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Corporate Pricing Strategies with Heterogeneous Adopters: The Case of Herbicide-Resistant Sugar Beet

Koen Dillen
Katholieke Universiteit Leuven

Matty Demont
Africa Rice Center (Africa Rice) and Katholieke Universiteit Leuven

Eric Tollens
Katholieke Universiteit Leuven

In *ex-ante* impact assessment of proprietary seed technologies, the assessor operates under scarce and imperfect data. No market has been established for the new technology and adoption has yet to take place. Recently, the scholarly literature has focused on the importance of accounting for heterogeneity among potential adopters to avoid homogeneity bias in the impact estimates. In this article, we argue that incorporation of heterogeneity in the corporate pricing strategy of the innovation is also needed to avoid a second bias in the welfare estimates—pricing bias. Therefore, a framework is developed which explicitly incorporates heterogeneity of proprietary seed technology valuation among adopters in both the pricing decision and the impact assessment. The results explain the tendency of innovators to engage in third-degree price discrimination if the market structure discourages arbitrage. Finally, the model is applied on the case study of herbicide-resistant sugar beet in the EU-27.

Key words: *ex-ante* impact assessment, GM crops, herbicide resistance, heterogeneity, parametric modeling, monopolistic pricing.

Introduction

Since the commercial introduction of the first generation of genetically modified (GM) crops in agriculture, both the value creation and benefit sharing of these technologies have been of great interest. In contrast to earlier, publicly funded technologies in agriculture, most of the commercially available GM technologies are developed and commercialized by the private sector. The laws and enforcement of intellectual property rights (IPRs) have provided innovating firms with some monopoly power in the market for GM seeds, affecting the value-creation and benefit-sharing of these proprietary seed technologies (Acquaye & Traxler, 2005; Falck-Zepeda, Traxler, & Nelson, 2000; Moschini & Lapan, 1997; Moschini, Lapan, & Sobolevsky, 2000). The first generation of GM crops were introduced more than a decade ago and *ex-post* impact studies have uncovered the global value creation (Brookes & Barfoot, 2009) and benefit sharing (Demont, Dillen, Mathijs, & Tollens, 2007) of these technologies. Regardless of the variability of the impact evidence, Demont et al. (2007) found that, on average, two-thirds of the global benefits of first-generation GM technologies are shared among domestic and foreign farmers and consumers, while only one-third is extracted by the input suppliers (developers and seed suppliers).

Previous research has shown that the heterogeneous character of farmer populations (Weaver, 2004) results in a downward-sloping aggregate derived-demand curve for GM seed technologies (Falck-Zepeda et al., 2000). This suggests that, despite their high value, GM seed innovations can be considered non-drastic (Arrow, 1962) because the monopolist's pricing decision is constrained by the threat of competition (Lemarié & Marette, 2003), leading to restricted monopoly pricing (Weaver & Wesseler, 2004) and reduced adoption. In this article, we argue that the observed benefit-sharing of first-generation GM technologies is a direct reflection of heterogeneity of farmers' technology valuation, constraining pricing strategies of monopolistic technology providers. This is in contrast with earlier research stating that the pricing of biotechnology innovations has a clear strategic dimension (Fulton & Giannakas, 2001).

Oehmke and Wolf (2004) developed a model to assess to what extent observable farmer rents can be explained by adopter heterogeneity in the US Bt cotton market. Although heterogeneity is implicitly captured by *ex-post* adoption data, Demont et al. (2008a) show that *ex-ante* impact assessments need to explicitly account for it in order to avoid homogeneity bias. However, their impact estimates and the model application by Demont and Dillen (2008) are based on fixed, exogenous, technology pricing. In this article, we elaborate on their framework and relax the assumption of exogeneity by introducing alternative corporate pricing strategies. A parametric framework to fully incorporate farmer heterogeneity in *ex-ante* impact assessment of proprietary seed technologies under data scarcity is developed. Within this framework, alternative corporate pricing strategies are simulated to assess the effect of heterogeneity on classic adoption parameters such as profits and adoption. The output of this framework can be aggregated through a trade model—as has been done by Dillen, Demont, and Tollens (2009) in an earlier issue of this journal—to assess the effect of pricing strategies on total welfare distribution. The approach offers both a tool for policy makers to implement *ex-ante* socio-economic assessments with limited resources and for seed technology and gene developers to assess the value of proprietary seed technologies.

The article is organized as follows. In the next section, a theoretical framework for modeling heterogeneity among potential adopters of a new technology protected by IPRs is developed and some comparative statics are derived. In the third and fourth sections, an empirical application on herbicide-resistant (HR) sugar beet in the EU-27 is presented. A final section discusses the theoretical and empirical results of our framework.

Model

We define a technology as a marketable good that allows farmers to surmount an agricultural constraint. Moreover, we introduce the concept of *technology valuation* to represent the willingness to pay (WTP) for the technology, which can include both pecuniary and non-pecuniary attributes (e.g., see Marra & Piggott, 2006). While some articles assess both the irreversible and reversible benefits and costs of the technology to determine the maximum incremental social tolerable irreversible costs (MISTIC) (Demont, Wesseler, & Tollens, 2004; Wesseler, Scatasta, & Nillesen, 2007), this article focuses on the reversible private benefits and costs, as these drive adoption among profit-maximizing farmers. It is important to recognize the fact that the innovation does not happen in a vacuum. Certain innovations alter the nature of production decisions, such as decisions about individual input (e.g., seeds and pesticides) decisions over bundles of complementary inputs (e.g., HR seed complimented with a broad-spectrum herbicide) (Alexander & Goodhue, 2002). Therefore, the value of such technology should be calculated as the value of the new production system as a whole. Previous research showed that the value of a technology is not uniformly distributed among farmers; some realize a profit from the technology and adopt it while others rationally choose not to adopt. In particular, GM seed technologies will pay off differentially depending on field conditions, pest densities, crop rotation and environmental conditions. Moreover, the technology valuation to any particular farm will depend on managerial expertise and local market conditions that condition the profitability of GM seed technologies relative to alternative technologies (Weaver, 2004). Furthermore, technology valuation is affected by the attitude towards risk of the potential adopter. Empirical evidence shows that most farmers are risk averse (e.g., Anderson & Hardaker, 2003). Farmers are averse to being exposed to unexpectedly low returns, and this affects their technology valuation and adoption behavior.

In *ex-post* adoption data of a technology, technology valuation is revealed by adopters through their adoption decisions and technology expenditures. From an *ex-ante* perspective, adoption has not yet occurred and the revealed preference information of a technology is *quasi*-unobservable to the researcher. Stated-preference information can be collected through contingent valuation (CV) analysis. However, this method requires costly survey data, as surveys need to be reproduced in different years and different regions in order to capture both the structural and stochastic foundations of heterogeneity. Moreover, farmer preferences are elicited directly based on hypothetical, rather than actual, scenarios. These constraints severely limit the use of CV analysis in large-scale, *ex-ante* impact assessment under time and resource constraints.

Therefore, we propose a framework that explicitly models heterogeneity of proprietary seed technology valuation among adopters under data scarcity. Just, Hueth, and Schmitz (2004) recommend the use of a probability density function (PDF) to model heterogeneity among producers. We adapt this modeling approach to the case of heterogeneous technology adopters. In *ex-ante* impact assessment, imperfect information is endogenous to the problem and parametric approaches can be used to complete scarce data with estimates based on assumptions, analogy, and theory.

Let x represent farmers' valuation or WTP for a new proprietary seed technology and assume that the new technology is an innovation such that $x > 0$. Farmers' technology valuation may include pecuniary benefits such as yield increases and cost reductions, as well as non-pecuniary benefits such as convenience and enhanced flexibility of farming operations induced by the technology (Marra & Piggott, 2006). Hence, it summarizes the total value of all attributes of the technology for which the farmer is willing to pay. Let $f(x)$ represent the PDF of individual technology valuations in a heterogeneous population of farmers. From the ascending cumulative density function (CDF) of technology valuations, $F(x)$, the descending CDF, $Q(x)$, can be derived, which can be interpreted as a normalized demand curve, $Q(x) \in [0,1]$, for the new technology:

$$Q(x) = 1 - F(x). \tag{1}$$

The restricted monopoly in the market for privately developed proprietary seed technologies allows the innovator to set a monopolistic price, which is higher than the price of the conventional technology bundle. In most *ex-ante* impact studies, this technology fee (θ) is treated exogenously (Demont et al., 2008a, 2008b; Demont & Dillen, 2008; Demont & Tollens, 2004; Flannery, Thorne, Kelly, & Mullins, 2004; Hareau, Mills, & Norton, 2006; May, 2003). Alston, Hyde, Marra, and Mitchell (2002) endogenize θ based on first-order statistics, i.e., they assume that the technology would be competitively priced, which implies that the technology fee is set at the mean technology valuation. However, neglecting higher-order statistics does not account for heterogeneity and leads to homogeneity bias in the estimation of the impact of the technology on welfare and corporate revenue (Demont et al., 2008a). Throughout this article we assume that farmers act rationally, adopting a technology if valuation, net from technology price, is positive, i.e., $x - \theta > 0$. Assuming constant long-run marginal costs, c, the profit function of the monopolistic innovator is represented by:

$$\pi(\theta) = (\theta - c)Q(\theta). \tag{2}$$

The optimal price of the technology bundle, θ^*, satisfies the following first-order condition:

$$\frac{d\pi(\theta)}{d\theta} = \frac{dQ(\theta)}{d\theta}.(\theta - c) + Q(\theta) = 0. \tag{3}$$

Alexander and Goodhue (2002) argue that if users are heterogeneous, q^* may be below the technology valuation of a potential adopter, therefore leaving significant rents with the adopter. Lapan and Moschini (2000) alternatively interpret this pricing strategy as the monopolist choosing the profit-maximizing marginal adopter, $m = q^*$, directly from a heterogeneous population of farmers and allowing the adoption to be incomplete. This marginal adopter is indifferent between adopting and a *status quo.* Therefore, all potential adopters with a higher technology valuation will adopt the new technology, leading to the adoption rate

$$\rho = \int_{\theta^*}^{\infty} f(x)dx. \tag{4}$$

We define $f_a(x)$ as the adopters' density function of technology valuation:

$$f_a(x) = \begin{cases} \dfrac{f(x)}{\rho} & (x > \theta^*) \\ 0 & (x \le \theta^*) \end{cases}. \tag{5}$$

The average net value (farmer surplus) of the new technology, $\overline{\alpha}$, for all adopters can be measured by aggregating the farmer surplus, $\tau(x) = x - \theta^*$, and amounts to

$$\overline{\alpha} = \int_{\theta^*}^{\infty} \tau(x).f_a(x)\,dx. \tag{6}$$

Similar to Oehmke and Wolf (2004), we derive some comparative statistics. Assume $f(x)$ is characterized by a mean μ, standard deviation σ, and risk premium R. In order to derive comparative statistics analytically, independence between μ and σ is required. For R not to thwart this assumption, constant absolute risk aversion is assumed. Constant absolute risk aversion is often used to analyze farm decisions under risk (see Mitchell, Gray, & Steffey, 2004, for an application in GM crop literature). Assuming an increasing von Neumann-Morgenstern utility function (Babcock, Choi, & Feinerman, 1993), we can calculate the risk premium R as

$$R(A,\sigma) = \frac{\ln(0.5(e^{-A\sigma} + e^{A\sigma})}{A\sigma}, \tag{7}$$

where A represents the coefficient of absolute risk aversion.

The effect of a change in mean technology valuation over all farmers on θ^* is determined by

$$\frac{d\theta^*}{d\mu} = -\frac{-F_\mu(x) + (c-\theta)f_\mu(x)}{-F(x)_\theta - f(x) - \theta f_\theta(x)}, \tag{8}$$

where subscripts denote partial differentiation. In order to determine the sign of the derivative, additional assumptions are needed. The denominator is negative under the assumption that $f(x)$ is unimodal and θ^* lies on the lower tail of the PDF. As we assume the innovation will be marketed, $\theta^* > c$ and the denominator becomes positive. Therefore, as the mean technology valuation increases, the technology fee will follow.

The effect of a change in variance is determined by

$$\frac{d\theta^*}{d\sigma} = -\frac{-F(x)_\sigma + (c-\theta)f(x)_\sigma}{-F(x)_\theta - f(x) - dF(x)_\theta}. \tag{9}$$

Under the same assumptions, this derivative will be negative. This means the innovator will drop the price in order to maintain his customer base as the variance or heterogeneity increases. This price decrease originates both from the direct effect of a more heterogeneous population and the decrease of the risk premium, which acts as a shifter as $\frac{dR(A,\sigma)}{d\sigma} < 0$ for $\sigma > 0$. The effect of increased risk aversion is determined in a similar way by

$$\frac{d\theta^*}{dA} = -\frac{-F(x)_A + (c-\theta)f(x)_A}{-F(x)_\theta - f(x) - dF(x)_\theta}, \tag{10}$$

where under the same assumptions, θ^* decreases if absolute risk aversion increases as $\frac{dR(A,\sigma)}{dA} < 0$ for $A > 0$. The induced changes in θ^* translate to changes in the welfare effects of the technology. However, the outcome of these parameters depends on the specific shape of the PDF as the general form used before leads to ambiguous results. Therefore, we discuss the results in the next section through an empirical case study.

Application

The case of herbicide resistant (HR) sugar beet is very appealing for EU agriculture as this crop is grown in most EU countries and economic sugar production is impossible without weed control. Moreover, the recent reform of the sugar regime (see Dillen, Demont, & Tollens, 2008) towards more market-driven and a booming market for raw materials (biofuels and bio-based chemistry) increases the need for cost reduction in the sector. We understood that the major impediment comes from the concentrated group of refiners, processors, and manufacturers of sugar and sugar-containing products. Processors face risks related to market acceptability of sugar and by-products (DeVuyst & Wachenheim, 2005). However, it seems that sugar processors recently opened their doors to biotechnology following the food and feed approval in Australia, New Zealand, Japan, and the European Union. The success of the commercial introduction of HR sugar beet in the United States in 2008—reaching an unprecedented adoption level of nearly 100% of the total sugar beet area in the second year (Kilburn, 2009)—proves the high value of the technology for farmers.

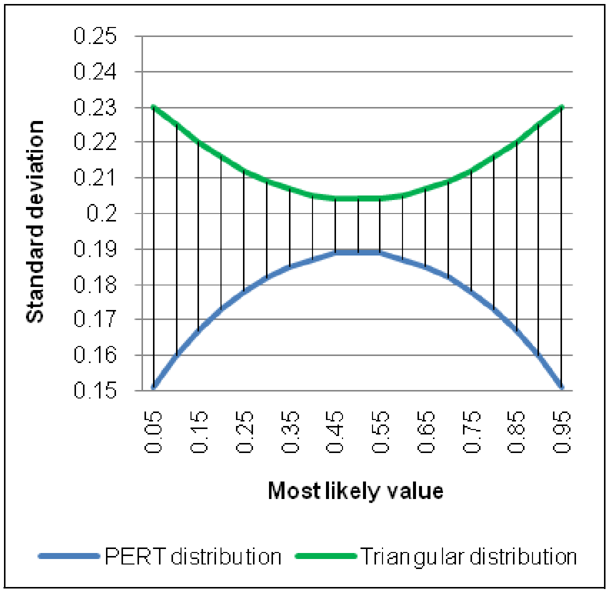

Figure 1. Effect of parameter specification on the standard deviation of the triangular and the PERT PDF.

The appropriate PDF of the technology valuation among potential adopters is the centerpiece of the developed model. Oehmke and Wolf (2004), in their *ex-post* assessment, construct the PDF through a kernel density estimator on available adoption data. In *ex-ante* assessment, the assessor faces the endogenous problem of imperfect information that makes a similar approach impracticable. The amount of data available to the researcher can be situated in an *information continuum*. At the lower end of the continuum, no information is available and theoretical considerations dictate the parametric estimation procedures. Towards the higher end of the information continuum, in the direction of full information, empirical findings gradually replace theory and parametric procedures substitute for non-parametric procedures. Although the probability of selecting the correct parametric model is zero, a parametric approach does not necessarily lead to biased results. With a false model, parameters will converge such that the Kullback-Leibler distance between the true density and the best parametric estimate is minimized. Therefore, an incorrect parametric model may have greater efficiency than the correctly modeled density and a non-parametric model (Goodwin & Ker, 2002). In the case of data scarcity, expert opinions are often used to construct subjec-

Table 1. Cumulative loglogistic distributions fitted on survey data on weed expenditures.

	Model: $H(z) = 1/(1+(z/\gamma)$^$(-\delta))$ (Equation 12, assuming $\phi = 0$ before adoption of HR sugar beet)					
	France, 1997		France, 2000		Netherlands, 2004	
Parameter	**Scale (γ)**	**Shape (δ)**	**Scale (γ)**	**Shape (δ)**	**Scale (γ)**	**Shape (δ)**
Estimate	103.3* (1.0)	4.8* (0.2)	160.2* (0.4)	4.7* (0.04)	803.3* (3.7)	5.0* (0.1)
R^2	0.99852		0.99981		0.99917	
Goodness-of-fit (RMSE)	0.003		0.006		0.005	

Sources: IRS (2004), Institut Technique de la Betterave (ITB; 2000), and Lemarié et al. (2001).

*Notes: Standard deviations are shown between brackets. * = significant at the 0.01 level*

tive probabilities for uncertain parameters. Although very popular, the triangular PDF might not be the best way to model expert opinions for modeling heterogeneity of technology valuation. Both tails are overemphasized and experts often have better knowledge on the central tendencies than on the extremes. Therefore, the PERT PDF, a special case of the Beta distribution, is preferred for modeling expert opinions. It can range from highly skewed to symmetrical distributions, has a close fit to normal and lognormal distributions, and attributes less weight to the extremes. The excessive reliance of the triangular PDF on the extremes also influences the variance introduced into the model. In Figure 1 we observe that for the same values of the extremes, the triangular distribution always has a higher standard deviation, therefore introducing unnecessary uncertainty in the model if we assume that we can rely on the expert's knowledge. Demont et al. (2008a) use a re-parameterized version of the classic PERT specification to construct a PDF based on their specific context of limited data availability. In this article, we are one step further in the information continuum as we combine expert opinions with evidence from farmer surveys, which allows us to select the PDF based on empirical goodness-of-fit instead of forcing a pre-defined PDF to fit our expert data.

For economic sugar-beet production, effective weed control is crucial. Yield losses can be up to 100%; such is the poor ability of beets to compete with the large range of weeds present in arable soils (Dewar, May, & Pidgeon, 2000). Expert opinions on the herbicide expenditures for most of the EU countries are reported by Hermann (1996; 1997; 2006), while detailed cross-sectional survey evidence is available for the Netherlands (Institute of Sugar Beet Research [IRS], 2004) and France (ITB, 2000; Lemarié et al., 2001). We use the first data source to obtain basic first- and second-order moments of the underlying data, while we use the second data source to determine higher-order moments in order to determine the appropriate functional form to be used in our parametric modeling. We fit alternative CDFs on the available cross-sectional datasets on herbicide expenditures in sugar-beet growing. The loglogistic CDF consistently provides the best fit based on the root mean square error (RMSE) criterion. It is therefore chosen to model heterogeneity among potential adopters (Table 1). We combine the empirical results with the expert opinions through the estimation of the three fractiles in the survey data corresponding with the minimum, maximum, and mean expert opinions. By assuming that the correspondence between both data sources is constant, we calibrate loglogistic CDFs of herbicide expenditures on expert opinions for major sugar-producing member states of the EU-27 in 2004 (Table 2). With this procedure, we avoid the difficulties of experts to estimate the extreme fractiles of a distribution (Miller, 1956). This yields the following PDF, $h(z)$, and CDF, $H(z)$, for our case study:

$$h(z) = \frac{\delta.\left[\frac{z.(1-\phi)}{\gamma}\right]^{\delta-1}}{\gamma.\left[1+\left[\frac{z.(1-\phi)}{\gamma}\right]^{\delta}\right]^{2}} \text{ and} \tag{11}$$

$$H(z) = \frac{1}{1+\left[\frac{z.(1-\phi)}{\gamma}\right]^{-\delta}}, \tag{12}$$

where z represents herbicide expenditures, γ the scale parameter and δ the shape parameter of the loglogistic PDF. In order to make the concept of technology valuation more dynamic, a shift parameter, $\phi > 0$, is introduced. The parameter can be used to introduce constant absolute risk aversion premium, $R(A, \sigma)$, as presented earlier, and various exogenous price and cost effects into

Table 2. Weed control costs under conventional and HR sugar beet technology in the EU-27.

	Conventional weed control								HR weed control			
Member state	**Min (€/ha)**	**Mean (€/ha)**	**Max (€/ha)**	**Scale parameter γ**	**Shape parameter γ**	**Application cost *k* (€/ha)**	**nc**	**Total application costs (€/ha)**	**ng**	**Glyphosate dose *g* (l/ha)**	**Glyphosate expenditures *pgl* (€/ha)**	**Total application costs (€/ha)**
Austria	156	311	467	261	5.4	41.5	2.5	103.8	2.5	6	26.2	103.8
Belgium	104	261	417	207	4.2	18.5	3.5	64.8	2.5	6	26.2	46.3
Germany	76	206	334	160	3.9	18.2	3	54.6	2.5	6	26.2	45.5
Spain	141	261	381	223	6.1	13.0	3	39.0	1	3	13.1	13.0
Czech Republic	138	198	276	180	10.0	7.3[a]	3[b]	21.9	2.5	6	26.2	18.3
France	103	150	206	136	9.7	20.0	3.8	76.0	2.5	6	26.2	50.0
Finland	154	220	297	201	10.0	16.4	3.8	62.3	2.5	6	26.2	41.0
Greece	94	132	202	121	10.5	17.5	1.5	26.5	1	3	13.1	17.5
Italy	95	169	253	145	6.4	15.3	2.5	38.3	2.5	6	26.2	38.3
Ireland	64	93	122	84	9.7	13.3	3	39.9	2.5	6	26.2	33.3
Netherlands	135	176	238	164	13.5	40.4	3.5	141.4	2.5	6	26.2	101.0
Poland	121	214	332	185	6.4	7.3	3[b]	21.9	2.5	6	26.2	18.3
Sweden	77	186	308	149	4.3	13.3	2.9	38.6	2.5	6	26.2	33.3
United Kingdom	78	149	225	124	5.9	14.4	4.6	66.2	2.5	6	26.2	36.0
Denmark	88	212	372	166	4.4	26.0	4	104.0	2.5	6	26.2	65.0
Portugal	141[c]	261[c]	381[c]	223	6.1	13.0	3	41.7	1	3	13.1	13.9
Hungary	64[d]	159[d]	211[d]	132	2.7	7.3[a]	3[b]	21.9	2.5	6	26.6	18.3

Sources: Hermann (2006) for most cases, complemented by Hermann (1996; 1997) if recent data is missing, and Schäufele (2000).
Notes: nc = number of conventional herbicide applications; ng = number of glyphosate applications
[a] *no data available; used data from Poland*
[b] *Urban, Pulkrabek, Valenta, Beckova, and Kviz (2008)*
[c] *no data for Portugal; used data from Spain*
[d] *no data from Hermann (1996; 1997; 2006), data from Research and Information Institute for Agricultural Economics (AKII, 2004)*

our static model. For the assessment of a biotechnological innovation, the latter can include (i) the inclusion of coexistence measures (e.g., Devos et al., 2008), (ii) the existence of a market premium for non-GM crops, and (iii) changes in the pricing strategies of competing technologies. In the case of HR crops, history shows that conventional herbicide producers try to countervail the increased competition with price reductions. This effect took place with the introduction of HR soybeans in the United States. It can be observed with the introduction of generic products in the herbicide market as well (Just, 2006). Due to data limitations, we assume the cost implications of these price reactions to be homogeneous in the population and to shift the PDF without affecting relative heterogeneity measured by the ratio of the mean to the standard deviation as both statistics are multiplied by the same factor. Although spatial variation in some of these factors certainly exists, we assume that this heterogeneity is captured by the herbicide expenditures. In order to transform herbicide expenditures, z, to technology valuation, x, we subtract the total cost of the HR system, excluding the technology fee, from the total cost of the conventional system, including application and product costs. The country-specific PDF of technology valuation can then be calculated as

$$f_i\,(x) = h_i\,[x + (nc_i - ng_i)\,k_i - pgl_i . g_i\,], \tag{13}$$

where ng_i and nc_i represent the number of herbicide applications in the HR and conventional system respectively, k_i the cost of a single herbicide application (assumed equal for glyphosate and conventional applications), g_i the dosage, and pgl_i the price of glyphosate in country i. Note that $(x + nc_i k_i)$ represents the total cost of the conventional system while $(ng_i k_i + pgl_i g_i)$ represents the total cost of the HR replacement system, excluding the technology fee. Again, due to data limitations we assume application costs and glyphosate expenditures to be homogeneous at the country level and to shift the PDF of technology valuation horizontally without affecting its shape.

Based on the resulting PDF of technology valuation among potential adopters, the innovating sector (technology developers and seed suppliers) will set its price in order to maximize profits following the presented modeling framework. We differentiate between two distinct corporate pricing strategies. In the first pricing strategy, we use disaggregated data to calculate the price at the member-state level. This pricing strategy is known as *spatial third degree price discrimination* (Schmalensee, 1981). The second pricing strategy assumes a *uniform price setting* over the EU-27 sugar-beet producing countries. The resulting proprietary seed demand function for the proprietary seed is constructed based on the area-weighted average herbicide expenditures:

$$Q(x) = \sum_{i}^{n} f_i(x).\chi_i, \tag{14}$$

where n represents the number of countries taken into account and χ_i the share in area over the n countries. The two different pricing strategies enable investigating the effect of heterogeneity on the variables under research. Uniform pricing is a realistic pricing strategy for the European sugar sector, as it is common for sugar producers (processors) to purchase seed and distribute it upstream with contracted farmers. This practice, combined with the high concentration of the sugar sector through multinational companies (Smith, 2007), creates a situation of oligopsony at supranational levels, which would favor a uniform pricing strategy.

With these specifications, the impact of the different pricing strategies on adoption and value creation can be calculated following the system of Equations 3-6.

Data

Table 2 presents the data used in this study. Similarly to Desquilbet and Bullock (2009), we assume for simplicity that the long-run marginal costs of supplying seed are zero, which comes down to assuming that the technology developer maximizes revenue instead of profit. All prices are deflated to the 2008 level by using GDP deflators (World Bank, 2008). To aggregate the revenues to the national level and for yields, we use data from F.O. Licht (2005). The shift parameter, ϕ, is calibrated on the expected reduction of the price level of competing conventional herbicides. Analogous to the effect of HR soybeans in the United States, we estimate this reduction to take the value of 20% (Just, 2006). Moreover, analogously to other studies (Demont et al., 2008a; Demont & Dillen, 2008; Dillen et al., 2009), we include a 5% yield increase for adopting farmers due to reduced toxicity of the glyphosate herbicide regime in HR sugar-beet cultivation. The price of glyphosate is assumed uniform among member states (€4.37/l), first because of data limitations and second to abstract from markets where glyphosate is not well established. In such markets, the price structure is likely to change with the introduction of HR sugar beet. To construct the demand function in the uniform pricing strategy we use the area-weighted average of $f_i(x)$ for the countries producing three-quarters of the European production (Equation 14). These regions can be considered the main market. They include the efficient production regions where innovation incentives are positively affected by the recent sugar reform. They therefore are more likely to adopt HR sugar beet (Dillen et al., 2008).

Results and Discussion

In Table 3, the results of our pricing framework are presented. Under third-degree price discrimination, the technology fee ranges from €50/ha to €147/ha. The area-weighted average technology fee amounts to €98/ha. These spatially adapted technology fees result in adoption potentials (ceilings) that range from 51% for Ireland to 97% for Spain. The estimated adoption rates are remarkably close to potential market-penetration rates estimated by experts of national sugar-beet institutes (Coyette, Tencalla, Brants, & Fichet, 2002). The uniform pricing strategy yields a European-wide price of €95/ha. This fee, less adapted to local conditions and demand, generates a dramatically different adoption pattern, from almost no adoption in Ireland to almost full adoption in Spain. At first sight, the endogenous technology fees seem rather high compared to commercially available GM seeds of other crops. However, they are in line with the current technology fee of HR sugar beet in the United States, i.e., €90-106/ha (KWS, personal communication, 2006), and can be explained by the high herbicide expenditures in conventional sugar-beet cultivation (Table 2). The results confirm the theoretical model as the increased farmer heterogeneity of herbicide expenditures, generated by applying a uniform pricing strategy over a larger area, leads to a lower technology fee at the EU-27 level.

Table 3. Technology fee, innovator revenue, farmer rent, and total value of HR sugar beet under two alternative pricing strategies in the EU-27.

	Price discrimination					Uniform pricing				
Member state	Technology fee (€/ha)	Farmer incremental profits (€/ha)	Adoption (%)	Corporate revenue (million €)	Total value (€/ha)	Technology fee (€/ha)	Farmer incremental profits (€/ha)	Adoption (%)	Corporate revenue (million €)	Total value (€/ha)
Austria	147	123	74	4.9	270	95	188	84	3.8	283
Belgium	123	131	76	8.1	254	95	174	98	7.2	269
Germany	94	99	69	26.5	193	95	108	63	26.3	203
Spain	145	135	97	12.9	280	95	192	99	9.0	287
Czech Republic	98	87	88	5.6	185	95	101	91	5.6	196
France	87	133	90	27.0	220	95	131	78	26.9	226
Finland	125	68	79	3.5	193	95	102	97	2.7	197
Greece	75	95	90	2.2	170	95	63	43	1.8	158
Italy	77	59	79	9.7	136	95	45	43	8.6	140
Ireland	50	32	51	0.7	82	95	1	5	0.003	96
Netherlands	121	92	92	11.2	239	95	151	97	8.6	246
Poland	102	79	80	22.4	181	95	96	85	22.0	191
Sweden	86	74	65	2.5	160	95	71	47	2.5	166
United Kingdom	78	117	86	8.8	195	95	99	59	8.5	194
Denmark	106	122	80	4.3	228	95	145	82	4.0	240
Portugal	145	135	97	1.2	280	95	192	99	0.7	287
Hungary	108	63	84	2.6	171	95	78	92	2.4	173
EU-27 area-weighted average (total)	98	99		(154)	204	95	116		(141)	218

Note: For comparison, the market potentials estimated earlier by experts of national sugar beet institutes in six selected countries are 75% for Belgium, 71% for Germany, 100% for Spain, 90% for France, 93% for the Netherlands, and 89% for the United Kingdom (Coyette et al., 2002).

Under price discrimination, the area-weighted average of the farmer profits amount to €99/ha, with the extremes in Spain and Ireland. Corporate revenue in the EU-27 is €154 million. If third-degree price discrimination is not possible, e.g., due to the market structure, the farmer profits amount to €116/ha, while the corporate revenue drops to €141 million. Under increased farmer heterogeneity of herbicide expenditures, farmers are able to capture a higher rent while the innovator loses revenue. The lower technology fee will relocate the position of the marginal adopter, but the increased adoption rate is not enough to compensate for the reduced optimal technology fee on a per-hectare base. Therefore, the corporate goal of increasing adoption might not be the revenue-maximizing strategy. Under market structures with strong IPRs (which reduce arbitrage), third-degree price discrimination is a profitable strategy for the innovator. By dividing the population into smaller, more homogenous segments, corporate revenue increases by progressively extracting farmer surplus from the total value of the proprietary seed technology. Heterogeneity is minimized in each sub-market $f_i(x)$, and revenue is maximized. Empirical evidence can be found for Bt cotton in the United States, Mexico, and South Africa (Frisvold, Reeves, & Tronstad, 2006; Gouse, Pray, & Schimmelpfennig, 2004; Traxler, Godoy-Avila, Falck-Zepeda, & Espinoza-Arellano, 2003). The separation is mainly introduced by different germplasm due to the sensitive reaction of upland cotton varieties to agro-climatic changes (Acquaye & Traxler, 2005) and preventing farmers to buy seeds in other districts (Traxler et al., 2003). With strong IPRs, the sub-markets could be introduced through enforcement of a contract with a “no resale” clause, thereby strengthening monopoly power. In Europe, price discrimination can be found in Bt maize in Spain as a function of spatial pest-infestation levels (Gomez-Barbero, Berbel, & Rodriguez-Cerezo, 2008). These observations indicate that the innovator is aware that patent-based uniform pricing of a GM seed technology leaves substantial benefits with the producers, preventing full appropriation by the innovator due to heterogeneity among farmers. In developing countries with weak or no governance of IPRs, on the other hand, price discrimination of HR technologies can only be efficiently implemented in the case of hybrids as hybridization biologically strengthens IPR protection and acts as a substitute for weak IPR enforcement (Goldsmith, Ramos, & Steiger, 2003). This may explain the absence of price discrimination in the case of HR soybeans in developing countries (Qaim & Traxler, 2005).

Due to the antagonistic response of farmer rents and corporate revenues to changes in heterogeneity, the magnitude of total welfare depends on the shape of the parametric model. In the case of the loglogistic PDF, the upwards effect on farmer rents following an increase in heterogeneity more than compensates the downwards effect on corporate revenue on a per-hectare basis such that the total value increases. The total value under uniform pricing amounts to €218/ha, while it only reaches €204/ha in the case of third-degree price discrimination. Full welfare effects under uniform pricing are calculated using a partial equilibrium model, EUWABSIM (Dillen et al. 2008; Dillen et al. 2009).

Demont et al. (2008a) demonstrate the homogeneity bias that emerges from not incorporating second-order statistics in *ex-ante* impact assessment. They conclude that the bias is a decreasing function of the mean and an increasing function of the variance of $f(x)$. This result contrasts with earlier statements in the literature that the distribution is of minor importance as the lower and higher tails of the distribution will compensate each other (Breustedt, Muller-Scheessel, & Latacz-Lohmann, 2008). However, by using an exogenous technology fee, $\overline{\theta}$, they potentially introduce a second source of bias, i.e., pricing bias. In the literature on HR sugar beet, different assumptions and estimates have been reported for the technology fee, varying from €25/ha (Flannery et al., 2004), €30-40/ha (Märländer, 2005), €40/ha (Demont, 2006), €32-48/ha (May, 2003), €38/ha (Gianessi, Sankula, & Reigner, 2003), and €77/ha (Lemarié et al., 2001) in Europe to €128/ha (Gianessi, Silvers, Sankula, & Carpenter, 2002), €133/ha (Burgener, Feuz, & Wilson, 2000), €157/ha (Rice, Mesbah, & Miller, 2001), and €164/ha (Kniss, Wilson, Martin, Burgener, & Feuz, 2004) in the United States. We illustrate the magnitude of the exogenous pricing bias for France by comparing farmer surplus generated under the assumption of an exogenous technology fee of €40/ha with surplus generated under the assumption of third-degree price discrimination. The assumption of exogeneity would lead the researcher to overestimate the potential adoption ceiling by 11% (100% instead of 89%) and the value captured by farmers by 39% (€185/ha instead of €133/ha). If the technology developer commercializes HR sugar beet seed into the European sugar industry through uniform pricing, endogeneizing the technology fee but assuming third-degree price discrimination instead of uniform pricing would generate a second source of bias, i.e., farmer benefits would still be overestimated by 1.5% (€133/ha instead of €131/ha). The small bias is explained by the fact that France, the largest sugar producer, would play a determinant role in EU uniform pricing. The total pricing bias on farmer surplus would then be the sum of both biases and would amount to 41% (€185/ha instead of €131/ha).

Our results underline the importance of incorporating heterogeneity in *ex-ante* impact assessment of proprietary seed innovations, especially if the impact assessor is operating under data scarcity and imperfect expert information. Not accounting for heterogeneity introduces both homogeneity bias (Demont et al., 2008a) and pricing bias into the impact estimates. Moreover, the presence of heterogeneity explains the strategy of the innovating seed sector to engage in third-degree price discrimination, as the latter maximizes corporate revenue but possibly reduces total welfare.

Finally, our proposed parametric modeling framework provides a practical tool for breeders, technology developers, agricultural economists, crop protectionists, and biosafety regulators to estimate the value of future proprietary seed technologies under data scarcity. In particular, it can be useful for large-scale, *ex-ante* impact assessment under time and resource constraints, such as the socio-economic assessment of new technologies under the Cartagena Protocol. Falck-Zepeda (2009) argues that inclusion of socio-economic considerations may become an obstacle to potentially valuable technologies, particularly for developing countries facing higher barriers in terms of biosafety regulatory compliance due to resource constraints.

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