THE MARKET ACCEPTANCE AND WELFARE IMPACTS OF GENETIC USE RESTRICTION TECHNOLOGIES (GURTS)

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Abstract

We develop an analytical framework of heterogeneous consumers and producers to examine the market and welfare effects of Technology Use Agreements (TUAs) and variety-level Genetic Use Restriction Technologies (V-GURTs). Specifically, we examine an innovator's decision to introduce V-GURTs into a new seed variety that offers enhanced agronomic characteristics to producers and desirable functional properties to consumers, taking into account heterogeneous consumer preferences regarding interventions in the production process and farmer characteristics and incentives to engage in unauthorized use of proprietary seed.

JEL classification: Q13, Q18.

Keywords: Genetic use restriction technologies; Genetic modification; Producer and consumer welfare.

1. Introduction

An intellectual property rights (IPRs) system is effective when infringers can be identified, successfully sued for damages and deterred from further infringement. The effectiveness of IPRs in plant varieties is generally limited. The geographical distribution of farmers and the fact that seed reproduces naturally makes monitoring the unauthorized use of seed that embodies intellectual property very costly and a serious problem for seed providers. As a consequence, seed companies perform limited research and development (R&D) in self-pollinating plants mainly because seed saving limits their ability to recoup their investment.[1]

The use of variety level genetic use restriction technologies (V-GURTs) is a biological way of restricting the unauthorized use of seed that embodies intellectual property. Specifically,

[1] Globally, the largest quantity of seed is produced by farmers; about 1.4 billion farmers, mainly in developing countries, depend on saved seed as their primary seed source (ETC Group, 2007). In India, for instance, 83% of farmers use their own farm-saved seeds (Sharma, 2005). Even in developed countries farmers rely on saving seed. By some estimates, most North American wheat farmers typically rely on farm-saved seeds and return to the commercial market once every 4-5 years (ETC Group, 1998). The percentage of farm-saved seed for UK is 30%, for Germany 46%, for France 35%, for Portugal 75%, for Spain 88% (Toledo, 2002).

V-GURTs, which are commonly referred to as terminator technology, are technologies that can restrict the use of the entire variety through interference with reproduction resulting in the production of sterile seeds.[2,3]

Even though GURTs have not been commercialized yet, their potential introduction incites great controversy. The proponents of GURTs claim that their introduction will strengthen the protection of intellectual property and could work more effectively than other IPR regimes (e.g., patents, breeder's rights or licenses) as an innovation rent appropriation mechanism for innovators/breeders because they make it impossible for farmers to save and re-use seed. As a consequence, the introduction of V-GURTs might encourage innovating firms to invest more in R&D, especially in self-pollinating crops where hybrids are not effective (e.g., rice, wheat, soybean, cotton). GURTs supporters also claim that their introduction will result in increased agricultural productivity through an increased degree of accuracy in production (e.g., precision agriculture) and in crops with better agro-ecological characteristics; could be used as a tool that prevents the escape of horizontal gene flow into neighboring crops or wild species, limiting the potential negative environmental effects of genetically modified (GM) crops; and could be viewed as a lever to encourage countries to provide greater IP protection to GM crops.[4]

On the other hand, a number of countries (e.g., India, Brazil), consumer groups and non-

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[2] Unlike V-GURTs that can restrict the use of the entire variety, trait specific genetic use restriction technologies (T-GURTs) are technologies that can restrict the use of a specific trait by regulating its expression. That is, the gene(s) conferring the trait are switched on or off through specific chemical inducers. The seed itself remains viable, but farmers need to buy the inducers to take advantage of the specific trait.

[3] More than fifty GURTs patents have been issued to private firms, universities and the US Government, nineteen of which relate to V-GURTs/terminator technology (Pendleton, 2004). The first patent on GURTs was granted to Delta and Pine Land Co and the US Department of Agriculture in March 1998 (US patent 5,723,765, on the "Control of Plant Gene Expression" at http://www.ars.usda.gov/is/br/tps/). This patent describes "a set of interacting genetic elements that allows the controlled expression of value-added trait or of seed viability in a crop plant" (Visser et al., 2001, pp. 9). While current patent applications apply to plants, GURTs could be built into any organism (e.g., farm animals, fish and trees) (Visser et al., 2001).

[4] For instance, biotech companies can threaten to introduce terminator technology if a country does not improve its IPRs protection. In this case, a country that chooses to ban the technology loses the right to use the potentially valuable protected trait (Pendleton, 2004).

governmental organizations (NGOs) oppose the introduction of GURTs.[5] The main argument of the opponents of terminator technology is that it is an unethical technology that deprives farmers of their traditional right to save, use, and exchange seeds. In addition, critics are concerned about the environmental effects of gene flow from crops which are sterilized and could, as claimed, sterilize other plants and have serious effects on the ecosystem (Crouch, 1998; Jefferson et al., 1999). Those opposing terminator technology also claim that it would restrict access to genetic resources and hinder the efforts of public institutions and farmers, increasing the barriers between public and private gene pools and leading to less innovation in the long run. Related to this last concern is the argument that terminator technology will create perpetual monopolies which would lead to the unequal distribution of economic rents between farmers, seed companies and consumers (Srinivasan and Thirtle, 2002). Finally, there is concern that the introduction of terminator technology will lead to an increase in both horizontal concentration and vertical integration (between the seed breeding and agrochemical sectors) creating monopolies in agricultural R&D and a displacement of investment may occur away from biotechnological options that might be more beneficial to farmers in developing countries.

The potential impacts of GURTs from an environmental, biosafety and moral point of view have been the focus of early GURTs studies which discuss the possible welfare effects of the technology for farmers, firms and the society (Visser et al., 2001; Gari, 2002; Eaton and Tongeren, 2002; Eaton et al., 2002; Fisher, 2002; Pendleton, 2004). A group of empirical studies used data from the introduction of hybrid technology that shares some degree of use restriction

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[5] The Consultative Group on International Agricultural Research (CGIAR) pledged never to use any kind of terminator technology seeds and the Food and Agriculture Organization of the United Nations is against the use of terminator technology (Pendleton, 2004). Among civil society organizations that have expressed opposition and taken action against GURTs are the National Family Farm Coalition, International Center for Technology Assessment, Mothers and Others for a Livable Planet, Consumers Union, Consumer Federation, Sustainable Agriculture Coalition and the ETC group (ETC, 1999).

with V-GURTs to make inferences about its potential economic effects (Swanson and Goeschl, 2000, 2002a, 2002b, 2002c; Goeschl and Swanson, 2000, 2002a, 2002b, 2003; Srinivasan and Thirtle, 2000, 2002, 2003).[6] These studies show that hybridization enabled seed companies to capture greater profits and has attracted more private investment into plant breeding which could also occur in the case of V-GURTs.

Even though the above studies have shed light into understanding the potential benefits and costs associated with V-GURTs, they do not provide an analytical framework that could be used to examine their economic impacts. A few recent studies have made contributions to this effect. Lence et al. (2005) in a study that estimates the impact of changes in the strength of the IPR regime on welfare and determines a socially optimal appropriability level, assume that the introduction of GURTs is similar to a case where infinite IPR protection is granted, and, therefore, find that the optimal appropriability level is much lower than the one that would exist under GURTs. Lence and Hayes (2005) compare patents to GURTs as intellectual property protection mechanisms in the presence of R&D improvements that exhibit spillovers. They show that as long as GURTs contribute to the harmonization of IP protection among countries, they can be welfare enhancing. Burton et al. (2005) use a two-period principal-agent model to examine the property rights protection of GM crops and compare sterile GM seed to short and long term contracts between an innovator and farmers in terms of their efficiency in protecting intellectual property and their social welfare effects (where social welfare is the sum firm profits and farmer welfare). They find that the innovator always prefers, in order, the use of GURTs, long term contracts and short term contracts while farmers prefer, in order, long term contracts, short term

[6] Hybridization can be viewed as a weaker version of V-GURTs where the germplasm remains available to farmers and competing breeders for further breeding but where the crops grown from saved seed do not exhibit the desirable features of the initial seed. The loss from replanting hybrids is generally 25-30%, while the expected yield loss from using V-GURTs seeds is 100%.

contracts and GURTs use. Finally, Ambec et al. (2008) develop a two-period model to examine the impact of crop trait durability on a monopolist's pricing strategies and switching decisions from inbred line seed to hybrid seed. They show that the monopolist can produce technologically dominated hybrid seed to extract more surplus from farmers while the introduction of a fee paid by self-producing farmers improves efficiency.

Given the expressed opposition to GURTs by various consumer groups (see footnote 5) an analysis of the market and/or welfare effects of GURTs should not ignore consumers. As we show in this study, consumer attitudes towards GURTs affect an innovating firm's decision to introduce the technology as well as social welfare. A major contribution of our study is that we develop a flexible analytical framework to examine the system wide effects (for consumers, farmers and the innovator) of two IPRs regimes, Technology Use Agreements (TUAs), which represent the status quo, and GURTs, while accounting for both consumer and producer heterogeneity.[7]

In our framework, consumers differ with respect to preferences regarding interventions in the production process (e.g., genetic modification and genetic use restriction) and farmers differ in the agronomic benefits they realize from a seed variety and whether they choose to violate their TUAs or not. Specifically, our study examines an innovator's decision to introduce V-GURTs (GURTs hereafter) into a new GM seed variety that offers enhanced agronomic benefits to farmers and desirable functional properties to consumers and compares its potential market and welfare effects to a situation where the new variety is introduced using Technology Use Agreements (TUAs), instead.

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[7] Technology use agreements, also known as stewardship agreements, set forth the requirements and guidelines for use of proprietary technology, in this case GM seed. All farmers that want to purchase a patented seed variety have to sign a TUA which, among other things, specifies that it is illegal for the farmer to save and replant seeds produced from crops grown from the patented seed variety.

Our results show that the monopolist seed supplier does not always prefer GURTs to TUAs. Even though he is forced to charge a lower price for GM seed when he competes with farmers that illegally save and replant seed, his profits may be greater under TUAs if consumer aversion to GURTs is high. In addition, farmers may experience greater welfare under GURTs than under TUAs which contradicts the findings of Burton et al. (2005). Finally, while in most cases aggregate consumer welfare is greater under TUAs than under GURTs some consumers may be better off under GURTs; interestingly, those with high levels of aversion to interventions in the production process.

The rest of the paper is organized as follows. Section two develops the heterogeneous consumer and producer models, derives the market outcome under the TUAs (status quo) and under GURTs and examines the seed supplier's profit maximizing decisions. Changes in the market equilibrium outcomes when TUAs are replaced by GURTs are also considered in this section. The welfare analysis is carried out in section three while section four summarizes and concludes the paper.

2. Market effects of TUAs and GURTs

The model builds on previous work by Fulton and Giannakas (2004) and Giannakas and Yiannaka (2008) who study the market and welfare outcomes of different labeling regimes in GM product markets. Our model examines and compares the market and welfare effects of TUAs and GURTs when consumer products are labeled. These are markets where either GM products have to be mandatorily labeled (e.g., EU) or markets where processors/retailers have an incentive to voluntarily label the products to inform consumers about functional credence attributes for which consumers may be willing to pay a premium.[8]

Our analysis starts with an innovator who has generated a new GM seed variety with enhanced agronomic benefits for farmers (e.g., drought resistance) and desirable functional properties for consumers (e.g., health enhancing properties)[9] and decides whether to insert GURTs into the seed or sell the seed using TUAs.[10] We assume that the innovator/seed provider is a monopolist, farmers can choose between the new GM seed, its conventional counterpart or to produce an alternative crop and consumers can choose between the conventional or the new GM product. To keep the analysis tractable and the focus on the comparison between the two alternative IPRs schemes we do not include an 'old' GM seed variety (i.e., first generation GM seed) as an option for farmers. Implicitly we assume that the new GM seed variety will be introduced in a market where GM production has not been previously allowed or widespread (e.g., EU) or, alternatively, that the new GM seed variety is drastic with respect to the 'old' GM seed varieties (i.e., it will push the old varieties out of the market). Relaxing this assumption is discussed in the analysis that follows. Under TUAs some farmers may engage in unauthorized seed use (i.e., save and replant GM seed) but the innovator does not know ex-ante who these farmers are. Thus, under this case, in addition to determining the price of GM seed, the innovator also determines the effort she will exert to identify farmers that violate their licensing agreements.[11] Under GURTs farmers cannot save and replant seed since the technology makes

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[8] This could be the case with some second generation GM products in the US market, where labeling of GM products is not required, like high protein wheat, high oleic soybeans or vitamin A enriched rice and corn.
[9] An example could be drought resistant soybean seed that produces high oleic soybeans that, in turn, produce high oleic soybean oil.
[10] The innovator's decision to invest in R&D and develop the new seed variety has already taken place and all costs associated with it are sunk at this point.
[11] According to Monsanto, a very small percentage of U.S. farmers do not honor their TUAs. The company states that it becomes aware of potential infringers either through its own actions or through third parties (e.g., other farmers) and lawsuits are rare (145 lawsuits between 1997 and 2010) as most cases settle before going to trial. Interestingly, according to the company, many of the infringing farmers remain their customers (Monsanto, 2012).

the saved seed sterile, and the innovator does not have to incur monitoring/enforcement costs to identify potential infringers. The market and welfare outcomes associated with the two IPRs regimes are determined using backwards induction; we start with consumers' purchasing decisions, then consider farmers' production decisions and finally the innovator's profit maximizing decisions.

2.1 Consumers

The consumer market examined consists of a product which could become available in a conventional, GM or GM with GURTs (GM^G hereafter) form. It is assumed that the physical characteristics of the different product types (i.e., conventional, GM and GM^G) are indistinguishable to consumers (e.g., color, texture, smell) while their differentiating attributes, which are the process through which they have been produced and the additional functional properties of the GM and GM^G product forms (e.g., health enhancing attributes), are both credence attributes.[12] Therefore, consumers have to rely on labels for informed consumption decisions. It is important to note that inserting GURTs into the GM seed variety does not affect the functional attributes of the GM^G product that are desirable to consumers (i.e., the functional attributes are identical to those when the GM seed variety does not contain GURTs).

To capture revealed and stated consumer preferences towards genetic modification (see also Giannakas and Yiannaka (2008)) and opposition by some consumer groups to genetic use restriction, consumers in this market are assumed to be heterogeneous, uniformly distributed in the interval $[0,1]$ with respect to a differentiating characteristic A, where $A \in [0,1]$, reflects

[12] As an example, the market could be that for soybean oil where the conventional product will be soybean oil produced from conventionally produced soybeans, the GM product will be high oleic soybean oil produced from high oleic GM soybeans and the GM^G product will be high oleic soybean oil produced from high oleic GM soybeans which have been produced with GURTs seed. In this case, the functional property that is desirable to consumers is the high oleic content which is an attribute shared by the GM and GM^G products.

consumer aversion to interventions in the production process; the greater is the value of A, the greater is consumer opposition to interventions in the production process.[13] Assuming that each consumer buys one unit of the type of product they prefer and this purchasing decision represents a small share of their budget, the consumer utility function of a consumer with a differentiating attribute A is given by:

$$U_c = U - p_c - \delta A \quad \text{if a unit of the conventional product is consumed,}$$

$$U_{gm} = U + V - p_{gm} - \lambda A \quad \text{if a unit of the GM product is consumed, and} \tag{1}$$

$$U_{gt} = U + V - p_{gt} - \mu A \quad \text{if a unit of the GM}^{G} \text{ product is consumed.}$$

In equation (1), U_c, U_{gm}, and U_{gt} are the utilities derived from the consumption of one unit of the conventional, GM, and GM^G product, respectively. The parameter $U > 0$ is a base level of utility associated with the physical characteristics of the product and is the same for all products while the parameter $V > 0$ reflects the value consumers place on the functional attributes of the GM and GM^G product. The parameters p_c, p_{gm} and p_{gt} denote the market prices of the conventional, GM and GM^G product, respectively. The parameters δ, λ and μ are non-negative utility discount factors that are constant across consumers and, along with the differentiating attribute A, determine the level of consumer aversion to interventions in the production process; the greater are these parameters, the greater is consumer aversion to interventions in the production process for a given A value. To capture expressed consumer opposition to genetic modification and genetic use restriction we assume that $\mu > \lambda > \delta$.[14] To

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[13] A consumer with a value of $A = 0$ does not care about interventions in the production process while a consumer with an $A = 1$ is the most averse to interventions in the production process.
[14] Thus, μ captures opposition to <u>both</u> genetic modification and genetic use restriction. The assumption that $\mu > \lambda$ captures expressed consumer concerns about the environmental risks of seed sterility, biodiversity and the inability of farmers to save and replant seed (ETC Group, 1998, 2006, 2009; Pendleton, 2004).

keep the analysis simple and without loss of generality we set $\delta = 0$. Given the above, U, $U - \lambda A$ and $U - \mu A$ measure consumer willingness to pay for the conventional, GM and GM^G products, respectively.

Under TUAs

When the monopolist introduces the new GM seed without the use of GURTs, the product forms available to consumers are the conventional and the new GM product. A consumer chooses from the available products, the one that gives her the highest level of utility and as long as $U_c = U - p_c > 0$ all consumers that participate in the market will buy either the conventional or the new GM product. The consumer with a differentiating attribute A_o such that, $U_c(A_0) = U_{gm}(A_0) \Rightarrow A_0 = \dfrac{V + p_c - p_{gm}}{\lambda}$ is indifferent between consuming the conventional and the new GM product while consumers with an $A \in [0, A_0]$ will consume the new GM product and those with an $A \in (A_0, 1]$ will consume the conventional product.

Given that consumers are uniformly distributed with respect to their aversion to interventions in production process and their mass is normalized to one, A_0 determines the market share of, as well as the demand for, the new GM product, given by:

$$d_{gm} = A_0 = \frac{V + p_c - p_{gm}}{\lambda} \qquad (2)$$

The market share of, and demand for, the conventional product is given by:

$$d_c = 1 - A_0 = \frac{\lambda - V - p_c + p_{gm}}{\lambda} \qquad (3)$$

As equations (2) and (3) show, the greater (smaller) is the value consumers place on the functional attribute of the GM product (V), the lower (higher) is the price of the GM product (p_{gm}) and the lower (higher) is consumer aversion to genetic modification (λ), the greater is the market share of, and the demand for, the new GM (conventional) product.

Figure 1 depicts the utility schedules and consumption decisions of consumers participating in this market when both the new GM and the conventional product co-exist in the market, i.e., when $0 < A_o < 1 \Rightarrow p_{gm} - p_c < V < p_{gm} - p_c + \lambda$. In figure 1, the kinked dashed curve gives the effective utility schedule and the area below it gives the aggregate consumer welfare under TUAs. If the conditions for co-existence do not obtain, then either the utility schedule of the new GM product is above (below) the utility schedule of the conventional product for all A values, i.e., $U_{gm} > U_c \ \forall A \ i.e., V \geq p_{gm} - p_c + \lambda$ ($U_{gm} < U_c \ \forall A \ i.e., V = p_{gm} - p_c$) and only the new GM (conventional) product will be consumed.

Under GURTs

When the monopolist introduces GURTs into the new GM seed variety, the product forms available to consumers are the conventional and the new GM^G product. The consumer with a characteristic $A_0^G : U_{gt}\left(A_0^G\right) = U_c^G\left(A_0^G\right) \Rightarrow A_0^G = \frac{V + p_c^G - p_{gt}}{\mu}$ is indifferent between consuming the GM^G and the conventional product. Consumers with $A \in [0, A_0^G]$ will consume the GM^G product while those with $A \in (A_0^G, 1]$ will consume the conventional product.

The differentiating attribute A_0^G also determines the market share of, and the demand for, the new GM^G product, given by equation (4), while the market share of, and the demand for, the conventional product is given by equation (5).

$$d_{gt} = A_0^G = \frac{V + p_c^G - p_{gt}}{\mu} \tag{4}$$

$$d_c^G = 1 - A_0^G = \frac{\mu - V - p_c^G + p_{gt}}{\mu} \tag{5}$$

Equations (4) and (5) show that, the greater (smaller) is the value consumers place on the functional attribute of the GM^G product (V), the lower (higher) is the GM^G product's price (p_{gt}) and the lower (higher) is consumer aversion to genetic modification and genetic use restriction (μ), the greater is the market share of and the demand for the new GM^G (conventional) product.

This outcome is depicted in Figure 2 (when $0 < A_0^G < 1 \Rightarrow p_{gt} - p_c^G < V < p_{gt} - p_c^G + \mu$ so that the GM^G and the conventional product co-exist in the market) where the kinked bold curve shows the effective utility curve and the area below it the aggregate consumer welfare under GURTs.

2.2 Farmers

The market for the farm product is assumed to be competitive. Farmers are making decisions as to which product to produce based on the returns they earn, which depend on the market price they face for their product and the cost of producing each product type. With the introduction of the new GM seed variety that offers enhanced agronomic benefits to farmers, the decision a farmer needs to make is whether to produce the new GM crop, a conventional variety of the crop or an alternative crop. If the GM seed variety is introduced without GURTs then a farmer that has decided to produce the GM crop needs to further decide whether she will save GM seed and replant that seed the following period, violating her licensing agreement (i.e., cheat). When the GM seed variety contains GURTs (GM^G), it is not profitable for the farmer to save and replant seed as the saved seed is sterile. We assume that farmers know whether the GM seed contains

GURTs.[15] Note that the inclusion of GURTs into the GM seed does not alter its agronomic benefits in any way (i.e., the new GM seed and the new GM seed with GURTs yield identical agronomic benefits to producers).

To capture what one observes in practice, which is the co-existence of conventional and GM crops, farmers are assumed to be heterogeneous with respect to the agronomic benefits they realize from producing the different varieties (conventional or GM); which implies that farmers differ with respect to the net returns they realize from producing these crops. Farmer differences may stem from characteristics like management skills, experience, education, soil quality, technology used and farm size and location. We denote by Z where $Z \in [0,1]$ the attribute that differentiates farmers (e.g., skills, experience, land quality) and assume farmers are uniformly distributed in the interval $[0,1]$ each producing one unit of output. The net return function of a farmer with a value of Z is given by:

$$
\begin{aligned}
&\Pi_c = p_c^f - W_c - \beta Z && \text{if a unit of conventional variety is produced,} \\
&\Pi_{gm} = p_{gm}^f - w_{gm} - \gamma Z && \text{if a unit of GM variety is produced,} \\
&\Pi_{gm}^C = p_{gm}^f - c_s - \rho(\varepsilon)h - \alpha\gamma Z && \text{if a unit of GM variety is produced with saved seed,} \quad (6) \\
&\Pi_{gt} = p_{gt}^f - w_{gt} - \gamma Z && \text{if a unit of the GM}^{\text{G}} \text{ variety is produced, and} \\
&\Pi_a = 0 && \text{if a unit of an alternative crop is produced.}
\end{aligned}
$$

In equation (6) p_c^f, p_{gm}^f and p_{gt}^f denote the farm prices of the conventional, the GM, and the GM^G products, respectively. The parameter W_c denotes an average cost of purchasing

[15] Even if a farmer were unsure about the inclusion of GURTs into the GM seed, she would find out if she saved and replanted that seed and could adjust/correct her decision the next period.

conventional seed and chemicals and saving and replanting conventional seed.[16] The costs W_c is assumed to be exogenous and thus not affected by the introduction of the new GM seed variety (the relaxing of this assumption is discussed throughout the analysis).[17] The parameters w_{gm} and w_{gt} denote the seed and chemical costs of the GM and GM[G] product, respectively. The parameters β, γ and a are cost-enhancement factors and are constant across farmers. To capture the enhanced agronomic benefits of the GM and GM[G] crops relative to the conventional crop we assume that $\beta > \gamma > 0$. To capture the fact that saved seed may lose some of its germination potential we assume that $a > 1$ and that $\beta > \alpha\gamma > \gamma$. All other costs of saving seed are denoted by c_s.[18] The term ρh is the expected penalty farmers pay when they are caught violating their TUAs (cheating) where ρ is the probability of being caught saving GM seed and h is the penalty imposed. The probability of being caught cheating is given by $\rho = \varepsilon$ where $\varepsilon \in [0,1]$ is the effort the monopolist exerts in detecting cheaters. To keep the analysis simple we assume that the penalty, h, is determined by the legal system and thus, is exogenous to the monopolist.[19] Also, for simplicity the profits of producing the alternative crop are normalized to zero. Given the specification of the net return functions in equations (6), a farmer with a Z value of zero realizes higher profits than a farmer with a Z value of one.

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[16] The parameter W_c could be given by $W_c = \theta w_c + (1-\theta)c_s$ where θ is the portion of seed purchased, w_c is the price of conventional seed and c_s is the cost of saving conventional seed. Please note that saving and replanting conventional seed is not illegal. The decision whether to purchase or save conventional seed is not explicitly considered here to keep the analysis tractable.

[17] This would be consistent with a perfectly competitive conventional seed supply sector and use of a constant returns to scale technology.

[18] An alternative interpretation of c_s could be the cost of purchasing seed from unauthorized channels (e.g., other farmers).

[19] In some cases, companies set their own penalties. For example, Monsanto imposes a penalty of $15 per acre for every acre planted with Roundup Ready canola seed not covered by the technology use agreement and if the grower sells, gives or transfers any seed containing the Roundup Ready gene for each acre capable of being planted using that seed (Network of Concerned Farmers, *Copy of Technology User Agreement*, 2003, available at http://www.non-gm-farmers.com/news_details.asp?ID=310).

Under TUAs

Under TUAs two periods must be considered. Period one, refers to the period when the new GM seed variety is first introduced. During this period a farmer cannot save and replant GM seed (or purchase it from unauthorized channels) since the seed has not been previously available. During period one, a farmer can produce the conventional crop, the GM crop with purchased seed or the alternative crop while in period two, in addition to these options, she can plant GM seed saved from period one. A farmer with a differentiating attribute Z will choose the option that yields the highest net returns.[20]

Period One

The period one net returns from the production of a unit of the conventional, GM and alternative crop are given by $\Pi_{c1} = p_{c1}^f - W_c - \beta Z$, $\Pi_{gm1} = p_{gm1}^f - w_{gm1} - \gamma Z$ and $\Pi_{a1} = 0$, respectively. The farmer with a differentiating attribute $Z_0 : \Pi_{c1}(Z_0) = \Pi_{gm1}(Z_0) \Rightarrow Z_0 = \dfrac{p_{c1}^f - p_{gm1}^f + w_{gm1} - W_c}{\beta - \gamma}$ is indifferent between producing the conventional and new GM crop while the farmer with a differentiating attribute $\bar{Z} : \Pi_{gm1}(\bar{Z}) = \Pi_a(\bar{Z}) \Rightarrow \bar{Z} = \dfrac{p_{gm1}^f - w_{gm1}}{\gamma}$ is indifferent between producing the new GM and the alternative crop. Note that, for co-existence of the conventional and new GM crop the following conditions must hold, $0 < Z_0 < \bar{Z} \le 1$ which implies that $\gamma \ge p_{gm1}^f - w_{gm1}$ and $W_c > \dfrac{\beta(p_{c1}^f - p_{gm1}^f + w_{gm1})}{\gamma}$. If the net returns schedule of the conventional crop is above the net returns schedule of the new GM crop for all Z values, the conditions for co-existence do not

[20] It is important to point out that unlike farmers who face different options under the two periods, the options consumers face are the same in both periods; a choice between the conventional and the GM product. This implies that consumers cannot tell whether the GM product they see in the market came from farmers that violated their TUAs and used saved GM seed to produce the product or from farmers that complied. What may be different for consumers is the prices of the conventional and GM product in the two periods.

obtain, (i.e., if $\Pi_{c1} > \Pi_{gm1}\ \forall Z \in [0,1]$ in Figure 3, panel (i)) then the new GM will not be adopted and the new GM technology will be ineffective. If the opposite is true and $\Pi_{c1} < \Pi_{gm1}\ \forall Z \in [0,1]$ then the new GM will push the conventional crop out of the market and the new GM technology will be drastic. Co-existence of the new GM and conventional crops implies that the GM technology is effective but non-drastic.

Farmers with a Z value of $Z \in [0, Z_0]$ will produce the conventional crop, those with a $Z \in (Z_0, \bar{Z}]$ will produce the new GM crop while those with a $Z \in (\bar{Z}, 1]$ will produce the alternative crop. Since farmers are uniformly distributed in the interval $[0,1]$ and each produces one unit of the product, Z_0 gives the supply of the conventional product, as shown in equation (7), $\bar{Z} - Z_0$ gives the supply of the new GM product, as shown in equation (8), and $1 - \bar{Z}_0$ gives the supply of the alternative crop, as shown in equation (9).

$$s_{c1} = \frac{p_{c1}^f - p_{gm1}^f + w_{gm1} - W_c}{\beta - \gamma} \tag{7}$$

$$s_{gm1} = \frac{\beta(p_{gm1}^f - w_{gm1}) - \gamma(p_{c1}^f - W_c)}{\beta\gamma - \gamma^2} \tag{8}$$

$$s_{a1} = \frac{\gamma + w_{gm1} - p_{gm1}^f}{\gamma} \tag{9}$$

Equation (8) shows that the greater is the price farmers receive for the GM crop and the cost of producing the conventional crop and the lower is the seed costs of producing the GM crop and the price of the conventional crop, the greater is the supply of the GM crop. Figure 3, panel (i), depicts the net returns and the production decisions in period one when the conventional and the new GM crop coexist. The kinked dashed curve is the effective net returns schedule and the area below it gives the aggregate producer welfare in period one under GURTs.

Period Two

The period two net returns from the production of a unit of the conventional, GM produced with purchased seed, GM produced with illegally saved seed and alternative crop are given by $\Pi_{c2} = p^f_{c2} - W_c - \beta Z$, $\Pi_{gm2} = p^f_{gm2} - w_{gm2} - \gamma Z$, $\Pi^C_{gm} = p^f_{gm2} - c_s - \rho(\varepsilon)h - \alpha\gamma Z$ and $\Pi_{a2} = 0$, respectively. The farmer with a differentiating attribute $Z_c : \Pi_{c2}(Z_c) = \Pi^C_{gm}(Z_c) \Rightarrow Z_c = \dfrac{p^f_{c2} - p^f_{gm2} + c_s - W_c + \varepsilon h}{\beta - \alpha\gamma}$ is indifferent between producing the conventional crop and the new GM crop with illegally saved seed, the farmer with a differentiating attribute $Z_{gm} : \Pi^C_{gm}(Z_{gm}) = \Pi_{gm2}(Z_{gm}) \Rightarrow Z_{gm} = \dfrac{w_{gm2} - c_s - \varepsilon h}{(\alpha - 1)\gamma}$ is indifferent between producing the new GM crop with saved seed and with purchased seed (i.e., violating her TUAs versus complying) while the farmer with $\tilde{Z} : \Pi_{gm2}(\tilde{Z}) = \Pi_{a2}(\tilde{Z}) \Rightarrow \tilde{Z} = \dfrac{p^f_{gm2} - w_{gm2}}{\gamma}$ is indifferent between producing the new GM crop with purchased seed and the alternative crop. Farmers with a Z value such that $Z \in [0, Z_c]$ will produce the conventional crop, those with a $Z \in (Z_c, Z_{gm}]$ will produce the new GM crop with illegally saved seed, those with a $Z \in (Z_{gm}, \tilde{Z}]$ will produce the new GM crop with purchased seed and those with a $Z \in (\tilde{Z}, 1]$ will produce the alternative crop. For the co-existence of conventional farmers, GM farmers that cheat and GM farmers that do not cheat, the following conditions must hold, $0 < Z_c < Z_{gm} < \tilde{Z} \leq 1$, which implies that $c_s > p^f_{gm2} - \alpha p^f_{gm2} + \alpha w_{gm2} - \varepsilon h$ and $W_c > \dfrac{(\beta - \gamma)(\mathrm{c_s} + \varepsilon h) - (\beta - \alpha\gamma)\mathrm{w_{gm2}} + (\alpha\gamma - \gamma)(\mathrm{p}^f_{c2} - \mathrm{p}^f_{gm2})}{\alpha\gamma - \gamma}$ must hold. Since farmers are uniformly distributed along the unit length interval and each produces one unit of output, Z_c also gives the supply of the conventional crop, $Z_{gm} - Z_c$ the supply of the GM crop produced with saved seed, $\tilde{Z} - Z_{gm}$ the supply of the GM crop produced with purchased seed and $1 - \tilde{Z}$ the supply of the alternative crop; these supplies are given in equations (10) to (13).

$$s_{c2} = Z_c = \frac{p_{c2}^f - p_{gm2}^f + c_s - W_c + \varepsilon h}{\beta - \alpha\gamma} \tag{10}$$

$$s_{gm}^c = \frac{w_{gm2} - c_s - \varepsilon h}{\alpha\gamma - \gamma} - \frac{c_s + p_{c2}^f - p_{gm2}^f - W_c + \varepsilon h}{\beta - \alpha\gamma} \tag{11}$$

$$s_{gm2} = \frac{c_s + (a-1)p_{gm2}^f - \alpha w_{gm2} + \varepsilon h}{a\gamma - \gamma} \tag{12}$$

$$s_{a2} = \frac{w_{gm2} - p_{gm2}^f + \gamma}{\gamma} \tag{13}$$

Equation (11) shows that the greater is the cost of GM seed and the lower is the cost of saving seed, the probability of getting caught cheating (i.e., the effort the monopolist exerts to identify cheaters) and the penalty imposed when caught cheating, the greater is the portion of the GM product that will be produced with illegally saved seed (by farmers who cheat). Note that, the total quantity of GM product produced (with purchased and saved seed) is given by $s_{gmT} = s_{gm}^c + s_{gm2}$. Figure 3, panel (ii), depicts the net returns and production decisions in period two when all crops coexist. The kinked dashed curve shows the effective net returns schedule and the area below it gives the aggregate producer welfare in period two.

Under GURTs

When the new GM seed contains GURTs, a farmer cannot save and replant GM seed and the options available to her are to produce the conventional crop, the new GM^G crop or the alternative crop realizing net returns given by $\Pi_c^G = p_c^{fG} - W_c - \beta Z$, $\Pi_{gt} = p_{gt}^f - w_{gt} - \gamma Z$ and

$\Pi_a^G = 0$, respectively. When all products coexist in the market, the farmer who is indifferent between producing the conventional and the GM^G crop has a differentiating attribute Z_{gt} such that, $Z_{gt} : \Pi_c^G(Z_{gt}) = \Pi_{gt}(Z_{gt}) \Rightarrow Z_{gt} = \frac{p_c^{fG} - p_{gt}^f - W_c + w_{gt}}{\beta - \gamma}$ while the farmer who is indifferent between producing the new GM^G and the alternative crop has a differentiating attribute $\hat{Z}$ where $\hat{Z} : \Pi_{gt}(\hat{Z}) = \Pi_a^G(\hat{Z}) \Rightarrow \hat{Z} = \frac{p_{gt}^f - w_{gt}}{\gamma}$. Farmers with Z values in the interval $Z \in [0, Z_{gt}]$ produce the conventional crop, those with $Z \in (Z_{gt}, \hat{Z}]$ produce the new GM^G crop and those with $Z \in (\hat{Z}, 1]$ produce the alternative crop. For the co-existence of the conventional and GM^G crop the following condition must hold $0 < Z_{gt} < \hat{Z} \leq 1$ which implies that $\gamma \geq p_{gt}^f - w_{gt}$ and $W_c > \frac{\gamma p_c^{fG} - \beta(p_{gt}^f - w_{gt})}{\gamma}$.

The supply of the conventional crop is given by Z_{gt}, the supply of the new GM^G crop is given by $\hat{Z} - Z_{gt}$ and the supply of the alternative crop is given by $1 - \hat{Z}$; these supplies are given by equations (14) to (16).

$$s_c^G = \frac{p_c^{fG} - p_{gt}^f - W_c + w_{gt}}{\beta - \gamma} \tag{14}$$

$$s_{gt} = \frac{\beta(p_{gt}^f - w_{gt}) - \gamma(p_c^{fG} - W_c)}{\beta\gamma - \gamma^2} \tag{15}$$

$$s_a{}^G = \frac{\gamma - p_{gt}^f + w_{gt}}{\gamma} \tag{16}$$

Equation (15) shows that the greater is the price farmers receive for the GM^G crop, the agronomic benefits of GM^G seed (i.e., the lower is γ) and the cost of producing the conventional product and the lower is the seed cost of the GM^G crop and the price of the conventional product, the greater is the adoption of the new GM^G product. Figure 4, depicts the net returns and production decisions under GURTs when the conventional and new GM crops coexist.

2.3 The Monopolist

Having solved for the consumer and farmer optimal decisions under TUAs and under GURTs we can solve for the market outcome (the derived demand for GM and GM^G seed and the retail prices for the GM and GMG products) under these two scenarios. This will allow us to determine the monopolist's profit maximizing decisions and solve for the market equilibrium under TUAs and under GURTs.

We denote by y_{gm1} and y_{gm2} the seed sales of the monopolist under TUAs for period one and period two, respectively, and by y_{gt} seed sales under GURTs. We assume fixed proportions between farm and seed production which implies that $s_{gm1} = y_{gm1}$, $s_{gm2} = y_{gm2}$ and $s_{gt} = y_{gt}$. We also assume fixed proportions between the retail and farm level and a constant marketing margin for the conventional and GM products denoted by mm_c and mm_{gm}, respectively. The marketing margins are assumed to be the same under TUAs and under GURTs since the products will be labeled (e.g., identity preservation costs will be incurred) under both scenarios. Given the above, the relationship between the retail and farm prices for the conventional, GM and GM^G products are given by $p_c = p_c^f + mm_c$, $p_{gm} = p_{gm}^f + mm_{gm}$ and $p_{gt} = p_{gt}^f + mm_{gm}$, respectively.

We use the above relationships to solve for the market outcome under TUAs, in period one, by simultaneously solving the following equations: $d_{c1} = s_{c1}$ (where d_{c1} is given by equation (3) with $p_c = p_{c1}$ and $p_{gm} = p_{gm1}$ and the supply by equation (7)), $d_{gm1} = s_{gm1}$ (where d_{gm1} is given by equation (2) with $p_c = p_{c1}$ and $p_{gm} = p_{gm1}$ and the supply by equation (8)), $p_{c1} = p_{c1}^f + mm_c$,

$p_{gm1} = p^f_{gm1} + mm_{gm}$ and $s_{gm1} = y_{gm1}$.[21] Equations (17), (18) and (19) give the inverse demand for GM seed, the retail price of the conventional product and the retail price of the GM product, respectively:

$$w_{gm1} = V + W_c + \beta - \gamma + mm_c - mm_{gm} - (\beta - \gamma + \lambda) y_{gm1} \tag{17}$$

$$p_{c1} = W_c + \beta + mm_c - (\beta - \gamma) y_{gm1} \tag{18}$$

$$p_{gm1} = V + W_c + \beta + mm_c - (\beta - \gamma + \lambda) y_{gm1} \tag{19}$$

The market outcome under TUAs in period two is similarly determined by simultaneously solving the following equations: $d_{c2} = s_{c2}$ (d_{c2} is given by equation (3) when $p_c = p_{c2}$ and $p_{gm} = p_{gm2}$ and the supply by equation (10)), $d_{gm2} = s^c_{gm} + s_{gm2}$ (d_{gm2} is given by equation (2) when $p_c = p_{c2}$ and $p_{gm} = p_{gm2}$ and the total GM supply by the summation of equations (11) and (12)), $p_{c2} = p^f_{c2} + mm_c$, $p_{gm2} = p^f_{gm2} + mm_{gm}$ and $s_{gm2} = y_{gm2}$. Equations (20), (21) and (22) give the period two inverse demand for GM seed, retail price of the conventional product and retail price of the GM product, respectively:

$$w_{gm2} = c_s + \alpha\gamma - \gamma + \varepsilon h - (\alpha\gamma - \gamma) y_{gm2} \tag{20}$$

$$\begin{aligned} p_{c2} = {} & \frac{\lambda W_c - (\beta - \alpha\gamma)V + (\beta - \alpha\gamma)c_s + \lambda mm_c + (\beta - \alpha\gamma)mm_{gm} + (\beta - \alpha\gamma)\varepsilon h}{\beta - \alpha\gamma + \lambda} + \\ & \frac{\alpha\beta\gamma + \beta\lambda - \alpha^2\gamma^2}{\beta - \alpha\gamma + \lambda} - \frac{\alpha\beta\gamma - \beta\gamma + \alpha\gamma^2 - \alpha^2\gamma^2 - \gamma\lambda + \alpha\gamma\lambda}{\beta - \alpha\gamma + \lambda} y_{gm2} \end{aligned} \tag{21}$$

$$p_{gm2} = \alpha\gamma + c_s + \varepsilon h + mm_{gm} - (\alpha\gamma - \gamma) y_{gm2} \tag{22}$$

Finally, the market outcome under GURTs is found by simultaneously solving the following equations: $d^G_c = s^G_c$ (equations (5) and (14)), $d_{gt} = s_{gt}$ (equations (4) and (15)),

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[21] The software program Mathematica 8.0 was used to simultaneously solve the equations.

$p_c^G = p_c^{fG} + mm_c$, $p_{gt} = p_{gt}^f + mm_{gm}$ and $s_{gt} = y_{gt}$. Equations (23), (24) and (25) give the inverse demand for GM[G] seed, the retail price of the conventional and the retail price of the GM[G] products under GURTs.

$$w_{gt} = V + W_c + \beta - \gamma + mm_c - mm_{gm} - (\beta - \gamma + \mu) y_{gt} \tag{23}$$

$$p_c^G = W_c + \beta + mm_c - (\beta - \gamma) y_{gt} \tag{24}$$

$$p_{gt} = V + W_c + \beta + mm_c - (\beta - \gamma + \mu) y_{gt} \tag{25}$$

Monopoly decisions under TUAs

Under TUAs the monopolist decides how to price the GM seed or, equivalently, how much to supply in the market, as well as how much effort to exert to identify farmers that violate their licensing agreements. The monopoly profits are given as the summation of the period one and period two monopoly profits, $\Pi_m^{TUAs} = \pi_{gm1} + r\pi_{gm2}$, where r is the discount rate. Recall that the monopolist cannot tell ex-ante which farmers could violate their TUAs and illegally save and replant seed.[22]

To determine the monopoly profits in the two periods, we assume that the marginal cost of producing GM seed is constant and equal to zero and the cost of enforcing the TUAs is increasing in the effort at an increasing rate; these costs are given by $c_A = \varphi\varepsilon^2$ where $\varphi > 0$, $c_A'(\varepsilon) \geq 0$ and $c_A''(\varepsilon) \geq 0$ and for simplicity we set $\varphi = 1$. Also note that at this point all fixed costs that have been incurred for the production of the new GM seed (e.g., R&D costs) are sunk.

Given the above, in period one, where farmers do not have the option to save GM seed, the monopolist's profit maximization problem is given by equation (26):

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[22] If the monopolist could tell ex-ante which farmers would not violate their TUAs he would maximize profits by price discriminating; charging non-violators the period one price in all periods and charging only those that could violate their TUAs the period two price.

$$\max_{y_{gm1}} \ \pi_{gm1} = w_{gm1} y_{gm1} = (V + W_c + \beta - \gamma + mm_c - mm_{gm} - (\beta - \gamma + \lambda) y_{gm1}) y_{gm1} \tag{26}$$

where w_{gm1} is the inverse derived demand for GM seed given by equation (17). The first order conditions (F.O.C.) for a maximum of equation (26) yield the optimal quantity of GM seed supplied in period one, $y^*_{gm1} = \dfrac{V + W_c + mm_c - mm_{gm} + \beta - \gamma}{2(\beta - \gamma + \lambda)}$. Substituting the optimal solution into equations (17), (18) and (19) and into the monopolist's profit function gives the equilibrium GM seed price, retail prices of the conventional and new GM product and monopoly profits in period one:

$$w^*_{gm1} = \frac{1}{2}(V + W_c + mm_c - mm_{gm} + \beta - \gamma) \tag*{(17)'}$$

$$p^*_{c1} = \frac{(\beta - \gamma + 2\lambda)W_c - (\beta - \gamma)V + (\beta - \gamma)mm_{gm} + (\beta - \gamma + 2\lambda)mm_c + \beta^2 - \gamma^2 + 2\beta\lambda}{2(\beta - \gamma + \lambda)} \tag*{(18)'}$$

$$p^*_{gm1} = \frac{1}{2}(V + W_c + mm_c + mm_{gm} + \beta + \gamma) \tag*{(19)'}$$

$$\pi^*_{gm1} = \frac{(V + W_c + mm_c - mm_{gm} + \beta - \gamma)^2}{4(\beta - \gamma + \lambda)} \tag*{(26)'}$$

As one would expect, the greater is the value consumers place on the enhanced functional attributes of the GM product (V), the greater is the price the monopolist can charge for the GM seed, his profits from selling the seed, as well as the retail price of the GM product and the farm price of the GM crop (recall that $p^*_{c1} = p^{f*}_{c1} + mm_c$ and $p^*_{gm1} = p^{f*}_{gm1} + mm_{gm}$).

In period two, where some farmers may choose to illegally save GM seed, the monopolist chooses the profit maximizing levels of output, y_{gm2} and enforcement, ε. The period two profits are given by equation (27):

$$\max_{y_{gm2,\varepsilon}} \ \pi_{gm2} = w_{gm2}y_{gm2} - c_A + \int_{Z_c}^{Z_{gm}} \rho h dZ = w_{gm2}y_{gm2} - \varepsilon^2 + \varepsilon h(Z_{gm} - Z_c) \qquad (27)$$

The second term in equation (28) gives the costs of enforcing the TUAs and the third term is the expected payment received from farmers who are caught violating their TUAs. Substituting the derived demand for GM seed in period two, given by equation (20), and the supply of GM crop produced with illegally saved seed, given by equation (11) (recall that $\rho = \varepsilon$ and $s_{gm}^{c} = Z_{gm} - Z_c$) into equation (27) and taking the F.O.C for a maximum of equation (27) yields the optimal output and enforcement levels in period two, $y_{gm2}^{*} = \frac{c_s + \alpha\gamma - \gamma}{2(\alpha\gamma - \gamma)}$, $\varepsilon^{*} = \frac{h(V + W_c - c_s + mm_c - mm_{gm} + \beta - \alpha\gamma)}{2(h^2 + \beta - \alpha\gamma + \lambda)}$. Substituting the optimal solutions into equations (20), (21) and (22) and (27) gives the equilibrium GM seed price, retail price for the conventional and GM product and monopoly profits in period two:

$$w_{gm2}^{*} = \frac{h^2(V + W_c + mm_c - mm_{gm} + \beta - \gamma) + (\beta - \alpha\gamma + \lambda)(c_s + (\alpha\gamma - \gamma))}{2(h^2 + \beta - \alpha\gamma + \lambda)} \qquad (20)'$$

$$p_{c2}^{*} = Nc_s - K(V - mm_{gm}) + \Lambda(mm_c + W_c) + M \qquad (21)'$$

$$p_{gm2}^{*} = \frac{h^2(V + W_c + mm_c + mm_{gm} + \beta + \gamma) + (c_s + 2mm_{gm} + \gamma + \alpha\gamma)(\beta - \alpha\gamma + \lambda)}{2(h^2 + \beta - \alpha\gamma + \lambda)} \qquad (22)'$$

$$\pi_{gm2}^{*} = \pi(V, W_c, c_s, mm_c, mm_{gm}, h, \alpha, \beta, \gamma, \lambda) \qquad (27)'$$

The expressions for the parameters K, Λ, N, and M and for the period two monopoly profits are given in the Appendix.

The greater is the penalty paid by farmers who are caught violating their TUAs (h), the costs of saving seed (c_s), the seed related costs of producing the conventional product (W_c) and the value consumers place on the functional attribute of the GM product (V), the greater is the price the monopolist can charge for GM seed and the price consumers will pay for the GM product in period two (see the Appendix for a proof). As shown in the Appendix, the monopoly profits in period two are increasing in the penalty h, the value of functional attribute V and the seed cost of the conventional product W_c.

A comparison of the seed prices the monopolist charges in period one and period two shows that seed prices are greater in period one where the monopolist does not 'compete' with farmers that illegally save GM seed (see the Appendix for a proof). Thus, in period two, the monopolist has to reduce its seed prices to make seed saving less appealing and capture more of the demand for seed. This finding is consistent with the literature on monopoly pricing of a durable good and the findings of Ambec et al. (2008). A comparison between the period one and period two retail prices of the GM product shows that the retail price of the GM product (and subsequently the price farmers' receive for producing the GM crop) is also higher in period one (see Appendix). A comparison of the seed supplier's monopoly profits between the two periods shows that for some parameter values profits in period two can exceed profits in period one.

Monopoly decisions under GURTs

When the monopolist sells the new GM seed variety with GURTs, he no longer has to compete with farmers that illegally save GM seed. The monopolist will thus charge the same seed price/supply the same quantity of seed in each period and earn the same level of profit. We assume that the marginal cost of producing the GM^G variety is zero, as in the case where seed is produced without GURTs and the costs of inserting GURTs into the new GM variety are fixed costs and, thus, sunk at this stage. The monopolist choses the optimal quantity of seed y_{gt} that maximizes profits in each period, given by:

$$\max_{y_{gt}} \Pi_m^G = w_{gt} y_{gt} = (V + W_c + \beta - \gamma + mm_c - mm_{gm} - (\beta - \gamma + \mu) y_{gt}) y_{gt} \quad (28)$$

where w_{gt} is the inverse derived demand for GM^G seed given by equation (23). The F.O.C. for a maximum of equation (28) yield the optimal quantity of GM^G seed supplied in each period under GURTs, $y_{gt}^* = \frac{V + W_c + mm_c - mm_{gm} + \beta - \gamma}{2(\beta - \gamma + \mu)}$. Substitution of the optimal solution y_{gt}^* and into equations (23), (24), (25) and (28) yields the equilibrium GM^G seed price, conventional product and GM^G product price and monopoly profits in each period under GURTs:

$$w_{gt}^* = \frac{1}{2}(V + W_c + mm_c - mm_{gm} + \beta - \gamma) \quad (23)'$$

$$p_c^{G*} = \frac{(\beta - \gamma + 2\lambda) W_c - (\beta - \gamma) V + (\beta - \gamma) mm_{gm} + (\beta - \gamma + 2\lambda) mm_c + \beta^2 - \gamma^2 + 2\beta\lambda}{2(\beta - \gamma + \mu)} \quad (24)'$$

$$p_{gt}^* = \frac{1}{2}(V + W_c + mm_c + mm_{gm} + \beta + \gamma) \quad (25)'$$

$$\Pi_m^{G*} = \frac{(V + W_c + mm_c - mm_{gm} + \beta - \gamma)^2}{4(\beta - \gamma + \mu)} \quad (28)'$$

2.4 Market equilibrium outcomes under TUAs and under GURTs

We will first compare the market equilibrium outcomes under TUAs in period one and under GURTs since these two cases share some notable similarities; under both cases producers cannot save and illegally replant proprietary GM seed, which implies that, the seed provider does not have to incur monitoring and enforcement costs to identify violators.

A comparison of the equilibrium seed prices (equations (17)' and (23)') shows that the seed supplier will charge the same price for GM seed under TUAs in period one and for GM^G seed in each period under GURTs ($w_{gm1}^* - w_{gt}^* = 0$). Consumers will pay the same prices for the GM product in period one and for the GM^G product in each period under GURTs ($p_{gm1}^* - p_{gt}^* = 0$)

(equations (19)' and (25)') which implies that farm prices will also be the same given our assumption that the marketing margin is the same under TUAs and under GURTs ($p^{f*}_{gm1} = p^{f*}_{gt}$). Given that farm prices and seed prices are the same for the GM crop in period one and the GM^{G} crop, the producer net returns will also be the same, $\Pi_{gm1} = \Pi_{gt}$ (see equation (6)). Note, however, that the monopolist will sell more seed in period one under TUAs than in each period under GURTs ($y^{*}_{gm1} > y^{*}_{gt}$) (see Appendix) which, given our earlier assumption of fixed proportions in production implies that more farmers will produce the GM crop in period one under TUAs than the GM^{G} crop in each period under GURTs ($s_{gm1} > s_{gt}$). Consequently, the monopoly profits of the seed supplier are greater in period one under TUAs than in each period under GURTs. An examination of the difference in monopoly profits (see Appendix) shows that this mainly stems from consumer attitudes towards GURTs.

The retail and farm prices of the conventional product are lower in period one under TUAs than in each period under GURTs ($p_{c1} = p^{G}_{c}$, $p^{f*}_{c1} = p^{fG*}_{c}$ see Appendix) which, given our assumption that the seed related costs of producing the conventional product stay unchanged, implies that the period one net returns for farmers producing the conventional crop are lower than their returns under GURTs ($\Pi_{c1} < \Pi^{G}_{c}$). It is easy to show (see Appendix) that fewer farmers will produce the conventional crop and fewer consumers will consume the conventional product in period one under TUAs compared to in each period under GURTs ($s_{c1} < s^{G}_{c}$ and $d_{c1} < d^{G}_{c}$, respectively) while more consumers will consume the GM rather than the GM^{G} product ($d_{gm1} > d_{gt}$).

The intuition behind these findings is that even though the number of options farmers face is the same under both cases, the nature of the options is different. For instance, under TUAs some farmers (potential violators) may purchase GM seed in period one with the intent to save and replant in the following period. Since under GURTs this option does not exist, these potential violators may choose to produce the conventional crop rather than purchase GM^G seed under GURTs.[23]

The comparison of the market equilibrium outcomes under TUAs in period two and in each period under GURTs is less straightforward. It is easy to show (see Appendix) that the equilibrium price of GM seed in period two under TUAs is lower than the equilibrium price of GM^G seed in each period under GURTs ($w^*_{gm2} < w^*_{gt}$), and the retail and farm price of the GM product is lower than the price of the GM^G product ($p^*_{gm2} < p^*_{gt}$). However, the difference between the seed prices is the same as the difference between the retail/farm prices so the net returns received by farmers who legally produce the GM product (with purchased seed) in period two are equal to the net returns of farmers producing the GM^G product under GURTs ($\Pi_{gm2} = \Pi_{gt}$). As discussed previously, the seed supplier has to lower the price of GM seed in period two, compared to the price of GM^G seed to compete with GM farmers that illegally save seed. It is not possible to compare the supply of GM and GM^G seed, the monopoly profits and the retail and farm prices of the conventional product under TUAs in period two and under GURTs without knowledge of the magnitude of the exogenous parameters. However, it is important to mention that for certain parameter values monopoly profits can be greater under TUAs in period two than under GURTs.

3. Welfare effects under TUAs and under GURTs

This section compares the welfare outcomes under TUAs and GURTs for consumers and

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[23] As was previously discussed, we assume that farmers know whether the seed they buy has GURTs and what that implies for their ability to save and replant seed.

farmers; changes in the welfare/profits of the monopolist seed provider were discussed in section 2.4. Since two periods have to be considered under TUAs we compare the welfare outcomes of each period to those under GURTs.

3.1 Consumer welfare effects

Figure 5 illustrates differences in consumer welfare between TUAs in period one and GURTs in each period. As discussed in section 2.4, a comparison of the equilibrium outcomes under TUAs in period one and under GURTs shows that, $p_{gm1} = p_{gt}$, $p_{c1} < p_c^G$. These imply that $U_{gm1}(A=0) = U_{gt}(A=0)$ and since the slope of the GM^G utility schedule is greater than the slope of the GM utility schedule ($\mu > \lambda$), the utility curve U_{gt} will be below the U_{gm1} utility curve for all A values. Also, the U_c^G utility curve will be below the U_{c1} utility curve for A values as shown in figure 5. This implies that welfare will be lower for all consumers with values $A \in (0,1]$ under GURTs (consumers with $A = 0$ do not experience any welfare change); the welfare change is given by the dotted area between the effective utility schedules under TUAs (kinked dashed curve) and under GURTs (kinked solid curve). The lower aggregate consumer utility results from the higher levels of aversion to the GURTs product and the higher price of the conventional product under GURTs.

From the discussion in section 2.4 we know that $p_{gm2} < p_{gt}$ which implies that the U_{gm1} utility schedule is above the U_{gt} utility schedule for all A values. Given that the relationship between the retail prices of the conventional product under TUAs, in period two, and under GURTs cannot be determined without knowledge of the magnitude of the exogenous parameters the following cases must be considered. If $p_{c2} < p_c^G$ then the U_c^G utility curve will be below the U_{c1} utility curve for A values and the welfare differences between the two scenarios will be similar to those depicted by figure 5. If, however, $p_{c2} > p_c^G$ then the U_c^G utility curve will be above the U_{c1} utility curve for A values and as depicted in figure 6, welfare will be lower for some consumers and higher for others under GURTs compared to TUAs in period two. Specifically, consumer with relatively low aversion to interventions in the production process (low A values) will have lower welfare and those with relatively high aversion to interventions in the production process (intermediate to high A values) will have higher welfare under GURTs than under TUAs in period two.[24] Finally, if $p_{c2} = p_c^G$ there will be no difference in the utility schedules of the conventional product, $U_{c1} = U_c^G$ which implies lower welfare for consumers with low A values and no welfare changes for consumers with intermediate to high A values under GURTs compared to TUAs, in period two (this case is not shown graphically).

3.2 Farmer welfare effects

Figure 7 illustrates differences in farmer welfare between TUAs, in period one and GURTs. As discussed in section 2.4, $w_{gm1} = w_{gt}$, $p_{gm1}^f = p_{gt}^f$ and $p_{c1}^f < p_c^{fG}$ which imply that the Π_{c1} net returns schedule is below the Π_c^G net returns schedule and $\Pi_{gm1} = \Pi_{gt}$ for all Z values. This results in greater welfare for some farmers under GURTs; these are all the farmers that under TUAs, in period one, would produce the conventional product (farmers with very low Z values) as well as who would produce the new GM product under TUAs, in period one, but would produce the conventional product under GURTs (farmers with intermediate Z values). The rest of the farmers, those with intermediate to high Z values, would not experience any welfare

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[24] The analysis is conducted under the assumption that consumers are uniformly distributed with respect to the A values. If the distribution of consumers across A is skewed, the magnitude of the welfare differences depends on the skewness of the distribution. For instance, in the case depicted in Figure 6, if relatively more consumers have high aversion to interventions in the production process (A values are close to one), more consumers would consume the GM^G product and experience greater welfare under GURTs compared to TUAs, in period two.

change. The difference in farmer welfare is given by the hatched area between the effective net returns schedules under TUAs (kinked dashed curve) and under GURTs (kinked solid curve) in figure 7.[25]

From the comparison of the equilibrium outcomes under TUAs in period two and under GURTs discussed in section 2.4 we know that $w_{gm2} < w_{gt}$, $p^f_{gm2} < p^f_{gt}$ and $\Pi_{gm2} = \Pi_{gt}$ since $p^f_{gt} - p^f_{gm2} = w_{gt} - w_{gm2}$. Since the relationship between the farm prices of the conventional crop in period two, under TUAs and under GURTs cannot be determined without knowledge of the magnitude of the exogenous parameters, the following cases must be considered. If $p^f_{c2} < p^{Gf}_c$, then the net returns schedule Π_{c2} is below the Π^G_c net returns schedule for all Z values and the welfare differences between the two scenarios will be similar to those depicted in figure 7. If $p^f_{c2} > p^{Gf}_c$ then the net returns schedule Π_{c2} will be above the Π^G_c net returns schedule for all Z values and welfare will be lower for farmers with low Z values under GURTs compared to TUAs in period two; there will be no welfare difference for farmers with intermediate to high Z values. This case is illustrated in figure 8. Finally, if $p^f_{c2} = p^{Gf}_c$ there is no difference in farmer welfare between GURTs and TUAs in period two.

4. Concluding remarks

An analytical model of heterogeneous consumers and producers was developed to examine the market equilibrium and welfare outcomes of TUAs and GURTs. In our model, a monopolist seed supplier, has developed a new GM seed variety with enhanced agronomic characteristics and functional properties desirable to consumers and decides whether to supply it using TUAs (status

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[25] The analysis is conducted under the assumption that producers are uniformly distributed in the interval $Z \in [0,1]$. If the distribution of producers between Z values is skewed, the magnitude of the welfare differences depends on the skewness of the distribution. For instance, in Figure 7, if relatively more producers have Z values closer to zero, then welfare differences will be greater.

quo) or GURTs. Two periods are considered under TUAs; period one where farmers cannot yet save and replant proprietary GM seed and period two where some farmers may save and illegally replant GM seed.

Analytical results show that the monopolist will charge a lower price for GM seed in period two compared to period one under TUAs while seed prices are the same under TUAs in period one and under GURTs. The monopolist reduces the price of seed in period two to compete with farmers that may illegally save and replant seed. However, monopoly profits are higher under TUAs in period one than under GURTs as consumer aversion to GURTs affects the demand for the GM^G product, farm prices and consequently the demand for GM^G seed. Also, consumer welfare is greater for all consumers under TUAs in period one compared to GURTs while aggregate farmer welfare is greater under GURTs; farmers with low production costs are those that benefit under GURTs while the welfare of those with intermediate to high production costs is not affected. Under certain parameter values, monopoly profits can be higher under TUAs in period two than under GURTs and while in most cases aggregate consumer welfare is lower under GURTs than under TUAs for certain parameter values some consumers may experience greater welfare under GURTs; consumers with high levels of aversion to interventions in the production process. Finally, farmer welfare can be higher or lower under GURTs depending on the magnitude of the exogenous parameters.

Our findings suggest that consumer acceptance of GURTs is critical for the adoption of the technology by farmers and consequently determines whether a seed supplier will find it optimal to introduce the technology. In addition, the markets for the products and crops available to consumers and farmers should be taken into account when analyzing the market and welfare effects of the technology.

List of Figures

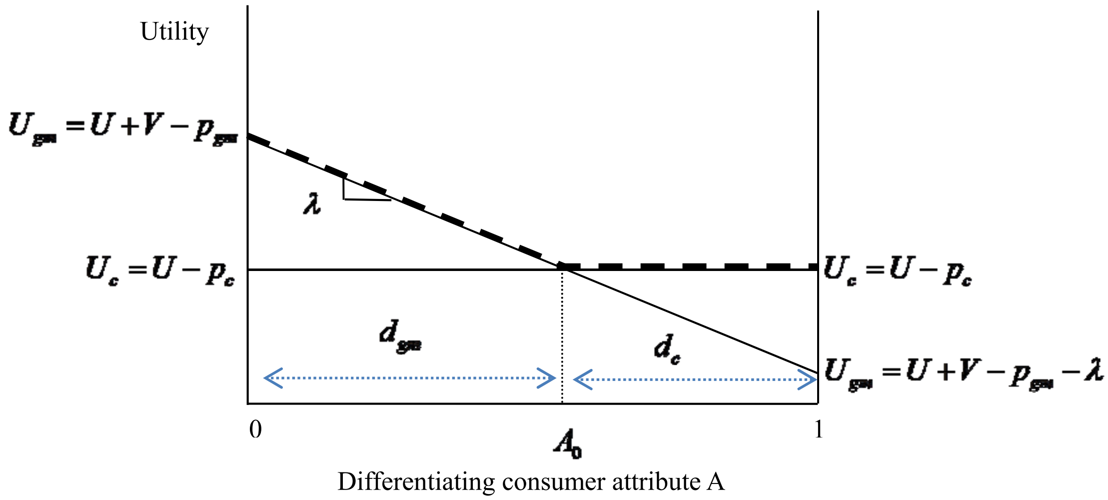

Figure 1. Consumer purchasing decisions, utility and welfare under TUAs - Status Quo

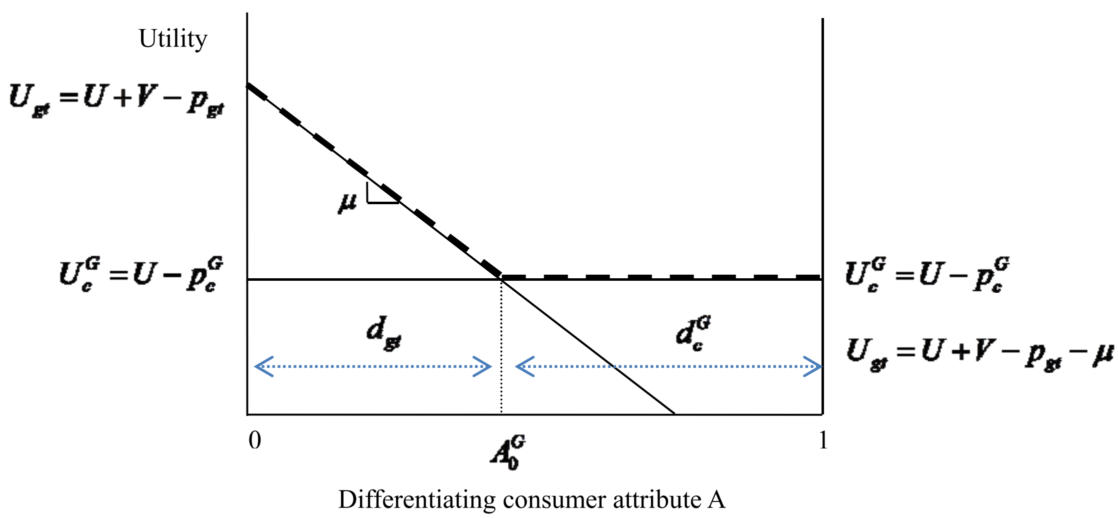

Figure 2. Consumer purchasing decisions, utility and welfare under GURTs

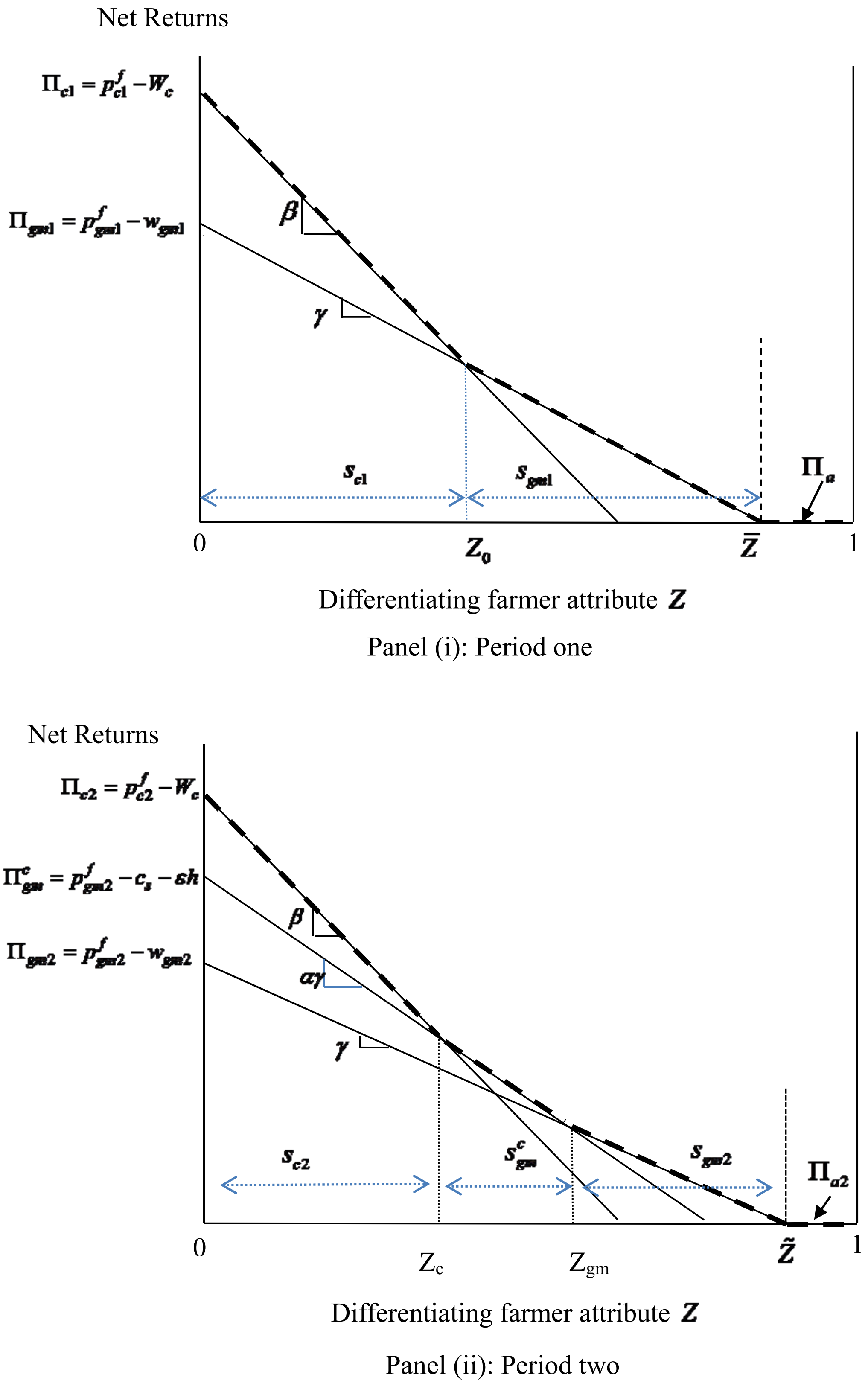

Figure 3. Farmer net returns and production decisions under TUAs

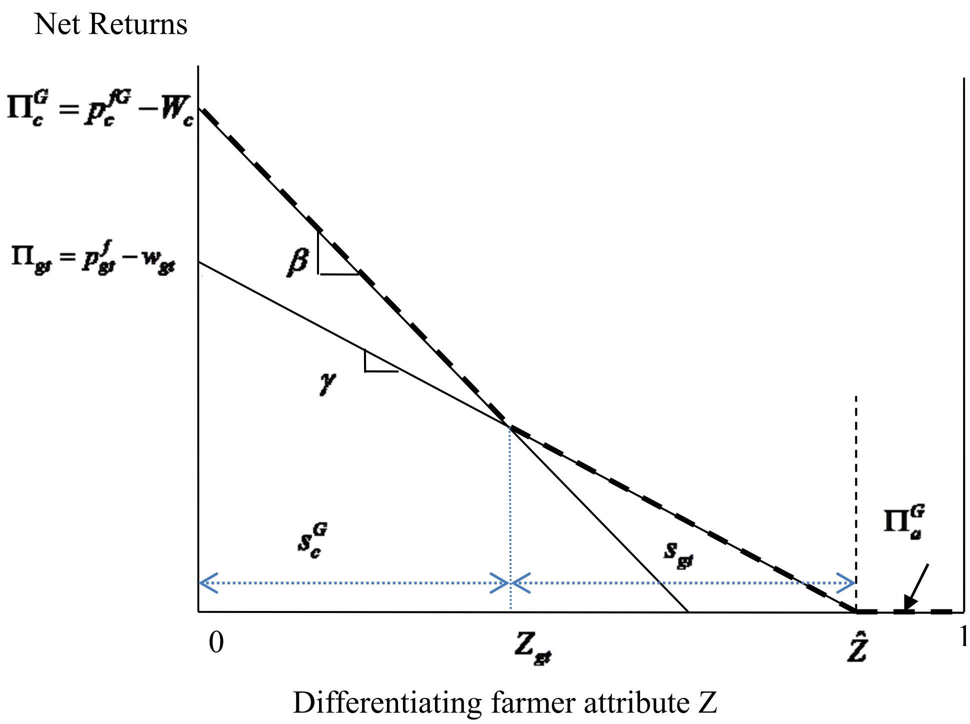

Figure 4: Farmer net returns and production decisions under GURTs

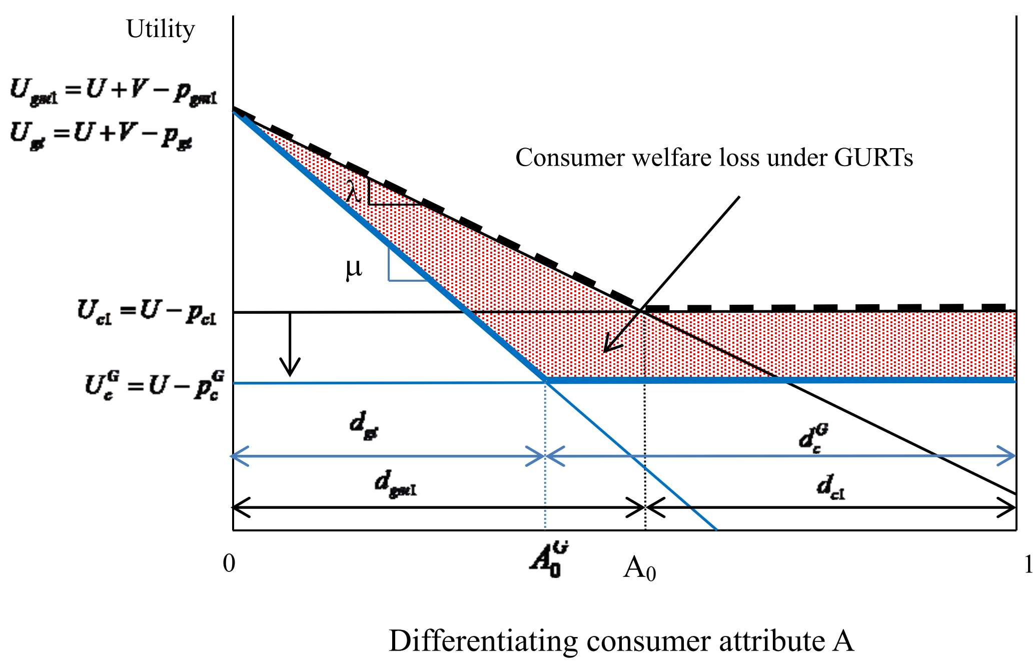

Figure 5. Consumer welfare changes: TUAs, in period one, versus GURT

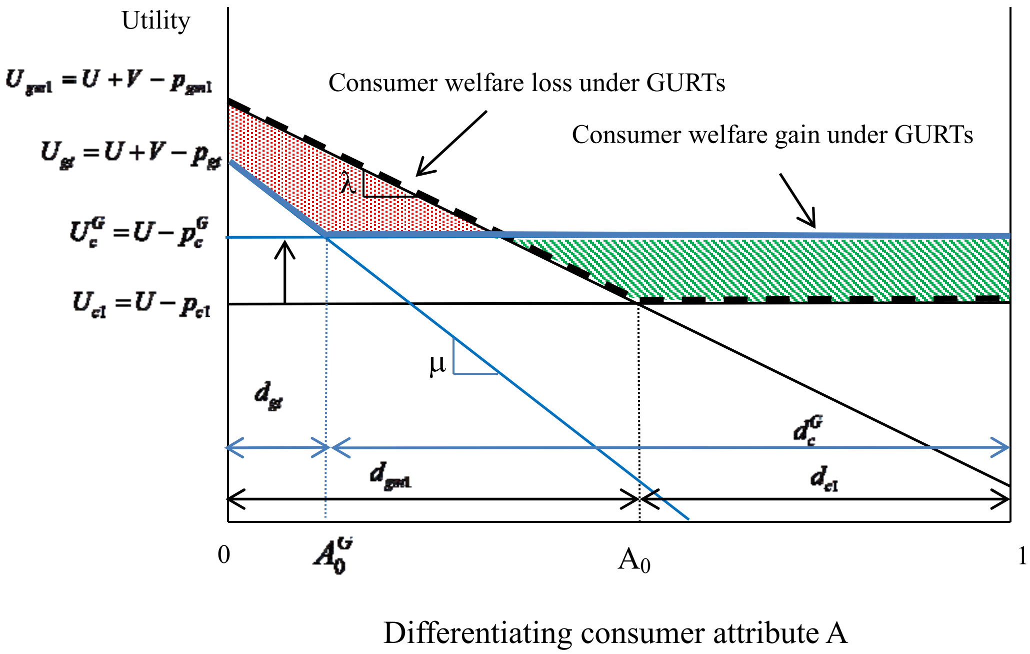

Figure 6. Consumer welfare changes: TUAs, in period two versus GURTs

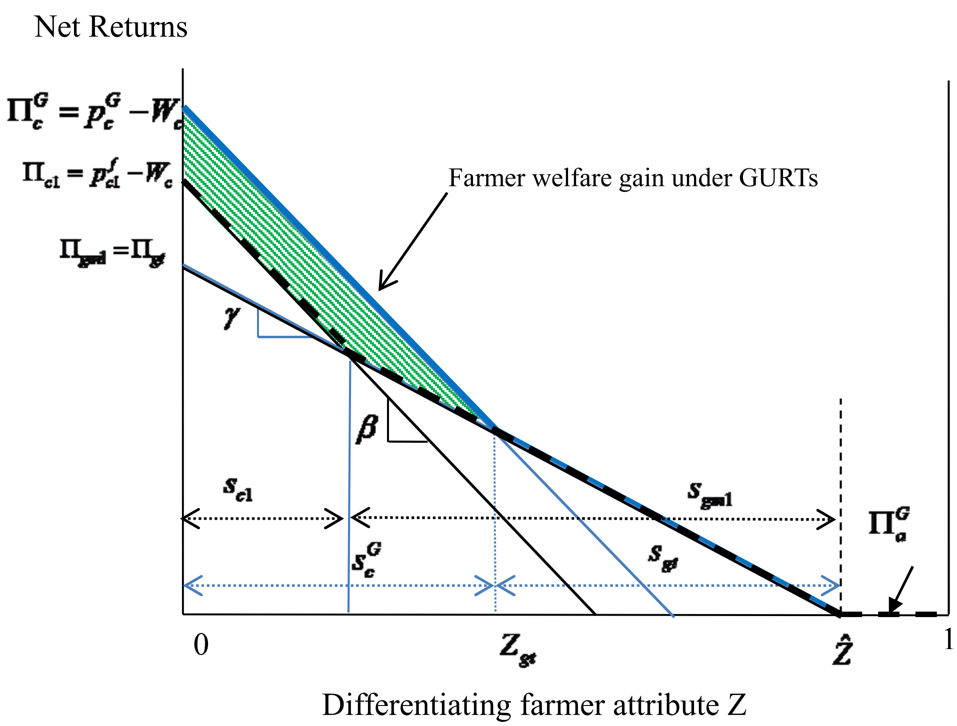

Figure 7: Farmer welfare changes: TUAs, period one, versus GURTs

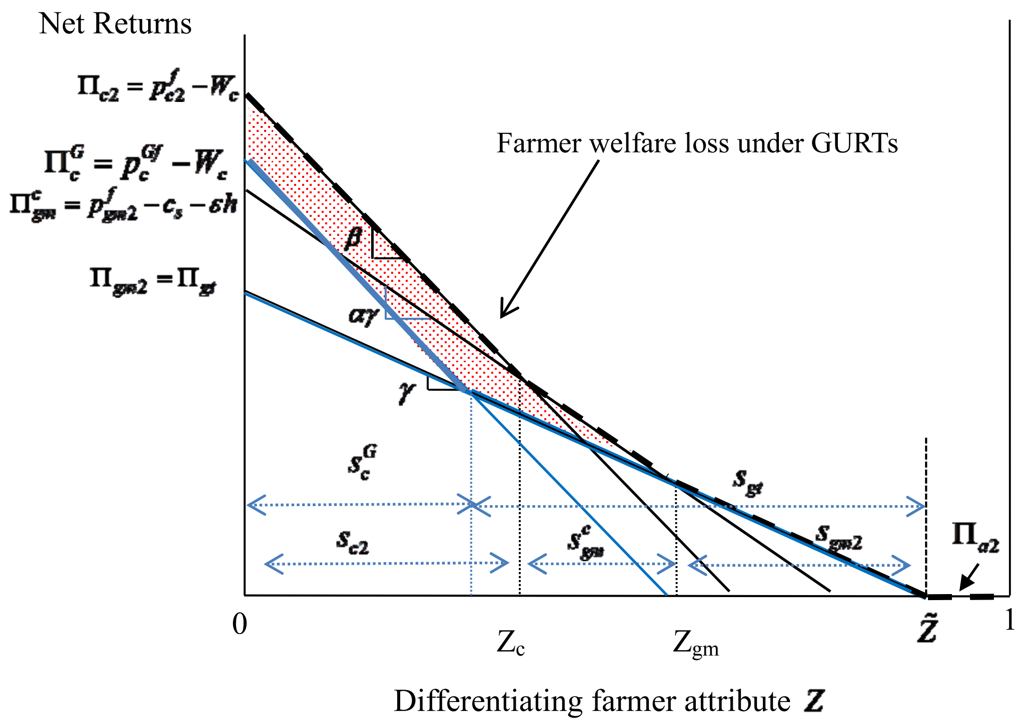

Figure 8. Changes in farmer welfare: TUAs, period two versus GURTs when $p_c^{Gf} < p_{c1}^f$

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APPENDIX

Parameters K, Λ, N and M and monopoly profits under TUAs in period two.

The expressions for parameters K, Λ, N and M are given by:

$$K = \frac{(\beta - \alpha\gamma)(h^2 + 2(\beta - \alpha\gamma + \lambda))}{2(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda)}, \ \Lambda = \frac{2\lambda(\beta - \alpha\gamma + \lambda) + h^2(\beta - \alpha\gamma + 2\lambda)}{2(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda)},$$

$$N = \frac{\beta^2 - 2\alpha\beta\gamma + \alpha^2\gamma^2 - \lambda(h^2 + \lambda)}{2(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda)} \text{ and}$$

$$M = \frac{(\beta^2(\gamma + \alpha\gamma + 2\lambda) - 2\beta(\alpha^2\gamma^2 + \alpha\gamma(\gamma + \lambda) - \lambda(\gamma + \lambda))}{2(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda)} + \frac{\gamma(\alpha^2\gamma^2 + \alpha^3\gamma^2 + \lambda^2 - \alpha\lambda(2\gamma + \lambda)) + h^2(\beta^2 + \beta(\gamma - \alpha\gamma + 2\lambda) + \gamma(\lambda - \alpha(\gamma + \lambda)))}{2(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda)}$$

The monopoly profits under TUAs in period two are given by:

$$\pi^*_{gm2} = \frac{2c_s(-h^2(mm_c - mm_{gm} + V + W_c - \lambda) + (\beta - \alpha\gamma + \lambda)^2) + c_s{}^2(h^2(\beta - \gamma + \lambda) + (\beta - \alpha\gamma + \lambda)^2)}{4(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda))} + \frac{(\alpha\gamma - \gamma)(\beta - \alpha\gamma + \lambda)^2}{4(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda))} + h^2(\frac{mm_c{}^2 + mm_{gm}{}^2 + V^2 + 2VW_c + W_c{}^2 + 2V\beta + 2W_c\beta + \beta^2}{4(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda))} + \frac{-2V\alpha\gamma - 2W_c\alpha\gamma - \beta\gamma - \alpha\beta\gamma + \alpha\gamma^2 - 2mm_{gm}(V + W_c + \beta - \alpha\gamma) - 2mm_c(mm_{gm} - V - W_c - \beta + \alpha\gamma) - \gamma\lambda + \alpha\gamma\lambda}{4(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda))})$$

Demand and Supply Constraints for co-existence

As it will become evident below, to conduct comparative statics analysis and compare the equilibrium outcomes under TUAs and under GURTs, we first need to substitute the equilibrium prices into the demand and supply constraints for co-existence, under TUAs and under GURTs, and solve for the parameter values. These substitutions yield:

Period one demand constraints (TUAs): $p_{gm1} - p_{c1} < V < p_{gm1} - p_{c1} + \lambda \Rightarrow$

$-mm_c + mm_{gm} - W_c - \beta + \gamma < V < -mm_c + mm_{gm} - W_c + \beta - \gamma + 2\lambda$.

Period two demand constraints (TUAs): $p_{gm2} - p_{c2} < V < p_{gm2} - p_{c2} + \lambda \Rightarrow$

$$c_s - mm_c + mm_{gm} - W_c - \beta + \alpha\gamma < V < \frac{1}{h^2 + 2\beta - 2\alpha\gamma + 2\lambda}(c_s h^2 - h^2 mm_c + h^2 mm_{gm} - h^2 W_c + 2c_s\beta + h^2\beta - 2mm_c\beta + 2mm_{gm}\beta - 2W_c\beta - 2c_s\alpha\gamma - h^2\alpha\gamma + 2mm_c\alpha\gamma - 2mm_{gm}\alpha\gamma + 2W_c\alpha\gamma + 2c_s\lambda + 2h^2\lambda - 2mm_c\lambda + 2mm_{gm}\lambda - 2W_c\lambda + 2\beta\lambda - 2\alpha\gamma\lambda + 2\lambda^2)$$

which can be rewritten as:

$$c_s + mm_{gm} + \alpha\gamma < mm_c + V + W_c + \beta \;\wedge\; (h^2 + 2(\beta - \alpha\gamma + \lambda))(h^2(mm_c - mm_{gm} + V + W_c - \beta + \alpha\gamma - 2\lambda) + 2(mm_c - mm_{gm} + V + W_c - \lambda)(\beta - \alpha\gamma + \lambda) - c_s(h^2 + 2(\beta - \alpha\gamma + \lambda))) < 0.$$

Demand constraints under GURTs: $p_{gt} - p_c^G < V < p_{gt} - p_c^G + \mu \Rightarrow$

$$-mm_c + mm_{gm} - W_c - \beta + \gamma < V < -mm_c + mm_{gm} - W_c + \beta - \gamma + 2\mu .$$

Comparative statics on period two equilibrium prices and profits under TUAs

To determine the effect of the parameters h, c_s, W_c **and** V on equilibrium seed prices, retail prices and period two profits, we first substitute the equilibrium prices into the period two demand constraints for co-existence (i.e.,). The substitution yields: Then we can show that

$$\frac{\partial w_{gm2}^*}{\partial h} = -\frac{h(c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma)(\beta - \alpha\gamma + \lambda)}{(h^2 + \beta - \alpha\gamma + \lambda)^2} > 0 \text{; since}$$

$c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma < 0$ from the first part of the period two demand constraint while $\beta > \alpha\gamma$ from our model assumptions. It is straightforward to show that:

$$\frac{\partial w_{gm2}^*}{\partial c_s} = \frac{\beta - \alpha\gamma + \lambda}{2(h^2 + \beta - \alpha\gamma + \lambda)} > 0, \quad \frac{\partial w_{gm2}^*}{\partial W_c} = \frac{\partial w_{gm2}^*}{\partial V} = \frac{h^2}{2(h^2 + \beta - \alpha\gamma + \lambda)} > 0.$$

$$\frac{\partial p_{gm2}^*}{\partial h} = -\frac{h(c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma)(\beta - \alpha\gamma + \lambda)}{(h^2 + \beta - \alpha\gamma + \lambda)^2} > 0, \quad \frac{\partial p_{gm2}^*}{\partial c_s} = \frac{\beta - \alpha\gamma + \lambda}{2(h^2 + \beta - \alpha\gamma + \lambda)} > 0$$

$\frac{\partial p_{gm2}^*}{\partial W_c} = \frac{\partial p_{gm2}^*}{\partial V} = \frac{h^2}{2(h^2 + \beta - \alpha\gamma + \lambda)} > 0$. From the above we note that, $\frac{\partial w_{gm2}^*}{\partial h} = \frac{\partial p_{gm2}^*}{\partial h}$, $\frac{\partial w_{gm2}^*}{\partial c_s} = \frac{\partial p_{gm2}^*}{\partial c_s}$ and $\frac{\partial w_{gm2}^*}{\partial W_c} = \frac{\partial w_{gm2}^*}{\partial V} = \frac{\partial p_{gm2}^*}{\partial W_c} = \frac{\partial p_{gm2}^*}{\partial V}$, i.e., the effect of these parameters on the equilibrium GM seed price and retail GM product price is the same.

The effect of the parameters h, W_c and V on period two profits is given by:

$$\frac{\partial \pi^*_{gm2}}{\partial h} = \frac{h(-c_s + mm_c - mm_{gm} + V + W_c + \beta - \alpha\gamma)^2}{2(h^2 + \beta - \alpha\gamma + \lambda)^2} > 0$$

$$\frac{\partial \pi^*_{gm2}}{\partial V} = \frac{\partial \pi^*_{gm2}}{\partial W_c} = \frac{h^2(-c_s + mm_c - mm_{gm} + V + W_c + \beta - \alpha\gamma)}{2(\beta - \alpha\gamma + \lambda)(h^2 + \beta - \alpha\gamma + \lambda)} > 0$$, where the nominator is positive

from the first part of the period two demand constraint.

Difference in seed and retail prices under TUAs

Under TUAs the difference in seed prices between period one and period two are given by:

$$w^*_{gm1} - w^*_{gm2} = -\frac{(c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma)(\beta - \alpha\gamma + \lambda)}{2(h^2 + \beta - \alpha\gamma + \lambda)} > 0$$ since the term

$c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma < 0$, from the first part of the period two demand constraints.

Similarly, the difference in retail prices for the GM product between the two periods is given by:

$$p^*_{gm1} - p^*_{gm2} = -\frac{(c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma)(\beta - \alpha\gamma + \lambda)}{2(h^2 + \beta - \alpha\gamma + \lambda)} > 0.$$

Comparison of equilibrium outcomes under TUAs and under GURTs

Period one (TUAs) versus GURTs

The difference in the equilibrium seed supply of GM and GM^G seed in period one under TUAs and under GURTs, respectively, is given by:

$$y^*_{gm1} - y^*_{gt} = -\frac{(V + W_c + mm_c - mm_{gm} + \beta - \gamma)(\lambda - \mu)}{2(\beta - \gamma + \lambda)(\beta - \gamma + \mu)} > 0$$. The first term in the nominator is

positive from the period one demand constraints for co-existence, while the second term is negative from our model assumptions.

The difference in period one TUAs and GURTs monopoly profits is given by:

$$\pi^*_{gm1} - \Pi^G_m = -\frac{(mm_c - mm_{gm} + V + W_c + \beta - \gamma)^2(\lambda - \mu)}{4(\beta - \gamma + \lambda)(\beta - \gamma + \mu)} > 0$$, the sign of the terms is as previously explained.

The difference in the equilibrium prices of the conventional product in period one under TUAs and in each period under GURTs is given by:

$$p_{c1} - p^G_c = \frac{(\beta - \gamma)(mm_c - mm_{gm} + V + W_c + \beta - \gamma)(\lambda - \mu)}{2(\beta - \gamma + \lambda)(\beta - \gamma + \mu)} < 0$$, the sign of the terms is as explained previously.

The difference in the supply of the conventional crop and the demand for the conventional product in period one under TUAs and in each period under GURTs is given by:

$$s_{c1} - s^G_c = \frac{(mm_c - mm_{gm} + V + W_c + \beta - \gamma)(\lambda - \mu)}{2(\beta - \gamma + \lambda)(\beta - \gamma + \mu)} < 0$$ and

$$d_{c1} - d^G_c = \frac{(mm_c - mm_{gm} + V + W_c + \beta - \gamma)(\lambda - \mu)}{2(\beta - \gamma + \lambda)(\beta - \gamma + \mu)} < 0.$$

The demand for the GM product in period one under TUAs is greater than the demand for the GM^G product in each period under GURTs since:

$$d_{gm1} - d_{gt} = -\frac{(mm_c - mm_{gm} + V + W_c + \beta - \gamma)(\lambda - \mu)}{2(\beta - \gamma + \lambda)(\beta - \gamma + \mu)} > 0.$$

<u>Period two (TUAs) versus GURTs</u>

The difference in the equilibrium prices of GM and GM^G seed and in the retail prices of the GM and GM^G products in period two under TUAs and under GURTs, respectively, is given by:

$$w^*_{gm2} - w^*_{gt} = \frac{(c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma)(\beta - \alpha\gamma + \lambda)}{2(h^2 + \beta - \alpha\gamma + \lambda)} < 0$$ and

$$p^*_{gm2} - p^*_{gt} = \frac{(c_s - mm_c + mm_{gm} - V - W_c - \beta + \alpha\gamma)(\beta - \alpha\gamma + \lambda)}{2(h^2 + \beta - \alpha\gamma + \lambda)} < 0$$. The first term in the

nominator is negative (from the period two demand constraints) and the rest of the terms are positive.

The difference between the equilibrium supply of GM and GM^G seed is given by:

$y^*_{gm2} - y^*_{gt} = \frac{c_c + \alpha\gamma - \gamma}{2(\alpha - 1)\gamma} - \frac{mm_c - mm_{gm} + V + W_c + \beta - \gamma}{2(\beta - \gamma + \mu)}$ since both terms are positive the sign is inconclusive. If $c_s > \frac{(\alpha\gamma - \gamma)(mm_c - mm_{gm} + V + W_c - \mu)}{\beta - \gamma + \mu}$ then $y^*_{gm2} > y^*_{gt}$.