Production System Competition and the Pricing of Innovations: An Application to Biotechnology and Seed Corn

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The American agricultural sector is undergoing a process of value differentiation, moving from a commodity orientation to a differentiated product orientation. This process is associated with closer coordination of different levels of the production chain and product differentiation at earlier earlier production stages. Elsewhere, we argue that these changes are due to changes in technology and demand, which are creating complementarities across various differentiation-enabling activities (Goodhue and Rausser). Biotechnology has been an important force driving this transformation. Previously, commodities such as corn were homogeneous products. With the advent of seed innovations such as high oil corn and high protein corn, farmers are now faced with the challenge of marketing a differentiated product in order to capture the price premium associated with the quality trait innovation.[1] One of the most notable organizational aspects of the agricultural transformation has been the reorganization of agricultural input companies into biotechnology-life science companies that cut across traditional demarcations. This reorganization is due in no small part to the nature of biotechnology innovations. Bio-engineered seeds are blurring the lines among traditionally separate agricultural input sectors. For example, insect resistant seeds substitute for insecticides and herbicide tolerant seeds complement a specific herbicide. Production decisions are no longer separable across inputs. Farmers now choose among production systems, or a set of inputs, rather than choosing inputs separately from each sector.

These advances in biotechnology are occurring concurrently with a movement of agricultural research from the public to the private sector. Historically agricultural research and development (R&D) was conducted by USDA research centers and land grant universities. Increasingly, agricultural R&D is shifting from the public sector to the private sector (Alston and Pardey; Frisvold *et al.*). Established intellectual property rights (IPR) are a prerequisite for investment in R&D; a firm must be confident that it can capture sufficient rents from innovation to cover its costs of

[1] Resistance to bio-engineering may imply another need for product differentiation. For example, Europe does not want to consume bio-engineered soybeans and hence they are reluctant to import American crops. Corn may need to be differentiated into bio-engineered and genetically unmodified corn as well as value-added products.

development. Legal developments over the past thirty years, as well as recent technical developments, are strengthening crop trait IPR (Fuglie *et al.*). In this more protective intellectual property environment, many key bio-engineering innovations are the patented intellectual property of private firms. For example, Mycogen owns 21 patents in the US to genes from *Bacillus thuringiensis* (Bt) that have been inserted into corn and cotton to confer resistance to the European Corn Borer (ECB) and the Cotton Bollworm, respectively (Kalaitzandonakes). The shift from public to private research may affect the distribution and magnitude of the welfare gains from research. Agricultural economists have utilized the standard economic arguments regarding the market power effect of patents on the pricing of the resulting innovation (Moschini and Lapan; Alston, Sexton and Zhang; Just and Hueth). While it is clear that patents provide protection for intellectual property, firms' ability to extract the full rents associated with the innovation is bounded by the availability of alternative production systems. As Moschini and Lapan note, if farmers' adoption constraint is binding on the firm, it will be unable to charge the monopolistic price for its innovation.

Evidence from case studies and industry sources shows that there is substantial competition in the seed market and between seeds and chemicals (Kalaitzandonakes, Renkoski, Begemann). Agro-biotechnology firms have monopoly rights to their innovations, but their innovations face competition in the market. This tension raises the following questions: How large are the rents to an innovation? What portion of the innovation rents can the agro-biotechnology firms capture? We argue that there is sufficient competition in the agricultural inputs sector so that the farmer's adoption constraint binds. Equivalently, firms' ability to exercise monopoly power in the pricing of their innovation is limited by farmers' ability to choose an alternative production system.

This analysis examines a simple question: does farmers' adoption constraint bind firms' pricing decisions? We develop a simplified calibrated simulation model of the production decisions of a south-central Iowa corn producer. Using the costs estimated by the model and actual test plot yields, we compare net returns for farmers choosing various hybrids. We then compare these results to actual hybrid corn seed prices. While we do not claim our findings provide precise measures of the cardinal returns to farmers, our methodology provides ordinal rankings. We find that the adoption rule appears approximately binding for corn with the Liberty Link gene, while corn with the Bt gene provides consistently higher returns than standard high yielding hybrids or Liberty Link hybrids. High oil corn consistently underperformed the other hybrids.

1. Conceptual Model

A profit maximizing farmer will choose the hybrid that results in the highest net returns, accounting for differences in revenues and in production costs, including both the direct cost of the seed and its effect on the cost of other inputs. The profit maximizing biotechnology firm will price its innovation based its ability to exercise market power. The farmer's adoption rule will translate into the biotechnology firm's pricing rule if there is sufficient competition in the seed input sector. As long as the farmer has alternatives to a seed innovation, the biotechnology firm will not be able to charge a monopolistic price that reduces net revenues obtained by the farmer below those he obtains with his next best alternative.

2. Empirical Model, Data, and Implementation

We construct an extremely simplified optimization model of a corn farmer's production decisions, calibrated for a south-central Iowa corn producer on a corn following soybeans rotation.[2] We examine the farmer's decisions for four corn hybrids: a high yield hybrid, which we use as our base hybrid, a Liberty Link hybrid which is resistant to the Liberty herbicide, a Bt hybrid which is resistant to the ECB, and a high oil hybrid that earns a price premium. We consider only those decisions that are most likely to vary by hybrid: the amount of nitrogen applied and whether or not to apply insecticides. For weed management, we do not have enough information to model weed

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[2] Our yield data are actual yields from field test plots, not expected yield, so our simulations do not precisely reveal the expected information driving the farmer's decision. If yield shocks are roughly proportional across hybrids, this is less important since we make ordinal rather than cardinal comparisons. To control for this, we are in the process of computing break even yields for a range of corn prices.

damage. Instead, we model the farmer's choice of a herbicide program as a function of his seed choice. The farmer will apply herbicide regardless of the seed chosen, but that the type of herbicide will depend on the seed hybrid. For each hybrid, the farmer maximizes net revenue excluding seed costs.[3]

This model depends on two key functions: the fertilizer-yield function and the insect damage function. For the fertilizer-yield function, we use the logistic function estimated by Reck and Overman (1996). $Y(A, \alpha, \beta, N) = A/1 + e^{(\alpha - \beta * N)}$ where Y is the actual yield, A is the maximum potential yield for the hybrid, α is the intercept parameter in bushels/acre, β is the response coefficient in lbs nitrogen/acre, and N is the amount of nitrogen applied in lbs/acre. We use Reck and Overman's estimates for α and β, which are constant across hybrids.

We use the insect damage function described by Carlson and Wetzstein (1993) and the Iowa State Integrated Crop Management website (6/11/98). Farmers scout their corn fields, counting the number of insects per plant. Farmers chose to apply insecticides when the marginal value of the crop saved from insect damage equals the marginal cost of treatment. $I(D, P, E, App) = D * P * (1 - E * App)$ where I is the actual insect damage in percentage of yield, D is the percent yield damage per insect, P is the density of the insects measured by average number of ECB per plant, E is the effectiveness of the insecticide measured in percent of insects killed, and App is a binary variable for the choice to apply the insecticide. If the farmer chooses not to apply insecticide ($App = 0$) then the crop suffers the full damage from the insects: $I(D, P, E, App) = D * P$.

The rest of the farmer's decisions are not affected by hybrid characteristics and are treated as constant. For instance, farmers will till the field, fumigate for rootworm, and harvest the corn regardless of the hybrid. Seed costs are not included in the net revenue calculation so that the net

[3] **Base Model:** We assumed the price of No. 2 Yellow corn was $2/bu, the corn was planted at 30,000 kernels/acre. Our information on the price of fertilizer, lime, standard herbicide, labor, and land came from "Estimated Costs of Crop Production in Iowa 1997". Costs of drying corn, applying insecticide and herbicide came from the 1998 Iowa Farm Custom Rate Survey. Further information on the price of herbicides came from Cargill's website (1/8/99). Information on the high oil corn premium came from Eddyville Corn Milling (8/5/98) and Iowa Farmer Today, 12/19/98. Our corn seed prices from Pioneer and Cargill are for Spring '99.

revenue associated with a seed hybrid represents the maximum price the farmer would pay for the seed. We view the high yield hybrid as the base hybrid; Begemann and Kalaitzandonakes comment that since yield is the standard measure of performance, biotechnology firms couple quality traits with already high yielding germplasm in order to maximize the value of the innovation. Hence the net revenue gains from the other hybrids over the base hybrid can be viewed as the revenue gains from the innovation.

We use the mathematical programming approach for two reasons. First, we determine the net revenue advantage of seed innovations by comparing their estimated net revenue to the net revenue of the base hybrid. Second, we have collected corn seed price lists and we compare actual prices to the estimated net revenue gain. While the simplified nature of our model limits our ability to make direct comparisons of absolute values, we are still able to make ordinal comparisons. This allows us to make judgments about whether the premium charged by biotech companies for bio-enginered innovations is consistent across firms and innovations. To implement this we compare the net revenues before seed costs calculated above to net revenues after actual seed costs, to see if the relative profitability of different hybrids is altered.

Second, we can vary parameters such as insect pressure, herbicide price, fertilizer price, insecticide price, etc. As these parameters change, so does the net revenue advantage of each innovations. Under different circumstances, different innovations will dominate in terms of the farmer's net revenue. Assuming the farmer's adoption constraint is binding, we can illustrate that the firm's incentives to innovate depend on the firm's other activities. For instance, a company like AgrEvo, which owns both the Liberty herbicide and the Liberty Link gene, can choose the price of the Liberty herbicide to increase the net revenue advantage of the seed. Since the Liberty herbicide and the Liberty Link gene are complements, a reduction in the price of Liberty herbicide will increase the demand for Liberty Link Seed, and vice versa.

Clearly, our model suffers from all the weaknesses of programming models, and is further hampered by its simplified form. We do not claim to make estimates of actual revenues obtained by farmers with our simulations; rather, we are trying to gain some perspective on how seed costs for different innovations compare in terms of their ability to capture net gains from the innovation.

3. Results

We tested the sensitivity of the representative farmer's net revenue associated with each hybrid[4] tested with respect to exogenous factors such as the number of pests, the price of corn and the price premium for high oil corn. Figure 1 shows that as insect pressure increases, and before seed costs are subtracted, Bt corn net revenue dominates all other hybrids. Figure 2 shows that after seed costs are subtracted, Bt corn only net revenue dominates when the ECB reaches a density of one per plant. As the insect pressure increases, the farmer's portion of the net revenue gains increases substantially. There is one other point to note in Figures 1 and 2: the slope of the net revenue curves for non-Bt hybrids changes at 2 ECB per plant, when the farmer begins to apply insecticides. Empirically, we would expect south-central Iowa farmers who plant relatively early to adopt Bt hybrids, since early corn is most susceptible to first-generation corn borers. For corn planted later in the season, the seed cost is more likely to outweigh the benefit of adoption.

Figures 3 and 4 show that as the price of corn increases, so does the net revenue for all hybrids. As the price of corn increases, farmers apply more fertilizer and are more likely to apply insecticides. For the high yield hybrid, the farmer applied 102 lbs/acre at $1.90/bu and 123 lbs/acre at $3.00/bu and once the price of corn reached $2.90/bu, the farmer started to apply insecticides. Again, the relative net revenue performance of the hybrids changed once seed costs were subtracted. Bt corn provided slightly higher returns than the base variety at all price levels, even after seed costs were

[4] We selected the highest yielding hybrids from a sample of Pioneer hybrids. High yield hybrid: 34G81 with average yield 185 bu/ac and price $41.21/ac. Bt hybrid: 33A14 with average yield 185 bu/ac and price $52.09/ac. Liberty Link hybrid: 32J49 with average yield 178 bu/ac and price $41.21/ac. High oil hybrid: 34K79 with average yield 162 bu/ac and price $52.46/ac.

subtracted. Before seed costs are subtracted, the high oil hybrid has a higher net revenue than the Liberty Link corn at corn prices below \$2.30. After seed costs, Liberty Link corn has a much higher net revenue than the high oil hybrid across the tested range of prices.

Figures 5 and 6 show that as the high oil premium increases, so does the net revenue for high oil corn. In Figure 5, before seed costs have been subtracted, high oil corn only has a net revenue advantage with respect to the high yield hybrid once the high oil premium reaches \$0.35/bu (almost double the \$0.20/bu premium offered by Eddyville Milling in November, 1998). Once seed costs are subtracted, the high oil hybrid results in lower net revenues than all of the alternatives, across all the evaluated premium levels. The poor net revenue performance of the high oil hybrid reflects the high seed price and the low average yield.

We also examine the sensitivity of the farmer's net revenue associated with each hybrid with respect to the price of Liberty herbicide. This simulation is interesting due to the insight it provides into the effects of the multiple product pricing decisions under the control of the biotechnology companies. Figure 7 shows how net revenue minus seed costs changes with the price of the Liberty herbicide. The Liberty hybrid will have a positive net revenue gain above the high yield hybrid when the price of the Liberty herbicide is less than \$14/acre; Liberty herbicide currently costs about \$17.25/acre in Spring 1999. Note that even at low prices for the Liberty herbicide the net revenue advantage for Liberty corn is much smaller than the net revenue advantage for Bt corn. In part, this may be due to the inability of our model to control for weed damage; that is, our estimate of the net revenue change due to Liberty Link contains only the difference in herbicide cost. We do not include any difference in yields due to differential herbicide effectiveness.

We also examined the net revenue performance in a good year versus a bad year after seed costs for 20 hybrids from Pioneer and Cargill with base hybrid: Cargill 5677. We characterized a good year as having low pest pressure (0.5 ECB/plant) and nothing hindering yield. We characterized a bad year as having 10% yield loss due to weather, such as a very dry July and August, and in addition severe insect pressure (2 ECB/plant). Table 1 shows that the relative performance for many hybrids was different in good years versus bad years. Overall, Pioneer's Bt hybrids performed well compared to all other hybrids, which is consistent with the figures. Furthermore, Pioneer's Bt hybrids performed relatively better in bad years than good years. The high yield hybrids tended to perform relatively better in good years. Pioneer's Liberty hybrids performed relatively better than many of the high yield hybrids in both good and bad years. With the exception of the high oil hybrids, the ordinal ranking of net revenue performance matched the ordinal ranking of seed costs.

The only seed innovation that consistently outperformed the high yield hybrids was Bt corn. According to our simulations, the seed companies capture a substantial portion, but by no means all, of the net revenue advantage of Bt corn. That is, they are charging less than the adoption constraint allows. Perhaps, since several seed producers offer Bt hybrids, the seed companies are seeking to provide farmers an incentive to adopt their Bt corn, or using their Bt hybrids as loss-leaders for farmers' entire seed order. Another explanation is that since farmers can lose money with Bt corn (relative to high yield corn) in years with little or no insect pressure, the seed companies could have priced Bt corn to capture *expected* net revenue gains. Of course, the simplifications in our model may have failed to capture a *relative* difference between Bt corn and the other hybrids that may account for the difference in net revenues after seed costs, such as a requirement to plant some non-Bt corn.

The Liberty Link hybrid performs similarly to the high yield hybrid and has the potential to outperform the high yield hybrid slightly if the price of the Liberty herbicide decreases or relative yield improves. Given the simplifications of our model it appears that the adoption rule essentially determines the price of the Liberty Link hybrids.

The most troubling result from our simulation analysis is the relative performance of high oil corn. Net revenue after seed costs for high oil corn is substantially lower than all the other hybrids.

Since we assume that high oil corn has the same production costs, with the exception of higher drying costs, as the base hybrid (which if anything understates production costs due to the need to separate the product from harvest until delivery), this result is unlikely to be an artifact of the simplifications in our model.[5] This conclusion may be due to our data on yields; if weather reduced high oil corn yields disproportionately to other hybrid yields, then our estimated net returns would be distorted downward. Of course, such a distortion can not explain the result fully, since the possibility of such an event should affect the *expected* returns to the high oil hybrid, and hence the farmer's adoption rule and the firm's pricing decision. Given the limitations of our model, the relatively low net returns to high oil corn suggest that firms *may* have mispriced this innovation. Alternatively, farmers may not include high oil corn in the same set of possible production alternatives as the others, so that our analysis is comparing noncomparable products. A third explanation returns to the tendency of value differentiation to promote closer coordination across different stages of the production chain. Anecdotally, high oil corn is more likely to be produced under a marketing contract than the other hybrids. Our analysis does not account for any differences in costs or premiums due to the contractual relationship; for example, a farmer contracting with a biotechnology company that produces chemicals may receive a discount on that company's chemicals. The farmer may not have to pay delivery costs, or may receive an additional payment for storing the differentiated high oil corn on his farm.

4. Conclusion

There is widespread concern among researchers and others in the agricultural sector regarding the implications of the shift from public to private agricultural research for the magnitude and distributions of welfare gains from innovation. In order to predict the behavior of biotechnology firms, it is important to understand the demand side of their market. Earlier research has noted

[5] Of course, this would not be true if, say, high oil hybrids were less susceptible to ECB or required less herbicide, but this seems fairly improbable.

that if farmers' adoption constraint binds, firms will not be able to charge the monopoly price for their innovations. We examine whether the adoption constraint binds for corn farmers in south-central Iowa using a simplified mathematical programming model of the farmer's decision process. Subject to the caveats noted earlier, we find that the adoption constraint roughly binds for the case of Liberty Link corn, and that farmers may obtain some of the gains from Bt corn. These results indicate that monopoly pricing may be less important under some conditions than is conventionally believed, although our analysis provides suggestive rather than conclusive evidence.

Table 1: Compares the seed cost and net revenue performance of 20 hybrids from Pioneer and Cargill to the base hybrid: C-5677.

Hybrid	Type	Seed Cost/ Acre	Seed Cost/Acre above base	Net Revenue above base,bad year (Rank)	Net Revenue above base,good year (Rank)
C-6890TC	High Oil	56.63	20.63	13.75 (19)	-16.45 (18)
P-34K79	High Oil	52.46	16.46	20.29 (6)	24.75 (8)
P-33A14	Bt	52.09	16.09	45.13 (2)	32.59 (2)
P-35N05	Bt	50.96	14.96	34.1 (3)	20.19 (7)
P-34R07	Bt	50.96	14.96	53.04 (1)	41.47 (1)
P-33Y09	Bt	50.96	14.96	29.39 (4)	14.89 (9)
C-7821	Bt	46.5	10.5	15.3 (10)	-0.97 (17)
C-8021	Bt	43.13	7.13	-0.26 (18)	-18.49 (20)
P-36H75	Liberty	41.21	5.21	19.283 (7)	22.15 (5)
P-34K77	High Yield	41.21	5.21	12.86 (11)	15.54 (8)
P-34G81	High Yield	41.21	5.21	21.47 (5)	25.93 (3)
P-32J49	Liberty	41.21	5.21	19.43 (8)	21.81 (6)
C-5021	Bt	40.13	4.13	16.86 (9)	0.79 (15)
P-3489	High Yield	39.71	3.71	8.57 (13)	10.35 (11)
P-3335	High Yield	39.71	3.71	7.14 (14)	8.62 (12)
C-4111	High Yield	39	3	5.71 (16)	6.89 (14)
C-7770	High Yield	37.5	1.5	-14.18 (20)	-17.17 (19)
C-6888	High Yield	37.5	1.5	5.71 (15)	6.89 (13)
C-6303	High Yield	36	0	11.43 (12)	13.81 (10)
C-5677	High Yield	36	0	0 (17)	0 (16)

Figure 1: Net Revenue before Seed Costs and Insect Pressure

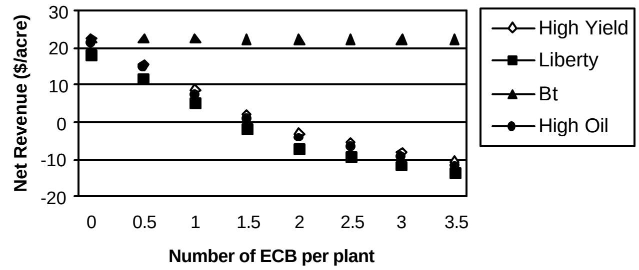


Figure 2: Net Revenue and Insect Pressure

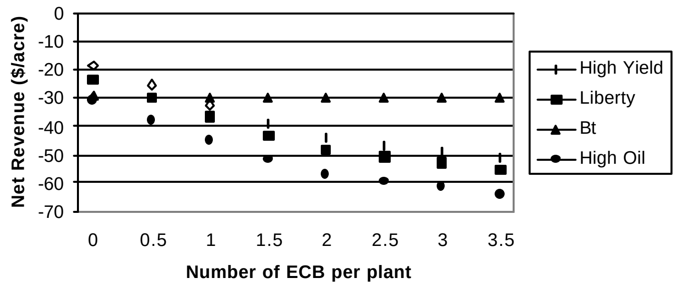


Figure 3: Net Revenue before Seed Costs and Price of Corn

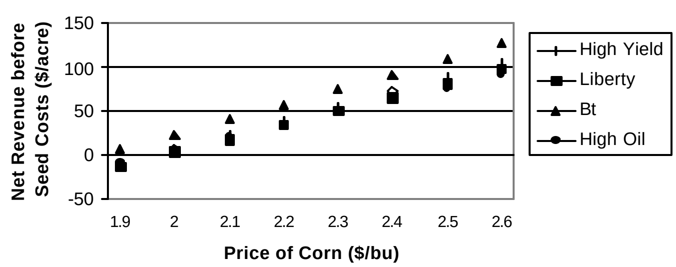
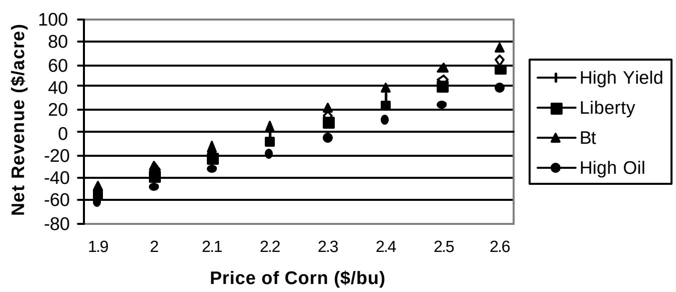


Figure 4: Net Revenue and Price of Corn



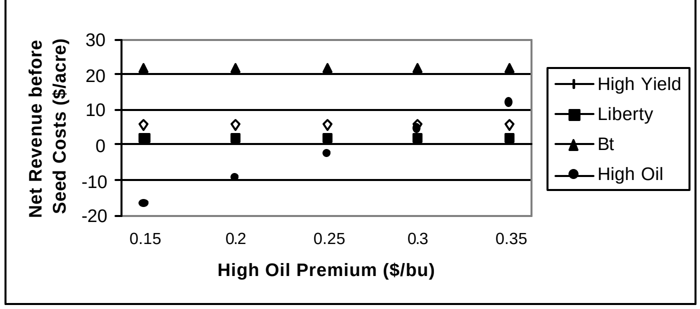


Figure 5: Net Revenue before Seed Costs and the High Oil Premium

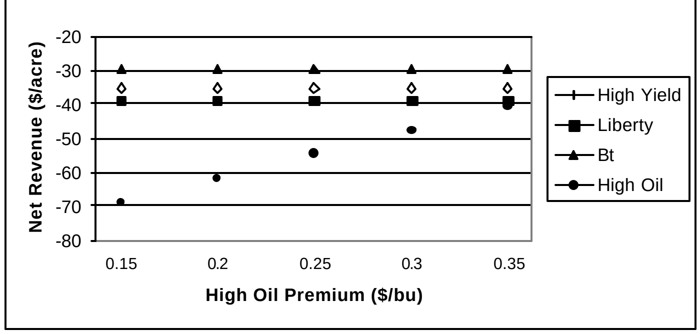


Figure 6: Net Revenue and the High Oil Premium

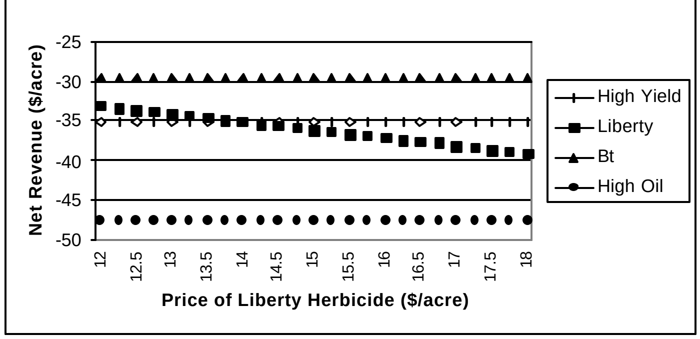


Figure 7: Net Revenue and Price of Liberty Herbicide

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