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Is Monsanto Leaving Money on the Table? Monopoly Pricing and Bt Cotton Value with Heterogeneous Adopters

James F. Oehmke and Christopher A. Wolf

We examine the allocation of technology rents between a price-setting, innovating monopolist and heterogeneous technology adopters. A model of monopoly pricing in the presence of heterogeneous adopters is used to examine conditions under which greater producer (farmer) heterogeneity leads to greater producer benefit from innovation in non-competitive markets. An application to Bt cotton determines the profit-maximizing price of Bt cotton seed and reveals that Monsanto and Delta and Pine Land are indeed leaving money on the table in the form of unexploited profit opportunities. However, we estimate that the presence of heterogeneous adopters explains over 80% of the rents that accrue to the farmers.

Key Words: biotechnology, Bt cotton, heterogeneous adopters, innovation, monopoly pricing, technology, valuation distribution

JEL Classifications: L1, O3, Q1

Agricultural production technologies yield benefits to innovating firms, producers (adopters), and consumers, with the benefit distribution depending on market and technology characteristics. Important considerations in the welfare analysis of technology innovation, adoption, and diffusion include the presence of market power, often conferred by intellectual property rights, and the ability of the innovating firm to price discriminate across agricultural producers. The former effect—market power of the innovating firm—has been a topic in recent literature. For example, Moschini and Lapan (1997), and Alston, Sexton, and Zhang examined the welfare effects of agricultural research and development (R&D) in the presence of intellectual property rights. This literature recognized that patents allow private firms that innovate to capture a sizable portion of the returns to R&D. In the presence of monopoly power in input markets, the traditional measure of welfare using output supply and demand curves in the output market is insufficient. Moschini and Lapan (1997) suggested that the innovating firms are likely to capture benefits that have routinely been measured as consumer or producer benefits.

Following the lead of Moschini and Lapan (1997), as well as Falck-Zepeda, Traxler, and Nelson (hereafter FTN), we examine the surplus distribution of a biotechnology cotton innovation, specifically the introduction of the *bacillus thuringiensis* (Bt) bacterium into the cotton plant, conferring resistance to budworm and other pests. FTN estimated that the majority of benefits from this innovation, 59%,

James F. Oehmke is professor and Christopher A. Wolf is associate professor, Department of Agricultural Economics, Michigan State University, East Lansing, MI.

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accrued to producers (farmers) with the innovators, Monsanto and Delta and Pine Land, receiving 21%. The allied innovators could very reasonably be considered to be a monopolist in this input market, and in the case of a monopoly technology market, one might expect that the innovators would extract a significantly higher proportion of the rents. FTN dealt with benefits as aggregate surplus, ignoring heterogeneity across producers and resulting effects on the distribution of technology value and benefits, although they noted that producer heterogeneity is a possible explanation for their results. Specifically, FTN modeled the demand for Bt cotton as represented by a constant elasticity demand curve. This is convenient for surplus calculations, but it obscures heterogeneity among potential adopters and, when combined with an inelastic demand, does not generate a finite solution to the monopoly-pricing problem. More generally, the distribution of benefits in the presence of heterogeneous adopters has yet to be addressed with respect to agricultural biotechnology innovations.

This paper examines the degree to which farmer and/or farm heterogeneity explains the seemingly high proportion of Bt cotton benefits that accrue to farmers. We present a model of monopoly pricing and use it to examine the allocation of surplus between the innovating firm and technology adopters, explicitly accounting for differences in technology valuation across heterogeneous potential adopters. These differences are represented by a probability distribution. The innovating firm acts as a monopolist in the sense of having at least some degree of price-setting power in the output (Bt seed) market. These assumptions are consistent with a variety of innovations that are protected intellectual property, such as patented brand-name pharmaceuticals, most agricultural biotechnology innovations, and Bt cotton in particular. Using an empirical distribution based on observed returns to Bt cotton, we examine whether Monsanto has priced Bt cotton optimally. Anticipating the results, heterogeneity in farmers' valuation of Bt cotton can restrict Monsanto and Delta and Pine Land's ability to extract rents from farmers, enabling adopting farmers to keep some rents from the introduction of Bt cotton. We show that this heterogeneity in fact explains over 80% of the Bt cotton rents that accrue to farmers.

The next section of the paper presents a formal model of monopoly pricing to heterogeneous potential adopters. Although there is no single standard model of monopoly pricing with heterogeneous consumers, the model we develop follows a traditional approach (see, e.g., Bain, Chamberlain, or Schmalensee, *inter alia*). The model is used primarily to develop results and intuition about the interaction among the probability distribution characterizing the heterogeneous potential adopters, monopolist pricing decision, and distribution of rents. The section following that derives an optimal monopoly price for Bt cotton given an empirically observed distribution of farmer Bt cotton values. The distribution of rents associated with this optimal price is calculated. We find that heterogeneity explains much of the rent that farmers accrue, but also that Monsanto and Delta and Pine Land are leaving a portion of the profits for adopters at the upper end of the technology valuation distribution and, therefore, could extract a greater proportion of rents by charging a higher price. The final section draws conclusions.

Monopoly Pricing with Heterogeneous Customers

Standard analysis of technology benefits considers a monopolist who sells to a group of homogeneous adopters (e.g., the "quality ladders" literature; see Grossman and Helpman). In this case, the monopolist sets marginal revenue equal to marginal cost and draws all of the rents out of the market for the technology in question. Although this model yields straightforward theoretical results, it is not necessarily consistent with market behavior. Several studies have established that a distribution of technology values exists across potential adopters, with some adopters realizing profits from the technology and others rationally choosing not to adopt the technology (e.g., see Hubbell, Marra, and Carlson's analysis of willingness to pay for Bt cotton, or Tauer's analysis of bST). With heterogeneous adopters, the monopolist-pricing problem changes (unless perfect price discrimination is possible) to picking the appropriate price and price scheme to achieve the sales/profit objective. In the case of uniform pricing, the monopolist understands that the adopters at the top end of the technology value distribution will capture some of the rents.[1]

There are three critical assumptions in the model utilized here. The first is that technology purchasers are heterogeneous, with the value of any innovation differing across potential adopters. The second assumption is that the innovating firm acts as a monopolist in the sense of having at least some degree of price-setting power in the output market. The third assumption is that the innovators cannot price discriminate.[2]

We are interested in the pricing and allocation of benefits between innovating firm and adopters as a consequence of the valuation distribution. To formalize these considerations, let x denote the value of the innovation to a potential adopter, $F(x)$ denote the cumulative distribution function for these values, and assume that $F(x)$ is analytic with the first derivative, $f(x)$, denoting the density function. The innovating firm's objective is to maximize profits from sale of the innovation by determining an optimal price. For any price, p, those individuals with $x > p$ adopt, whereas those with $x \leq p$ do not. The number of adopters is $1 - F(p)$. Firm profits are

$$\text{(1)} \qquad \Pi(p) = (p - c)[(1 - F(p)],$$

where c is the constant unit cost of production.

The firm chooses p to maximize profits, leading to the first-order condition

$$\text{(2)} \qquad 1 - F(p) = (p - c)f(p).$$

The left side of this equation represents the marginal revenue from charging adopters a higher price; the right side represents the marginal cost (loss in revenue) of losing customers due to the higher price.

At a particular price, p, the benefits to adopters can be measured by the consumer surplus, defined to be the difference between each adopter's valuation and the price, aggregated across adopters

$$\text{(3)} \qquad CS = \int_p^\infty xf(x)\,dx - p[1 - F(p)].$$

The integral represents the willingness to pay, aggregated across adopters. The remaining term represents the aggregate amount paid.

Comparing consumer surplus to monopoly profits provides information on the distribution of benefits. In particular, this is the type of comparison that FTN use to find that Monsanto and Delta and Pine Land capture approximately one fifth of the total benefits (although they use both a domestic and an international market). Again following FTN, who propose to explain the distribution of benefits as a result of heterogeneity, the question becomes how does the size of firm profits given by Equation (2) change relative to the consumer surplus given by Equation (3) as farmers become more heterogeneous?

Comparative static exercises facilitate intuition and understanding about the role of heterogeneity in the distribution of benefits. To conduct comparative static exercises, we first parameterize the distribution $F(p)$. Specifically, we assume that F is a two-parameter distribution characterized by its mean, μ, and standard deviation, σ, and that these parameters are independent (e.g., as in a normal or log-normal distribution). (We utilize a two-parameter distribution to sign comparative statics for illustrative purposes only. We impose no distributional assumptions below in the empirical application.) We interpret an increase

[1] A number of more profitable pricing schemes were analyzed some time ago, but are not practicable for Bt cotton. The uniform pricing scheme is in fact a subclass of the two-part pricing scheme (see, e.g., Leland and Meyer). We note that Monsanto started to price discriminate in 2003 by offering different prices for Bt cotton in different regions.

[2] The empirical evidence is that very little price discrimination exists for Bt cotton. Possible explanations for the lack of price discrimination include the intense public scrutiny surrounding biotechnology and the relative ease of transporting seed.

in the variance (standard deviation) of F to be an increase in the heterogeneity of potential adopters. That is, increased heterogeneity is associated with an increase in the dispersion of potential adopter valuations of the technology. We conduct comparative static exercises showing the effect of changes in mean, μ, and standard deviation, σ, on the monopoly price, p, profits, Π, and consumer surplus, CS.

The details of the comparative static exercises are relegated to the Appendix. Under some reasonable assumptions (see Appendix), we can summarize the results as

$$(4) \quad \frac{dp}{d\mu} > 0 \qquad \frac{dp}{d\sigma} < 0$$
$$\frac{d\Pi}{d\mu} > 0 \qquad \frac{d\Pi}{d\sigma} < 0$$
$$\frac{dCS}{d\mu} \leq 0 \qquad \frac{dCS}{d\sigma} \geq 0.$$

The first row of Equation (4) shows that the monopoly price is increasing in mean valuation and decreasing in standard deviation, the second row shows similar results for firm profits, and the third row shows that consumer surplus is nonincreasing in mean valuation and nondecreasing in the standard deviation.

The key results are that an increase in standard deviation decreases firm profits but does not decrease consumer surplus. In other words, greater heterogeneity leads to consumers capturing a greater share of the rents. This result provides a rigorous underpinning to the hypothesis that farmers are capturing the majority of the rents because of heterogeneity among potential adopters of Bt cotton. Below we examine evidence to test this hypothesis.

Optimal Pricing of Bt Cotton

Bacillus thuringiensis (Bt) cotton provides resistance to a number of pests, most importantly the bollworm (*Helicoverpa zea*), also called the corn earworm (Roberts and Guillebeau) and the budworm or tobacco budworm (*Heliothis virescens*). The potential advantages of Bt cotton over traditional varieties are reduced insect control costs and reduction of insect damage.

To apply our model, we characterize heterogeneity among potential U.S. adopters of Bt cotton, derive an optimal monopoly price for heterogeneous adopters, and examine the resulting distribution of rents. Adopter heterogeneity is approached from a bio-economic perspective. In particular, we follow FTN and assume that the advantage of Bt cotton depends on the incidence of susceptible pests, which in turn depends on agroclimatic considerations. We further assume that this agroclimatic heterogeneity is adequately summarized by the net economic returns from using Bt cotton. Data on net economic returns were obtained from compendia of field trials published in the *Proceedings of the Beltwide Cotton Conference*, which include both Monsanto public statements about the net economic benefits to farmers of Bt cotton, as well as many university comparisons of economic returns. These publications include field trial results from the authors cited in FTN, in addition to more recent results. The returns data are categorized by year and state or region with the assumption that all cotton producers are potential adopters of Bt cotton. They provide summary statistics, including mean net economic returns, for each of 24 sets of field trials disaggregated by year and region. The returns data are representative of the information that farmers had regarding Bt cotton, at least in the early years before farmers gained experience with the crop, and are an important factor in the adoption decision even when farmers have experience with Bt cotton (Marra, Hubbell, and Carlson). A summary of the economic returns data is provided in Table 1. The advantage of Bollgard over conventional cotton from 1995 through 2001 varied from −\$14.61/acre to +\$100.30/acre.[3] These results were driven by the pest incidence in that time and region, which could result in an economic advantage for Bt cotton over conventional varieties in two areas: avoided insect control costs (i.e., spraying) and increased yield. The

[3] Note that these studies value lint at observed prices, so that any downward pressure on price from increase supply due to Bt cotton is captured in the more recent valuation studies.

Table 1. Summary of Bollgard Economic Comparisons, 1995–2001

Source	State or Region	Year	Average Bollgard Net Return[a] ($/acre)
Reed et al.	MS	1995	91.80
Gibson et al.	MS	1995	94.80
Bacheler, Mott, and Morrison	NC	1996	−9.00
Rejesus et al.	SC	1996	11.62
Wier, Mullins, and Mills	MS	1996	24.70
Reed et al.	MS	1996	25.16
Karner, Hutson, and Goodson	OK	1996	83.53
Bryant, Robertson, and Lorenz	AR	1996	86.74
Stark	GA	1996	100.30
Bryant, Robertson, and Lorenz	AR	1997	−26.95
Cooke et al.	MS	1997	−14.61
Bacheler, Mott, and Morrison	NC	1997	−8.00
Reed et al.	MS	1997	41.16
Karner, Hutson, and Goodson	OK	1997	46.45
Wier, Mullins, and Mills	MS	1997	53.70
Cooke et al.	MS	1998	34.45
Mullins and Mills	MS, LA, AR	1998	36.00
Mullins and Mills	NC, SC, VA	1998	41.70
Seward, Shelby, and Danehower	TN	1998	52.25
Mullins and Mills	NT, North AR	1998	60.70
Karner, Hutson, and Goodson	OK	1998	64.12
Bryant, Robertson, and Lorenz	AR	1998	64.52
Reed et al.	MS	1998	83.30
Seward, Shelby, and Danehower	TN	1999	−9.00
Cooke et al.	MS	1999	1.23
Reed et al.	MS	1999	24.86
Karner, Hutson, and Goodson	OK	1999	40.06
Oppenhuizen, Mullins, and Mills	GA, AL	2000	2.64
Oppenhuizen, Mullins, and Mills	NC, SC, VA	2000	11.13
Oppenhuizen, Mullins, and Mills	LA, MS	2000	66.14
Oppenhuizen, Mullins, and Mills	East TX	2000	83.58
Deville, Mullins, and Mills	AR, MO, TN	2001	5.49
Deville, Mullins, and Mills	NC, SC, VA	2001	14.47
Deville, Mullins, and Mills	GA, AL	2001	15.69
Deville, Mullins, and Mills	LA, MS	2001	16.82

[a] The average net return is the return relative to a conventional variety with standard pest management practices net of the technology fee.

cost of a single insecticide application varies depending on the type of insecticide required, but the saved insecticide costs tended to be smaller than the benefit from increased yield from avoided insect damage.

We assume that regions not represented in these data either have the same distributional characteristics as the sample or that the underrepresented regions have limited insect pressure from Bt-susceptible insects (e.g., most of the California cotton area). That is, we treat the data as if they were an unbalanced panel representative of the population of potential adopters. This is consistent with FTN's treatment of the data and with Marra, Hubbell, and Carlsons' statement that the returns data are representative of information available in the early years of Bt cotton adoption. Using

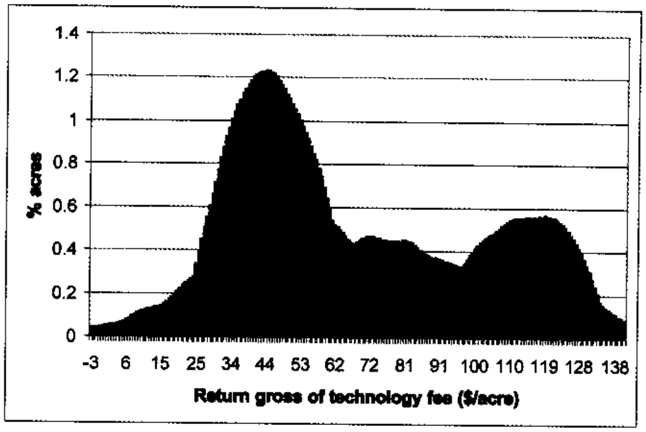

Figure 1. Distribution of Net Profit per Acre from Bt Cotton Use at Actual Bollgard Cost

the data, weighted by the total cotton acres planted that year obtained from the U.S. Department of Agriculture, National Agricultural Statistics Service, we estimate a distribution of expected benefits from Bt cotton adoption.

The distribution of expected benefits from Bt cotton adoption was estimated as a kernel density. A kernel density distributes the probability associated with each observation, V_i, by using a small density, a kernel, centered at each observation. A weight is assigned to each value based on its distance from V_i. The kernel is a function that determines the weight assigned to each value based on its distance from observation. The kernel density estimator gives a nonparametric estimate of the density. However, if the true density is a parametric function, then the kernel density estimate would still closely approximate the true distribution.

A kernel density estimator has the form

$$f(v) = \frac{1}{nh} \sum_{i=1}^{n} K\left[\frac{v - V_i}{h}\right],$$

where K is a symmetric probability density satisfying the condition

$$\int_{-\infty}^{\infty} K(z)\, dz = 1,$$

and where V_i is the observation that the kernel is centered on, n is the number of observations, and h is the width of the kernel.[4] The kernel density–based distribution of Bt cotton returns gross of the technology fee is displayed in Figure 1.

From the kernel density estimate, we see that the distribution of potential benefits appears to be bimodal with a global maximum around $43/acre and another mode with a peak at $119/acre. The appearance of two modes is due to the fact that the benefits tended to either be relatively small yield benefits or large insect control and yield benefits depending on the pest incidence in that time and location. This distribution, then, is the best available estimate of the expected returns of Bt cotton gross of the technology fee.

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[4] We utilize the Epanechnikov kernel, which Silverman concluded was the most efficient among kernels that are themselves probability density functions, where efficiency is defined as minimizing mean integrated squared error. The Epanechnikov kernel has the form

$$K_E(z) = \begin{cases} \frac{3}{4\sqrt{5}}\left(1 - \frac{z^2}{5}\right) & \text{for } |z| \leq \sqrt{5} \\ 0 & \text{else.} \end{cases}$$

The smoothing parameter, h, is critical to determining the shape of the density. Silverman examined the sensitivity of the kernel-width to skewness and kurtosis using the lognormal and t families of distributions and concluded that the optimal smoothing parameter was $h = 0.9An^{-1/5}$, where A = min(standard deviation, interquartile range/1.34).

We examined the rents generated at the observed price and technology fee using the kernel density of Bt cotton net returns. For simplicity assume that the Bt cotton seed price (excluding the technology fee) exactly covers the cost of seed production and distribution, and that the technology fee, usually \$32/acre, represents returns to the Monsanto and Delta and Pine Land investments in developing Bt cotton.[5] Based on our empirical distribution of gross returns (Figure 1), at a technology fee of \$32/acre farmers receive 61% of the benefits (after netting out the technology fee), which is very close to FTN's finding of 59%; in our model, Monsanto and Delta and Pine Land capture the remaining 39% of the benefits. At a technology fee of \$32/acre, Bt cotton captures a market share of almost 90% of potential adopters (measured by acres rather than farms), which is consistent with observed area planted to biotech soybeans in areas where expected insect pressures are greatest.

We also solved for an optimal price, treating the distribution of farmer net benefits from Bt adoption nonparametrically (i.e., we did not impose a functional form such as a two-parameter distribution). The optimization problem yielding this price is profit maximization, subject to farmer adoption behavior. Initially, we posit that Monsanto and Delta and Pine Land solve the problem

$$\text{(P1)} \quad \max_p pQ \quad \text{s.t.} \quad Q = \sum_i I_i q_i;$$

where

$$I_i = \begin{cases} 1 & \text{if } y_i - p > 0 \\ 0 & \text{if } y_i - p \leq 0. \end{cases}$$

In Problem (P1) Monsanto and Delta and Pine Land maximize monopoly rents by choosing the technology fee, p. We maintain the assumption that the seed price covers the cost of seed production and distribution, and that the technology fee represents monopoly rents. The quantity sold depends on the technology fee

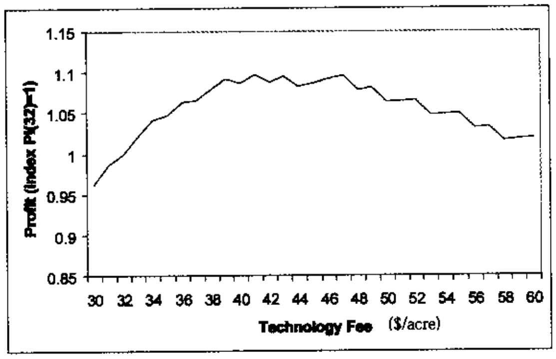

Figure 2. Predicted Bt Cotton Monopoly Profits as a Function of Technology Fee

through the farmers' adoption decisions. Farmer i with benefits (gross of the technology fee) per acre of y_i adopts the Bt variety at technology fee p if and only if her or his net benefits are positive. We assume that the quantity of seed purchased (q_i) is directly proportional to the number of acres planted. Note two important characteristics of this problem: (1) it implicitly assumes either that farmers know their expected returns y_i with certainty, or that farmers are risk-neutral and y_i represents their expected net returns from Bt cotton; and (2) there are no cash-flow constraints. We return to these assumptions momentarily.

Solving Problem (P1) nonparametrically and numerically results in an optimal price/technology fee p_1^* in the range of \$41–\$47, approximately \$9–\$15 higher than the standard \$32 fee that Monsanto charges. Profits are maximized at \$47, but graphing profits as a function of price shows a plateau between \$41 and \$47 (Figure 2). Given that this profit function is based on farmer trial data, rather than an actual farm survey of Bt cotton use and profitability, it seems counterproductive to specify too precisely and exactly an optimal technology fee. However, it seems clear that the optimal technology fee is higher than the observed \$32, which lies on a clearly upward-sloping portion of the graph.

For illustrative purposes, let us select a technology fee in the optimal range, say \$43. At this fee fewer farmers purchase the Bt cotton, so the predicted share of Bt cotton in total

[5] Bt cotton seed is typically priced slightly higher than non Bt cotton seed that is of comparable quality

Table 2. Market Share and Distribution of Returns by Technology Fee

Technology Fee ($/acre)	Market Share	Farmer Returns (%)	Monsanto and Delta and Pine Land Returns
32.00	89	61	39
43.84	73	47	53
% Change	−19	−23	+36

points from 89% to 73%.[6] The total (social) benefits from the innovation decrease by 9%; monopoly profits increase by 10%, and farmer benefits decrease by 24%. This is consistent with the standard monopoly model in which the monopolist restricts supply in order to raise price and profits, causing a decrease in consumer (farmer) benefits and a deadweight loss (decline in total surplus from the innovation).

Ultimately, we are trying to explain the distribution of benefits between the farmers and Monsanto. At a technology fee of $32, we estimate that Monsanto collects 39% of the rents, with farmers gaining the other 61% (Table 2).[7] At the technology fee of $43, farmers gain 47% of the rents.

Consequently, heterogeneity accounts for a large part of the pricing decision. Were adopters homogeneous and risk-neutral, Monsanto and Delta and Pine Land could capture nearly 100% of the rents from Bt cotton and farmers would gain at most a few percentage points. Instead, FTN observe that farmers gain 59% of the rents, and our model estimate of 57% at the current technology fee is consistent with this FTN finding. The question remains, how much of the 57% is attributable to adopter heterogeneity? To answer this question, we look at the proportion of benefits accruing to adopters if Monsanto priced the technology fee to maximize profits. In this case, our model predicted that farmers would gain 48% of the rents. That is, heterogeneity explains 48 percentage points of the 59% of the rents captured by farmers. In other words, heterogeneity among farmers' valuations of Bt cotton is the dominant, but not the sole, cause of farmers gaining rents from this innovation.

Additional Causes of Farmer Rents

Why are Monsanto and Delta and Pine Land not extracting as much of the rents from Bt cotton as they can (even in the presence of heterogeneity) by charging the higher, profit-maximizing technology fee? The first order of business is to check the data—in this case, the net benefits distribution—to see if relatively minor changes in the net benefits distribution can explain the discrepancy. To address this issue, we eliminated all studies generating net returns per acre of $60 or more. In other words, we place zero weight on the studies showing the highest net benefits (recall that each study consists of multiple observations). In this case, the optimal price falls to $35 dollars, much closer to the observed price but still slightly higher. However, we believe that placing no value on these studies is an extreme measure, and we seek alternative explanations of why the discrepancy between observed and optimal pricing exists.

Several explanations are possible. One candidate explanation is that we have derived the optimal technology fee under the implicit assumption that farmers are risk-neutral. This is probably an unrealistic assumption. What happens to the optimal price if farmers are not risk-neutral? A complete answer requires a full risk analysis of both traditional and Bt cotton farming, which is beyond the scope of this paper. However, a simple modification of Problem (P1) proves informative.

[6] The predicted adoption rate of 89% at a technology fee of $32 squares well with actual adoption rates in Arkansas, Georgia, Louisiana, Mississippi, and North Carolina. It is somewhat higher than the U.S. average because adoption in California was 39% in 2003, due in large part to different climatic conditions and greater use of pima varieties.

[7] Our estimated proportion of benefits received by the farmer is very consistent with the proportion found by FTN. The estimate of Monsanto benefits is higher largely due to our assumption that there is no production cost to Monsanto of imposing the technology fee: this contrasts with FTN, who assume a constant elas-

assuming risk-neutral farmers, Monsanto optimizes price assuming that farmers have some degree of risk aversion (and some degree of uncertainty about the new technology; e.g., Marra, Panell, and Ghadim). We can then ask, what degree of risk aversion is consistent with the observed price? To derive this level of implied risk aversion, suppose Monsanto solves

$$\text{(P2)} \quad \max_p pQ \quad \text{s.t.} \quad Q = \sum_i I_i q_i,$$

where

$$I_i = \begin{cases} 1 & \text{if } EU_i(\tilde{y}_i - p) > 0 \\ 0 & \text{if } EU_i(\tilde{y}_i - p) \leq 0, \end{cases}$$

and the net returns to farmer i of planting Bt cotton, $\tilde{y}_i$, is a random variable. For numerical purposes, suppose further that each farmer has the same degree of risk aversion, and that the density shown in Figure 1 represents the density of the random variable $\tilde{y}_i$.[8]

The difference between the solution to Problem (P2) and the solution to Problem (P1) can be treated similarly to a premium for the risk of adopting the Bt cotton.[9] Following Newbery and Stiglitz or Gardner, it is straightforward to use a Taylor series approximation to determine the relationship between the risk premium and the degree of relative risk aversion by the farmer:

$$R = 2\rho\bar{y}\ \text{Var}[\tilde{y}],$$

where R is the degree of relative risk aversion, ρ is the risk premium, and $\bar{y}$ is the mean of the $\tilde{y}$.

Applying this equation to the data yields a relative risk aversion coefficient of $R = 0.70$. This is a slightly lower value than is sometimes used in partial-equilibrium agricultural applications, although the range of relative risk aversion coefficients found empirically is wide.[10] Consequently, we conclude that although we have a somewhat small risk aversion coefficient, it is within the plausible range and represents one possible explanation for Monsanto and Delta and Pine Land's nonoptimal price.

A second possible reformulation of the problem is that farmers face a cash-flow constraint. That is, as prices and/or technology fees of Bt cotton rise, some farmers will have too little cash and/or short-term credit to purchase the seed (Moschini and Lapan, 2000, have a more general discussion of incomplete adoption). Algebraically, the monopoly pricing problem becomes

$$\text{(P3)} \quad \max_p pQ \quad \text{s.t.} \quad Q = \sum_i I_i q_i,$$

where

$$I_i = \begin{cases} 1 & \text{if } y_i - p > 0 \quad \text{and} \quad \Phi(x) \leq C \\ 0 & \text{if } y_i - p \leq 0 \quad \text{or} \quad \Phi(x) \leq C, \end{cases}$$

where $\Phi(x)$ is the operating cost with inputs x (including Bt cotton), and C is the cash constraint. If the cash constraint becomes binding at high technology fees, then farmers will not purchase the Bt cotton, and hence Monsanto profits will drop. Thus, the existence of a cash constraint could act to limit the monopoly price.

As a very simple way to explore the effects of a cash constraint on monopoly price, we assume that at the optimal price (i.e., the solution to Problem [P1]), a certain proportion of potential adopters would be lost due to a cash constraint. We ask the question, what proportion would need to face a binding cash constraint in order for Monsanto profits at a technology fee of $43 (with a cash constraint) to be the same as Monsanto profits at the observed technology fee of $32 (assuming that

[8] Ideally, we would like to know the distribution of benefits associated with each farmer, but the necessary data are not available. Consequently, we follow Leland and Meyer and use an alternative interpretation of the empirical density, namely that it represents the expected returns from adoption of Bt cotton.

[9] This is not a "true" risk premium in the sense that the alternative to Bt cotton is not entirely risk-free.

[10] For example, Green, using UK asset price data, finds a negative relative risk aversion coefficient. Choi and Menezes pose the question of whether or not it is >1. Campbell, using U.S. data and different methods, presents a range of estimates from 2.1 to 31. In agriculture, Abdulkadri and Langemeier estimate relative risk aversion coefficients in the range from 2.8 to 6.3.

no farmers face a binding cash constraint)? The answer is that if by charging a technology fee of $43 Monsanto lost 9%–10% of the potential Bt adopters due to cash constraints, then they would make no more profit at $43 than they do at $32.

There are several other possible explanations for the discrepancy in rent distribution. For example, the distribution of net economic benefits from Bt cotton could be more heterogeneous than estimated, which would tend to lower innovator rents and increase farmer rents. However, as we utilized the same net economic benefit data of FTN, this source of discrepancy should be minimal. Moreover, since these data are reported by Monsanto researchers (although from a variety of sources; see Table 1), it seems likely that to the extent Monsanto pricing policy depends on net economic benefits, and we have data similar to those used by Monsanto.

Another possible explanation is that there may be competitive constraints to monopoly pricing by Monsanto and Delta and Pine Land. For example, Dow, Syngenta, and Aventis are currently field-testing transgenic insect-resistant cotton. Competitive pressures may thus be holding Bt cotton technology fees below what an innovator with true monopoly power would charge. Note that the mere threat of entry—that is, of a competitor developing and marketing a *heliothis*-resistant variety—could limit the monopoly price. In particular, Monsanto and Delta and Pine Land may be maximizing some weighted average of market share and profits, thus lowering price below the profit-maximizing price to gain market share.

We have treated the monopoly pricing problem in a static framework, but Monsanto may be taking a multiyear perspective. They may be considering a dynamic adoption and diffusion problem with the intention of building brand loyalty by introducing Bt cotton to a larger base at a low price. If this were correct, then we would expect to see increasing prices over time. There is some limited evidence of this in recent years. The sensitivity of cotton varieties to meso-level agro-climatic influences means that Bt varieties are not perfectly substitutable across subregions. In the past year, Monsanto has started pricing varieties associated with different subregions differently, possibly in an attempt to price discriminate across regions with different expected Bt cotton benefits, and thereby capture additional rents.

Another influence on pricing is undoubtedly the international market. In their analysis of Bt cotton in Argentina, Qaim and DeJanvry conclude that

> the current [Argentine] price is almost 80% higher than the level that would maximize the monopolist's profits, . . . [and] is approximately the same as what U.S. farmers have to pay for Bt cotton. . . . A possible argument against more wide-spread international price discrimination may be the influence of the U.S. farm lobby, which fears that domestic producers might suffer competitive disadvantages. (pp. 826–27)

Thus, Monsanto might be holding U.S. prices slightly lower than domestically optimal levels in order to capture at least some rents from international markets.

Conclusions

Prior work on Bt cotton pricing exposed a conundrum: Monsanto and Delta and Pine Land apparently have a good deal of monopoly power, yet farmers reap the majority of the benefits from the innovation. In this paper, we attempt to resolve this conundrum by constructing and applying a model of monopoly pricing for heterogeneous farmers that is applicable to agricultural biotechnology. Comparative statics show that increases in heterogeneity decrease the monopolist's ability to extract rents. Application to Bt cotton shows that heterogeneity in farmers' valuations of Bt cotton explains over 80% of the discrepancy in the share of rents accruing to farmers (i.e., it explains why farmers get +80% of the rents that they accrue). Thus, we confirm the hypothesis that the primary reason why farmers are able to gain rents from Bt cotton is heterogeneity in the farmers' valuation of Bt cotton relative to non-Bt cotton.

In applying the model to Bt cotton, we calculated the monopoly price for Bt cotton conditional on the generated values for net economic benefits. The profit-maximizing technology fee is between \$41 and \$47/acre if potential adopters are risk-neutral, approximately \$9 to \$15/acre higher than the current fee. If they were to institute an optimum price, Monsanto and Delta and Pine Land would obtain approximately 52% of the rents, and farmers would collect approximately 48%.

Potential explanations for this suboptimal pricing discrepancy include accommodation for risk-averse adopters, competitive constraints to monopoly pricing as other companies aim to introduce potential substitute technologies, cash constraints, international pricing considerations, or that Monsanto is simply pricing suboptimally. If the last explanation is correct, then we expect to see significant increases in the price of Bt cotton over the next few years. More generally, we conclude that farmer heterogeneity is a significant deterrent to Monsanto earning greater rents from Bt cotton technology, but that Monsanto is leaving some money on the table (or in farmers' pockets).

This paper examined heterogeneous farmer valuations of new biotechnologies, but did not allow these valuations to change over time. An interesting avenue for further research would be to model endogenous shifts in valuation distributions over time, where the shifts might take into account changes in farm structure and farmer demographics, thus allowing for bidirectional causality between industry structure and innovation.

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Appendix. Derivation of Comparative Static Results

Parameterizing the distribution allows us to conduct traditional comparative static exercises. For example, suppose that the distribution is characterized by the mean, μ, and standard deviation, σ, and that these parameters are independent (e.g., as in a normal or log-normal distribution; a two-parameter distribution is useful to sign comparative statics for illustrative purposes). Rearranging the first-order condition and applying the implicit function theorem yields

$$\text{(A1)} \quad \frac{dp}{d\mu} = -\frac{-F_\mu + (c - p)f_\mu}{-F_p - f - pf_p},$$

where subscripts denote differentiation. We assume that the second-order condition holds, so that the denominator is negative. Signing the numerator requires additional assumptions. Since at the optimum $p \geq c$, sufficient conditions for the numerator (and hence $dp/d\mu$) to be positive are F_μ, $f_\mu < 0$. For example, suppose that F is unimodal, that p lies on the convex portion of the lower tail, and that shifting the mean does not alter the shape of the distribution (e.g., a normal distribution that is shifted to the right)—then $dp/d\mu > 0$. That is, as the average valuation increases, so does the price that the innovator charges.

Similarly, the effect of a change in variance is determined by

$$\text{(A2)} \quad \frac{dp}{d\sigma} = -\frac{-F_\sigma + (c - p)f_\sigma}{-F_p - f - pf_p}$$

(here we exploit the monotonic relationship between standard deviation and variance). Sufficient conditions for $dp/d\sigma > 0$ are F_σ, $f_\sigma < 0$; sufficient conditions for $dp/d\sigma < 0$ are F_σ, $f_\sigma > 0$. As with a shift in the mean, consider the case in which p lies on the lower tail of a unimodal distribution (e.g., hybrid corn, with essentially 100% adoption). Heuristically, consider a mean-preserving increase in the variance that "fattens" both tails of the distribution. To the extent that the optimal p lies in the fattened part of the lower tail, both $f(p)$ and $F(p)$ will increase as the tail gets fatter. Consequently, we would expect that for well-adopted innovations, $dp/d\sigma < 0$.

The change in profits as the mean of the distribution increases, evaluated at the optimal solution, is given by

$$\text{(A3)} \quad d\Pi/d\mu = (c - p)F_\mu(p).$$

A necessary and sufficient condition for profits to be increasing in μ is that $F_\mu < 0$. If we think of an increase in mean as shifting the entire distribution to the right, then the mass of the distribution to the left of any given point will decrease, and so profits will increase.

Similarly, the effect of an increase in variance is determined by

$$\text{(A4)} \quad d\Pi/d\sigma = (c - p)F_\sigma(p).$$

Analogously to the change in mean, the sign of the derivative is opposite to the sign of F_σ. Again, thinking of a normal distribution with an optimal price on the lower tail, we would expect $F_\sigma > 0$. That is, we expect the increase in variance to fatten the tail below the optimal price, increasing the number of nonadopters. This means that we expect profits to fall as variance increases.

For the case in which F is a two-parameter distribution that can be characterized by its mean, μ, and standard deviation, σ, the comparative statics are given by

$$\text{(A5)} \quad \frac{dCS}{d\mu} = \{-pf(p) - [1 - F_\mu(p)] + pf(p)\}\frac{dp}{d\mu} = [F_\mu(p) - 1]\frac{dp}{d\mu}$$

and

$$\frac{dCS}{d\sigma} = \{-pf(p) - [1 - F_\sigma(p)] + pf(p)\}\frac{dp}{d\sigma} = [F_\sigma(p) - 1]\frac{dp}{d\sigma}.$$

To examine these derivatives, consider the middle expression in the derivative with respect to the mean. Note that all effects work through the change in the price. The first term in the middle expression represents the loss in gross consumer gain from the displacement of the marginal consumer due to the price change. The middle term in parentheses represents the loss in consumer surplus due to higher prices paid by the inframarginal consumer. The third term represents the savings in expenditure because the marginal consumer no longer purchases; this term exactly offsets the loss in gross consumer gain from the displacement of the marginal consumer.

The effect of a change in mean depends on the sign of $dp/d\mu$. Following the discussion of Equation (A2), we assume F_μ, $f_\mu < 0$, so that $dp/d\mu >$

0 and $(F_{\mu} - 1) < 0$. In this case $dp/d\mu < 0$. In other words, the necessary and sufficient conditions for profits to be increasing in μ are sufficient for consumer surplus to be declining in μ.

Sufficient conditions for a change in variance to have a positive effect on consumer surplus are $f_{\sigma} > 0$ and $0 < F_{\sigma} < 1$. Since these conditions are also sufficient to show that profits are declining in the variance, in this case the greater the variance (standard deviation), the greater the proportion of rents that accrue to consumers (adopters) of the innovation.

This result formalizes the hypothesis that the reason for the high proportion of rents accruing to adopters of Bt cotton is the high degree of heterogeneity among potential adopters of Bt cotton.