

**Table 2. Piecewise Kumaraswamy Distribution Parameter Estimates**

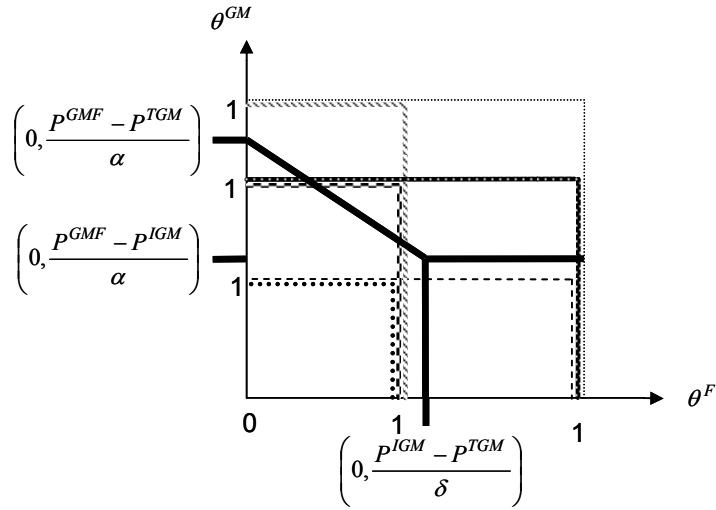
	$\theta_{GM}$	$a^{GM}$	$b^{GM}$	$\theta_F$	$a^F$	$b^F$
ALL	0.51	0.75	1.13	0.51	0.80	2.82
No Info	0.53	1.01	1.40	0.59	0.90	5.40
Pro-Biotech	0.70	1.50	15.20	0.45	1.12	2.27
Anti-Biotech	0.29	0.98	0.82	0.65	0.66	2.07
Pro & Anti	0.42	0.58	0.88	0.29	0.81	1.31
Pro, Anti, & Ver.	0.59	1.08	2.48	0.65	1.30	6.90



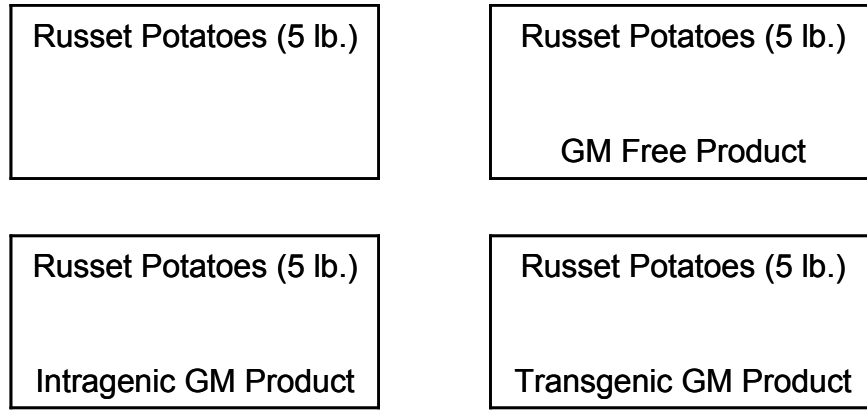
**Figure 1. Bounds of integration for consumer surplus under mandatory and voluntary policies 1**



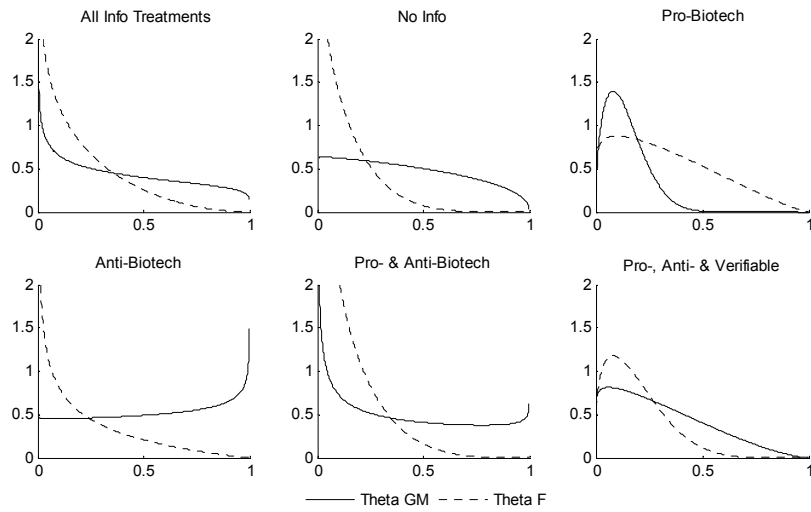
**Figure 2. Bounds of integration for consumer surplus under mandatory and voluntary policies 2**  
**assuming  $(P^{GMF} - P^{TGM})/\alpha < 1$  and  $(P^{IGM} - P^{TGM})/\delta < 1$**



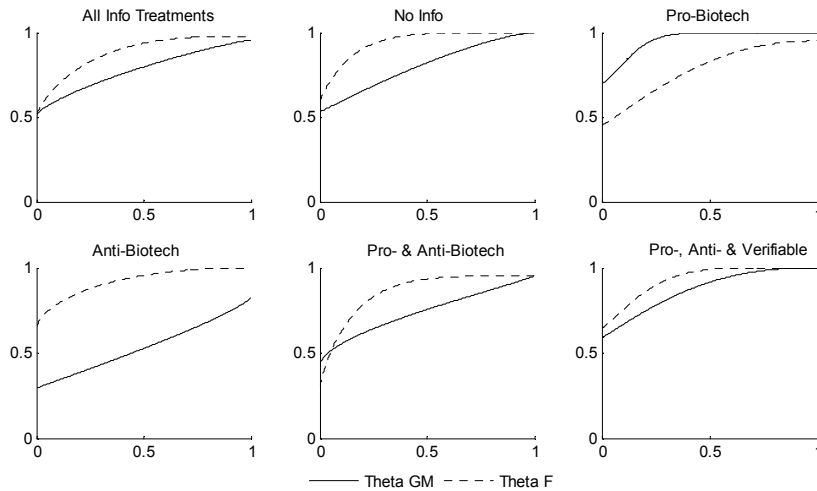
**Figure 3. Bounds of integration for consumer surplus under mandatory and voluntary policies 2**



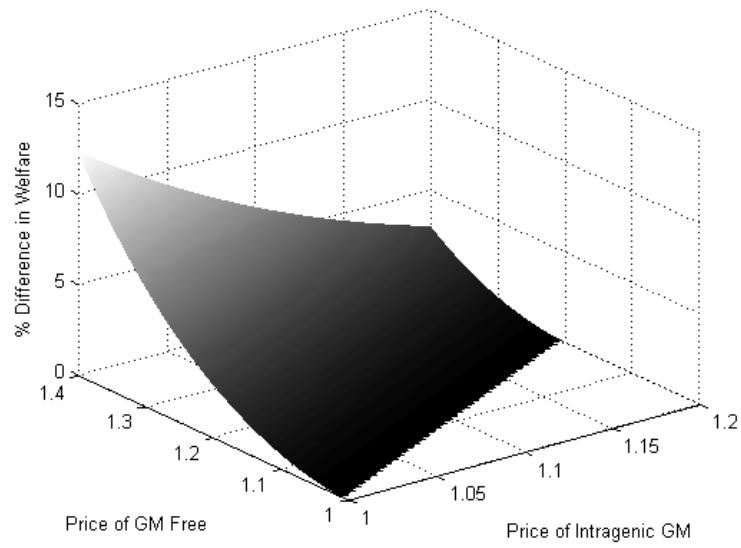
**Figure 4: Examples of Auction Food Labels**



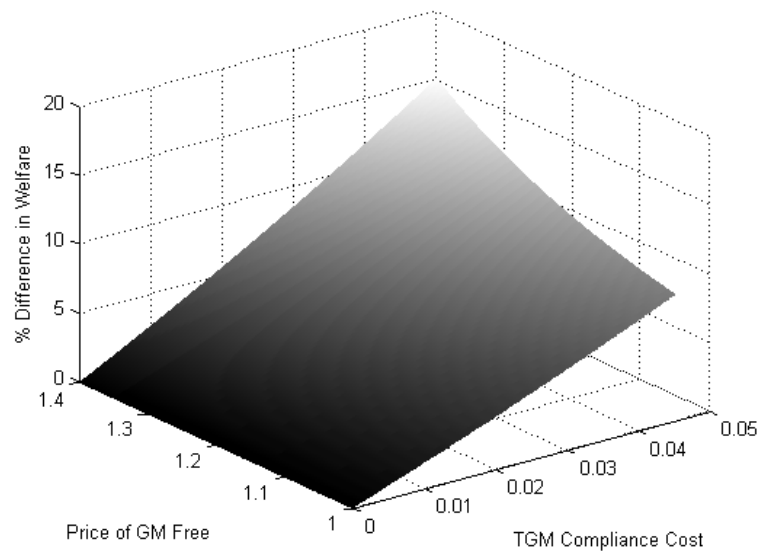
**Figure 5: Estimated Kumaraswamy PDF for  $0 < \bar{\theta}_i^\Psi < 1$**



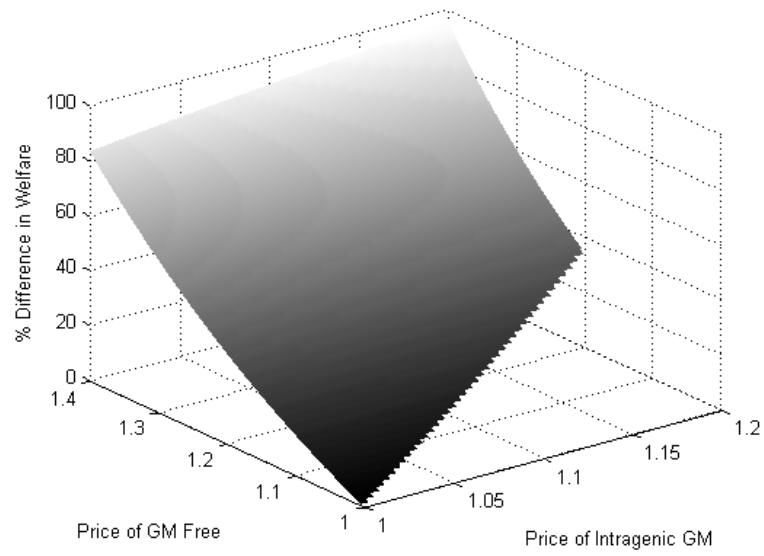
**Figure 6: Estimated Kumaraswamy CDF for  $0 \leq \bar{\theta}_i^\Psi \leq 1$**



**Figure 7. With vs. without labeling of intragenic products**



**Figure 8. Voluntary policy 1 vs. mandatory policy 1**



**Figure 9. Voluntary Policy 2: Estimated distribution vs. uniform distribution**