Technology Adoption and Product Differentiation: Market-Level Effects

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Abstract

The focus of the microeconomic technology adoption literature has been on the adoption and diffusion of new innovations: who adopts, and when they adopt. Implicit in the literature is that consumers will embrace the product that results from the use of the new technology. If producers have reason to believe that adopting a new technology may lead consumers to perceive differentiated products, then the decision of whether or not to adopt needs to consider not only the effectiveness of the new technology but also the consumer response to it. That is, producers have to incorporate the impact of consumer-driven market-level effects into their technology choice decisions. In these situations, producers considering the adoption of a new agricultural biotechnology have a more complex learning problem than the technology adoption literature generally addresses, because producers need to consider the interaction of demand and supply effects from the adoption of any new technology. We motivate our analysis with the case of recombinant bovine somatotropin (rbST). In order to address some of these issues, we construct an analytical model of technology adoption that considers a market with differentiated goods. We develop a multi-period economic model of a representative farmer's technology choice decision and integrate it into a market-level analysis that links the industry's use of the technology to the structure of consumer demand.

Introduction

A key feature of endogenous economic growth theory is that innovation and the adoption of productivity-enhancing technologies is important to long run growth. At the macroeconomic level, countries that invest in research and development reap the rewards of their investment through higher growth rates. At the microeconomic level, firms and producers that adopt new technologies may earn greater profits and invest these profits in research and development. The focus of the microeconomic technology adoption literature has been on the adoption and diffusion of new innovations: who adopts, and when they adopt. The assumption that is implicit in the literature is that consumers will embrace the product that results from the use of the new technology. In the case of process innovations, this has generally been the case. Process innovations do not alter the final outputs, only the manner in which they are produced, and so do not affect consumers' utility from the good, except through any price reductions. While the majority of these innovations have been readily accepted by consumers, the advances made in agricultural biotechnology have shown that exceptions do occur. We motivate our analysis with the case of recombinant bovine somatotropin (rbST), but are interested more generally in the adoption of agricultural biotechnology and the effects of consumer preferences on adoption. In order to address some of these issues, we construct an analytical model of technology adoption that considers a market with differentiated goods.

In the last two decades, goods produced using agricultural biotechnology have accounted for an increasing share of agricultural output in the U.S. and worldwide. The first generation of genetically modified (GM) products is characterized by having traits that offer no direct benefit to consumers (e.g., herbicide-resistant crops), but offer enhanced productivity or reduce costs for producers. The Roundup Ready crops that are herbicide-resistant and the Bt crops that are insecticide-resistant are two of the most well known and successful GM products. While government agencies, such as the Food and Drug Administration (FDA), and the producers who use these technologies insist that there is no difference between goods produced with or without these technologies, the evidence suggests that many consumers do not view these products as being identical to their non-GM counterparts (Huffman et al., 2003; Noussair, Robin and Ruffieux, 2004). One of the clearest examples of this has been the case of rbST, a GM growth hormone that stimulates milk production in cows and improves the efficiency with which cows can convert feed into milk.

Dairy producers have not adopted rbST to the extent predicted by many earlier studies (Centner and Lathrop, 1996; Caswell, Fuglie and Klotz, 1994; Raboy and Simpson, 1993; Lesser, Bernard and Billah, 1999) and the consumer backlash against milk from cows treated with rbST appears to be greater than it has been for some other GM products. If producers have reason to believe that adopting a new technology may lead consumers to perceive differentiated products, then the decision of whether or not to adopt needs to consider not only the effectiveness of the new technology but also the consumer response to it. That is, producers have to incorporate the impact of consumer-driven market-level effects into their technology choice decisions. In these situations, producers considering the adoption of a new agricultural biotechnology have a more complex learning problem than the technology adoption literature generally addresses. Producers must learn about the relative profitability of the new technology for themselves by taking into consideration the effects of technology on output and production costs, and must learn about the consumer response to the resulting product. In sum, producers need to consider the interaction of demand and supply effects from the adoption of any new technology.

RbST is such a case. It is an output-enhancing technology for producers, but, according to some consumers, it is also a product-altering technology. However, neither of these claims is unanimous; the heterogeneity of viewpoints on these matters is what makes rbST such an interesting case to study. On the supply side, some producers have had difficulty obtaining the same results as those reported in the animal science literature (see, for example, Bauman et al., 1999), leading them to question the true profitability of the technology. Some producers adopted rbST, only to disadopt it later and return to their pre-existing technology; i.e., once they realized rbST was not profitable for them. On the demand side, from the outset consumers have been inundated with information from both sides. Proponents of rbST tell them that "milk is milk" (http://www.dairyreporter.com/Industry-markets/Milk-is-milk-campaign-reaches-thousands) whether it comes from cows treated or not treated with rbST. Opponents of rbST cite the paucity of research on the potential detrimental health effects of consuming milk from cows treated with rbST as well as the negative effects on the cows themselves. These competing messages have generated a great deal of uncertainty about the safety and quality of milk from cows treated with rbST, and whether or not the two milks are different. It is common nowadays to see cartons of milk with the label "*milk produced by cows not treated with rbST*". This suggests that there are consumers who consider milk from cows treated with rbST to be different from milk that is produced by cows not treated with rbST. Some consumers have responded to the proliferation of labels differentiating rbST-free milk from conventional milk by choosing the former. This has prompted many large national retailers, such as Safeway, Wal-Mart and Kroger, to stock only rbST-free milk on their shelves.

As consumers become more concerned about how their food is produced and its implications for human health, animal health, and the environment, the adoption decision will need to consider the preferences and perceptions of consumers. It will not simply be a matter of whether adopting the technology will reduce costs; potential adopters will need to think whether the new innovation will render their products inferior or deficient or, alternatively, superior in any way from consumers' perspectives. Other researchers have considered the effects of consumer preferences on the adoption of GM technology (see Fernandez-Cornejo and Caswell (2006) for a summary), but they have not described in detail how that affects the producer's adoption decision.

This paper integrates elements from Stoneman (1981) and Lapan and Moschini (2004) in order to consider the market level effects on technology adoption. From the former, we use the framework of Bayesian updating to model how a producer learns about the profitability of a new technology for him. From the latter, we consider the effects of labeling and consumer preferences on the demand for GM products within a vertical differentiation framework. We develop a multi-period economic model of a representative farmer's technology choice decision and integrate it into a market-level analysis that links the industry's use of the technology to the structure of consumer demand. Our model allows us to answer the following questions: (1) how do adoption and disadoption decisions change when a process innovation is perceived as a product (dis)innovation?; (2) what are the different diffusion paths that a GM technology may take under different learning scenarios on the part of producers and consumers?; and (3) what are the welfare implications if consumers perceive GM foods to be differentiated products?

Background

In recent years, there has been an increasing emphasis on *how* food is produced and whether or not these methods are environmentally sustainable, ethical and – most importantly – safe.

Consumers have shown that they are willing to pay more for foods that are certified organic, and meat and eggs produced by animals in more "natural" environments attract premia vis-à-vis their "unnatural" counterparts. Many of the agricultural methods now being criticized were hailed as technological breakthroughs and the keys to cheaper food when they were first introduced. At the time, researchers and producers assumed that how the food was produced did not matter to consumers, and the only characteristics that mattered were those that were most tangible (e.g., taste, appearance and price). It appears that this is no longer the case. This has important implications for producers who are considering the adoption of a new technology. When producers adopt an agricultural biotechnology, not only are they adopting a new set of production practices but they may be – wittingly or unwittingly – producing a differentiated product in the eyes of the consumer. The technology adoption literature has generally focused on the benefits of the new technology to the potential adopter and has rarely considered it from the point of view of the consumer. Moreover, the literature has typically assumed that once a technology has been adopted, users do not abandon it and revert to their earlier technology. Once adoption occurs, it is assumed that the adopter will continue to use the technology until a newer, better technology replaces it. Both of these assumptions have been violated for a substantial share of producers in the case of rbST.

The literature on GM foods has focused either on how consumers perceive GM foods or on the adoption of GM technology by producers. Numerous analyses have shown that some consumers – notably EU consumers – do perceive GM products to be different from their non-GM counterparts. When this is the case, then process innovations that were initially intended to reduce production costs result in a differentiated inferior product.[1] However, sometimes the

[1] We acknowledge that some process innovations may lead consumers to perceive a superior product, but this has generally not been the case with the first generation of GM products.

differentiation perceived by consumers occurs at a level that is difficult to detect. GM products have credence attributes that cannot be observed through visual examination or experienced through consumption[2] (Darby and Karni, 1973). Because most current GM foods are virtually indistinguishable from their traditional counterparts, consumers have no ability to differentiate the two in the absence of labels. In these cases, consumers demand that the products be segregated and that appropriate labels be used to distinguish the GM foods from the non-GM foods.

In general, process innovations in agricultural biotechnology have not conferred any direct consumption benefits to the consumer, although they may have lowered prices. Nevertheless, producers have readily adopted GM crop varieties and in 2007, GM crops accounted for 282.4 million acres worldwide (www.ISAAA.org). In many cases, the adoption pattern for these innovations has followed the classic logistic, or S-shaped, pattern. For instance, U.S. producers who have adopted Bt crops and/or herbicide-resistant crops have continued using them and the abandonment rate has been low (Fernandez-Cornejo, Alexander and Goodhue, 2002). However, this has not been the case for all GM products. Producers have shown that they will adopt and then subsequently disadopt an innovation, as has been the case with rbST.

Giannakas and Fulton (2002) and Lapan and Moschini (2004) both model the implications of introducing GM products into a market where (some) consumers have heterogeneous tastes and perceive the GM product to be a weakly inferior substitute. Giannakas and Fulton focus on the welfare effects and show that, in the presence of market imperfections[3], the introduction of GM foods leads to a loss of consumer welfare as the cost-saving aspects of

[2] We ignore the possibility that GM goods may have negative observable health effects in the short run as this would make them experience goods, which would allow consumers to learn about their quality directly and differentiate them from their non-GM counterparts.
[3] For example, an innovator/monopolist who holds the intellectual property rights and extracts all the rent from the innovation via a technology fee.

the technology are not passed along to the consumer. They consider the welfare implications under scenarios of no labeling, mandatory labeling under full compliance and intentional mislabeling. Lapan and Moschini (2004) model the trade implications from the introduction of GM products in which consumers from one country perceive the GM product to be a weakly inferior substitute for the traditional product. Simply introducing the GM product is costly because producers need to label and segregate the GM and non-GM products, as demanded by consumers. While Lapan and Moschini consider the adoption decision, they set up their model in such a way that the monopolist who sells the GM technology effectively decides the level of adoption. Within their framework, they demonstrate that introducing GM products lowers overall efficiency and welfare under certain conditions.

Model

Our analysis contributes to the literature by integrating product market considerations into the technology choice decision. We consider the adoption of a process innovation; in this case, an agricultural biotechnology that reduces per-unit costs for the producer. The new technology has no observable impact on the final output but consumers consider it to be weakly inferior to the good produced using the existing technology. This preference ordering may be due to risk aversion (e.g., unknown long-term adverse health effects from consumption) or socio-political considerations (e.g., it is morally wrong to use genetic engineering). While consumers are heterogeneous in their taste parameters, at the same price all consumers prefer the good produced using the existing technology to the good produced using the new technology. That is, goods are vertically differentiated. While this is clearly a simplification[4], it is consistent with the stylized

[4] For instance, some consumers may actually prefer a GM good if it was produced using fewer pesticides.

facts regarding consumers' opinions and willingness-to-pay for GM products (Dhar and Foltz, 2005).

We model the impact of market effects on the technology choice decision by constructing an analytical model of technology choice that considers a market for goods differentiated by whether or not they are produced using the new technology. We develop a multi-period economic model of a representative producer's technology choice decision and integrate it into a market-level analysis that links the industry's use of the technology to the structure of consumer demand in order to determine the prices for both products. Consistent with the adoption literature, we model technology adoption and disadoption using a mean-variance approach to account for uncertainty and risk aversion (following Stoneman, 1981; and Tsur, Sternberg and Hochman, 1990), and specify that producers learn about the new technology in a Bayesian manner (see *inter alia*, Fischer, Arnold and Gibbs, 1996; Jovanovich and Nyarko, 1996). Throughout, we assume that the producer is uncertain about the profitability of the new technology for him but knows how to use it, and is risk averse. Our assumption that the producer knows how to use the technology but is unsure of its profitability for him reflects the experience of U.S. farmers and GM technology. The choice variable is the extent to which the producer adopts the new technology.

At the beginning of each period *t*, a representative producer decides how intensively he will adopt the new technology. We assume the producer has an exponential utility function:

(1) $$U(\Pi) = 1 - e^{-\phi\Pi},$$

where Π is profit per animal (or unit of land) and ϕ is the coefficient of absolute risk aversion. It can be shown that, given an exponential utility function, the optimization problem that the producer solves is:

(2) $$\max_{n} U = E(\Pi) - \frac{1}{2}\phi Var(\Pi).$$

The above is commonly referred to as a mean-variance utility function.

The producer's utility is essentially a function of his technology portfolio, or the extent to which he adopts the new technology. The initial adoption decision at $t = 0$ depends on the producer's prior belief about the profitability of the new technology. The old technology has returns whose distribution is time-invariant and normally distributed $N(\pi_F, \sigma_F^2)$, which the producer knows with certainty. The new (GM) technology also has returns that are distributed $N(\bar{\pi}_G, \bar{\sigma}_G^2)$ and are time-invariant; however, in this case the producer does not know the true mean $\bar{\pi}_G$ with certainty but he does know $\bar{\sigma}_G^2$, with $\bar{\sigma}_G^2 \geq \sigma_F^2$. Instead, the producer has a prior belief regarding the true return at time *t* that is distributed $N(\pi_{Gt}, \sigma_{Gt}^2)$. At time *t*, the producer realizes a return from the new technology y_t and updates his prior in a Bayesian manner. Using Bayes' theorem, the posterior density of the mean is $N(\pi_{Gt+1}, \sigma_{Gt+1}^2)$ where

(3) $$\pi_{Gt+1} = \frac{y_t \sigma_{Gt}^2 + \bar{\sigma}_G^2 \pi_{Gt}}{\sigma_{Gt}^2 + \bar{\sigma}_G^2}$$

and

(4) $$\sigma_{Gt+1}^2 = \frac{\bar{\sigma}_G^2 \sigma_{Gt}^2}{\sigma_{Gt}^2 + \bar{\sigma}_G^2}.$$

Returning to equation (2) for a moment and considering a producer who uses both technologies, the total profit at time *t*, Π_t, is the sum of the anticipated returns and is distributed $N(\pi_t, \sigma_t^2)$, where

(5) $$\pi_t \equiv \Pi_t = n_t \pi_{Gt} + (N - n_t)\pi_F$$

and

(6) $$\sigma_t^2 = n_t^2 \sigma_{Gt}^2 + (N - n_t)^2 \sigma_F^2 + 2n_t(N - n_t)\rho\sigma_{Gt}\sigma_F,$$

where n_t and N are the numbers of animals treated with the new technology and the total herd size, respectively[5]; and ρ is the correlation between the two returns and $\rho\sigma_{Gt}\sigma_F$ is the covariance.

We decompose profit from using the old technology into

(7) $$\pi_F(p_F) = p_F q_F - c_F(q_F),$$

where we assume a constant marginal cost $c_F^{'}(q_F) > 0$, and p_F is fixed (i.e., the producer is a price taker). We assume that the output per animal q_F on the old technology is $q_F = \bar{q}_F + \epsilon_F$, where $\bar{q}_F$ is the mean output and ϵ_F is an error term reflects uncertainties in production; ϵ_F is independent and identically distributed across producers and has a zero mean and constant variance $\sigma_{\epsilon_F}^2$. The producer knows $\bar{q}_F$.[6] For the new technology, the profit function is expressed as

(8) $$\pi_{Gt}(p_{Gt}) = p_{Gt} q_{Gt} - c_G(q_G),$$

where we assume constant marginal costs $c_G^{'}(q_G) > 0$ and p_{Gt} is the price of the good produced using the GM technology. Output per animal q_{Gt} from the new technology is $q_{Gt} = \bar{q}_{Gt} + \epsilon_{Gt}$, where ϵ_{Gt} is an error term reflects uncertainties in production; ϵ_G is independent and identically distributed across producers and has a zero mean and constant variance $\sigma_{\epsilon_{Gt}}^2$. The distinguishing feature of the new technology is that its performance is unknown so the producer does not know $\bar{q}_{Gt}$ with certainty. He does, however, know $\sigma_{\epsilon_{Gt}}^2$. We assume that, at $t = 1$, the producer's prior belief is that the GM technology is more profitable than his existing technology, otherwise he would never adopt the GM technology since we exclude 'learning from others' in our model. We also impose the restriction that the producer does use the new technology on his entire herd at $t = 1$. Now that we have established our general framework, we will consider the decision model

[5] In the case of crops, n_t and N would represent the number of acres under the GM technology and the total number of acres, respectively.
[6] While the assumption of a constant (with error) output from using the old technology is somewhat restrictive, it greatly simplifies the analysis without affecting the main results of the study.

in greater detail under different scenarios regarding consumers' beliefs about the quality difference between goods produced using the two technologies.

Case 1 – Undifferentiated Products

As our benchmark case, we consider what happens when the product produced using the existing technology, henceforth referred to as the non-GM good, and the product produced using the new technology, henceforth referred to as the GM good, are undifferentiated and consumers pay one price for the undifferentiated good. In Bayesian updating, the first few draws have a larger effect on the producer's beliefs regarding the profitability of the GM technology than later draws. As the producer gains experience (i.e., after a large number of draws), his prior becomes tighter (i.e., the distribution has a smaller variance) and the new information acquired each period has less of an impact on shaping his beliefs. Whether or not the producer ultimately disadopts rbST is determined to a large extent by what happens in the initial few draws after adoption. This leads to the hypothesis that if producers do disadopt rbST, it is most likely to occur sooner rather than later.

Substituting in equations (6), (7) and (8), we can rewrite equation (2) as the following:

(9)
$$U_t = n_t\big(p_{Gt}q_{Gt} - c_G(q_G)\big) + (N - n_t)\big(p_F q_F - c_F(q_F)\big) \\ -\frac{1}{2}\phi\left(N^2\sigma_F^2 + 2Nn_t(\rho\sigma_{Gt}\sigma_F - \sigma_F^2) + n_t^2(\sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F)\right).$$

Because the GM good and the non-GM good are undifferentiated, they receive a single price $p = p_F = p_{Gt}$. Taking the first order necessary condition of (9) yields:

(10)
$$U_t'(n_t) = \big(pq_{Gt} - c_G(q_G)\big) - \big(pq_F - c_F(q_F)\big) - \phi\Big(N(\rho\sigma_{Gt}\sigma_F - \sigma_F^2) + n_t(\sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F)\Big).$$

Solving for n_t^*, we obtain:

(11) $$n_t^* = \frac{\left(pq_{Gt} - c_G(q_G)\right) - \left(pq_F - c_F(q_F)\right) + N\phi(\sigma_F^2 - \rho\sigma_{Gt}\sigma_F)}{\phi(\sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F)},$$

where n_t^* describes the optimal intensity of GM adoption. In the case of rbST, n_t^* would represent the number of cows to inject with rbST whereas in the case of crops, n_t^* would describe the number of acres planted with the GM variety. After the decision is made, the producer observes the actual return to using the new technology in period t and revises his prior beliefs about its profitability in a Bayesian manner. Specifically, the producer revises his prior regarding the anticipated output from using the GM technology.

Before continuing with market-level considerations, it will be useful to examine two comparative statics under this baseline case: (1) the change in n_t^* with respect to a change in the herd size and; (2) with respect to a change in the anticipated profit differential between the new and existing technology. Assuming a (weakly) convex cost function (i.e., non-decreasing marginal costs), in order for n_t^* to be a maximum the denominator $\phi(\sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F)$ must be greater than 0. This is easy to show since $\rho \leq 1$. Therefore,

(12) $$\frac{\partial n_t^*}{\partial N} = \frac{\sigma_F^2 - \rho\sigma_{Gt}\sigma_F}{\sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F} > 0 \; if \, \frac{\sigma_F}{\sigma_{Gt}} > \rho \, .$$

If the above condition holds, as the size of the herd (or number of acres) increases, the producer will choose to adopt the GM technology to a larger extent if the ratio of the variance of the returns to using the non-GM technology is greater than the covariance of the returns from the two technologies. Solving for the effect of changes in the profit differential, we obtain

(13) $$\frac{\partial n^*}{\partial \Delta\pi} = \frac{1}{\phi(\sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F)} > 0,$$

where $\Delta\pi = \big(pq_{Gt} - c_G(q_G)\big) - \big(pq_F - c_F(q_F)\big)$. Not surprisingly, as the profit differential between using the GM technology and the old technology increases, the producer chooses to use the new technology to a greater extent.

The supply of the GM product is:

(14) $$s_{Gt}(n_t^*) = n_t^* q_{Gt}.$$

The supply of the non-GM product is:

(15) $$s_F(n_t^*) = (N - n_t^*)q_F,$$

and the total supply of the product is:

(16) $$s(n_t^*) = n_t^* q_{Gt} + (N - n_t^*)q_F.$$

If we have M^P identical producers, the aggregate supply is

(17) $$\mathcal{S}(n_t^*) = M^P(n_t^* q_{Gt} + (N - n_t^*)q_F).$$

On the demand side, we assume a market with M^C total consumers who may choose to consume one unit of the undifferentiated good or none at all. Each consumer is endowed with income E and derives some (indirect) utility θ from the consumption of the good, where θ is distributed uniformly [0,1]. Consumers consume a unit of the good if $E - p + \theta > E$, otherwise they consume nothing and get utility E. Therefore, demand is:

(17) $$\mathcal{D}(p) = (1 - p)M^C.$$

Equilibrium conditions are met when demand equals supply, or

(18) $$\mathcal{S}(n_t^*) = \mathcal{D}(p), \text{ or}$$

$$M^P(n_t^* q_{Gt} + (N - n_t^*)q_F) = (1 - p)M^C.$$

The goods are undifferentiated so there is a single price, and the decision to continue using the new technology depends on the producer's prior knowledge and the initial returns from the GM technology. It does not depend on the demand for the goods, except through the price associated with total supply, $p(M^P(n_t^* q_{Gt} + (N - n_t^*)q_F))$. Solving (18), we obtain an analytical solution for the equilibrium price:

(19)
$$p^* = \frac{\phi B(M^C - M^P N q_F) - M^P(q_G - q_F)(c_F - c_G + N\phi A)}{M^P(q_G - q_F)^2 + M^C \phi B},$$

where $A = \sigma_F^2 - \rho\sigma_{Gt}\sigma_F$, $B = \sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F$, and the arguments of the cost functions c_F and c_G have been omitted for simplicity.

Case 2 – Differentiated Products of Known Quality

Now consider the case where consumers perceive a quality difference between the two goods. The key issue here is how consumers perceive the new good or how different they think it is from the traditional good. We assume that, because the technology only reduces per-unit costs and confers no known benefits and possible long term adverse health effects, consumers regard the new good as having lower quality than the traditional good, or $0 < k_G < k_F < 1$, where k_i is a parameter for quality and the subscripts are the same as above. In this case, we assume that $k_{Gt} = k_G \forall t$. We also assume that the price of the non-GM good $\bar{p}_F$ is constant across time.

Following Mussa and Rosen (1978), assume the market includes two differentiated, but substitutable, goods. The goods are vertically differentiated in the sense that one good is of a higher quality than the other. Given a choice between the two goods at the same price, all consumers would prefer the higher quality good to the lower quality good. Once again, our market consists of M consumers with equal income, E, and heterogeneous tastes represented by the parameter θ. Each consumer can choose to buy nothing, one unit of the GM good, or one unit of the non-GM good. The utility from consuming one unit of good i is $U = E - p_i + \theta k_i$ where

$i \in (G, F)$. To find the consumer who is indifferent between consuming nothing and consuming one unit of the low quality good, we solve the following equation:

(20) $$E = E - p_{Gt} + \theta_{0t} k_G.$$

This yields $\theta_{0t} = \frac{p_{Gt}}{k_G}$. Consumers with taste parameter $\theta < \theta_{0t}$ do not purchase the good. To find the customer indifferent between the high quality good and the low quality good, we solve the following equation:

(21) $$E - p_{Gt} + \theta_{1t} k_G = E - \bar{p}_F + \theta_{1t} k_F.$$

Solving this yields $\theta_{1t} = \frac{\bar{p}_F - p_{Gt}}{k_F - k_G}$.

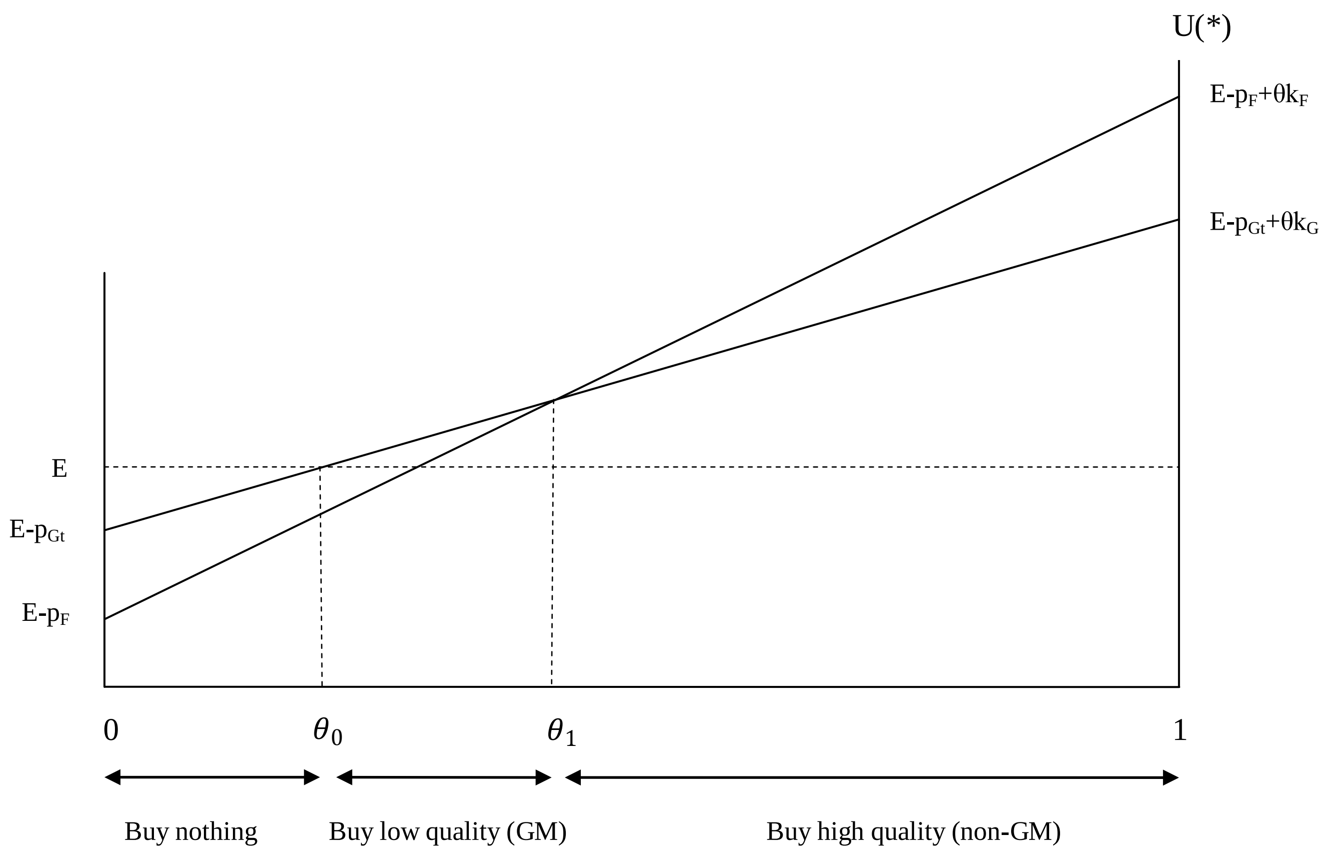

Figure 1. Consumption decision with differentiated products and heterogeneous consumers

The direct demand functions are:

(22a)
$$\mathcal{D}_{Ft}(\bar{p}_F, p_{Gt}) = Q_{Ft} = \left(1 - \frac{\bar{p}_F - p_{Gt}}{k_F - k_G}\right) M^C$$

and

(22b)
$$\mathcal{D}_{Gt}(\bar{p}_F, p_{Gt}) = Q_{Gt} = \left(\frac{\bar{p}_F - p_{Gt}}{k_F - k_G} - \frac{p_G}{k_G}\right) M^C.$$

The producer solves equation (2) as in the first case to obtain n_t^*:

(23)
$$n_t^* = \frac{\left(p_{Gt}\left(Q_{Ft}, Q_{Gt}\right) q_{Gt} - c_G(q_G)\right) - \left(\bar{p}_F q_F - c_F(q_F)\right) + N\phi(\sigma_F^2 - \rho\sigma_{Gt}\sigma_F)}{\phi(\sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F)}.$$

The difference now is that we have differentiated products and, accordingly, different prices. The aggregate supply of the non-GM product is:

(24)
$$\mathcal{S}_F(n_t^*) = M^P(N - n_t^*) q_F.$$

The aggregate supply of the GM product is:

(25)
$$\mathcal{S}_{Gt}(n_t^*) = M^P(n_t^* q_{Gt}).$$

At equilibrium, the following market clearing conditions are satisfied:

(26a)
$$\mathcal{S}_F(n_t^*) = \mathcal{D}_F(\bar{p}_F, p_{Gt}), \text{ or}$$

$$M^P(N - n_t^*) q_F = \left(1 - \frac{\bar{p}_F - p_{Gt}}{k_F - k_G}\right) M^C$$

and

(26b)
$$\mathcal{S}_{Gt}(n_t^*) = \mathcal{D}_{Gt}(\bar{p}_F, p_{Gt}), \text{ or}$$

$$M^P(n_t^* q_{Gt}) = \left(\frac{\bar{p}_F - p_{Gt}}{k_F - k_G} - \frac{p_G}{k_G}\right) M^C.$$

Solving (26b), we obtain an analytical solution for the equilibrium price of the GM good:

(27)
$$p_{Gt}^* = \frac{\phi B M^C \bar{p}_F - \Delta K M^P q_G (N\phi A - \Delta c - \bar{p}_F q_F)}{\Delta K M^P q_G^2 + \frac{K_F}{K_G} \phi B M^C},$$

where $A = \sigma_F^2 - \rho\sigma_{Gt}\sigma_F,\ B = \sigma_{Gt}^2 + \sigma_F^2 - 2\rho\sigma_{Gt}\sigma_F, \Delta K = K_F - K_G > 0, \Delta c = c_G - c_F > 0$ and once again the arguments of the cost functions c_F and c_G have been omitted for simplicity.

If consumers are able to differentiate the GM good from the non-GM good and if they perceive the GM good to be inferior in quality, then $\bar{p}_F \geq p_{Gt}$. If $\bar{p}_F = p_{Gt}$, then consumers will either choose the non-GM good or nothing at all. Consequently, *ceteris paribus*, n_t^* will be lower in the case of differentiated products because

$$\left(p_{Gt}(Q_F, Q_{Gt})q_{Gt} - c_G(q_G) - \bar{p}_F q_F - c_F(q_F)\right) < \left(pq_{Gt} - c_G(q_G) - pq_F - c_F(q_F)\right).$$

The lower price that the producer receives for the GM good offsets to some extent any cost-reduction benefits of the new technology, reducing the producer's net gain relative to case 1. In this scenario, consumers know the quality level of both GM and non-GM goods. This may be a strong assumption but in the case of rbST, there is a significant amount of information in the public realm. While most producers may disagree with how the typical consumer values the milk, it is not unreasonable to assume that they know what it is.

Conclusion

This paper's main contribution is the incorporation of consumer-driven market-level effects into the technology choice decision. There has been much effort put into the discovery and introduction of agricultural biotechnologies in the adoption literature, and separate efforts in the food labeling literature to measure its acceptance by consumers. However, very little has been done that integrates the two by examining the interactions between micro-level decisions and market-level outcomes when product differentiation is a factor. If product differentiation leads to price differences, then this will affect the technology choice decision. From a policy standpoint, our results suggest that output-enhancing and/or cost-reducing technologies may not be readily adopted if these new technologies result in differentiated products. Therefore, it would behoove the manufacturers of these technologies as well as the producers who adopt them to spend resources to educate the public about the true nature of their products and the impact, if any, of the new technology. More broadly, our results suggest that product differentiation may affect the extent and speed of diffusion.

Future work will include considering the case where the consumer's beliefs regarding the quality of the GM good vis-à-vis the non-GM good evolve over time. This would occur if perceptions about quality are influenced by new information and/or interaction with other consumers who share different beliefs. Another natural extension is to set up a numerical mathematical programming model using the results from the analytical model and calibrated to conform to known estimates of supply and demand elasticities to simulate the adoption, diffusion and disadoption of the GM technology under different conditions.

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