MARKET STRUCTURE AND INNOVATION IN AG-BIOTECHNOLOGY

by

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I. Introduction

Between 1995 and 1998, a striking feature of the plant biotechnology industry structure was its increasing concentration, accomplished primarily through mergers and acquisitions (M&A). The consolidation in the vertically integrated seed, biotechnology and chemical markets resulted in concentration in specific output and innovation markets. Kalaitzandonakes and Hayenga (2000) report that in 1998, Monsanto and Pioneer Hi-Bred had, respectively, a market share of 15% and 39% of the U.S. seed corn market, and 24% and 17% of the soybean seed market. The cottonseed market is essentially controlled by Delta and Pine Land (with a 71% market share) and Stoneville (with a 16% market share) (Kalaitzandonakes and Hayenga, 2000). Brennan, Pray and Courtmanche (2000) provide preliminary evidence of concentration in the plant biotechnology R&D market. Using firm level data on field trials of genetically modified organisms (GMOs) in the U.S., they construct a four firm concentration ratio for innovation in plant biotechnology. In 1998 the top four firms conducted 87% of all field trials, which declined to 63% in 1995 and then rose to reach a high of 79% in 1998 (Brennan, Pray and Courtmanche, 2000). Whereas the evidence of concentration in the plant biotechnology industry is compelling its implication on output, innovation and market performance is somewhat ambiguous

The effect of different market structures on economic performance and social welfare is a key issue for market economies. Increase in market concentration raises concerns that the market power associated with monopolistic (and oligopolistic) behavior will result in static allocative inefficiencies. Schumpeter (1934) argued that a few firms were more likely efficiently to develop and employ more advanced technology than a competitive industry. Formal models of firms' innovation-seeking behavior have evolved, that have either confirmed or refuted the so-called 'Schumpeterian tradeoff.'[1] Similar to the mixed theoretical results, the findings of the vast empirical literature on the Schumpeterian tradeoff are mixed and ambiguous as no obvious relationship between industrial concentration and R&D performance emerges from the data.

[1] For a review of this literature see Kamien and Schwartz (1982) or van Cayseele (1998). Among the many writers who subscribe to Schumpeterian are Kamien and Schwartz (1982). The claim has been challenged by Arrow (1962) and Dasgupta and Stiglitz (1980).

In this paper we take a long-run perspective on product innovation in biotechnology research and explore how the incentives to innovate for firms are shaped by two features of the ag-biotech R&D market. The highly concentrated upstream market (the R&D market) and a competitive downstream market, suggests that firm's R&D decisions are a consequence of the demand for the R&D output (or farmer's input) and the strategic interaction with other firms in the R&D market. A second feature is the observed cyclical nature of concentration and R&D effort in the ag-biotechnology that has been reported by Oehmke et. al. and Kaliatzandonakes and Hayenga. Industry concentration seems to move pro-cyclically with M&A activity (Oehmke et al.). Since M&A activity has increased dramatically over the past four years, concerns about continued increases in R&D industry concentration arise (Brennan, Pray and Courtmanche). Oehmke et. al. showed that depending on the level of productivity increase generated by the innovation, the level of R&D may decrease or exhibit cyclical behavior, but in either case, the industry becomes more concentrated. The research issue than is to examine how concentration will affect the rate of innovation in the *long* run?

However any analysis of the long-run relationship between innovation and market structure requires that the mechanism of how the demand for an innovation by a farmer drives the research effort of the R&D firm be understood. If in the long run, with free entry and exit, the profits of the innovating firm's are assumed to be zero, do incentives for R&D exists? In this paper we show that this question can be answered in the affirmative, which suggests that the nature of market structure (in the short run) may be moot, as in the long run productivity increasing innovations will occur in spite of the cyclical nature of concentration and innovation.

The plan of the paper is as follows. The next section presents the model. Section 3 presents the simulation and discussion and section 4 concludes the paper.

II. Theoretical Model

This analysis is conducted in a vertical relationship framework. There are two successive stages in the vertical production-distribution chain for a biotechnology innovation (for example a biotech seed) . The upstream stage of this vertical chain consists of the suppliers of the innovation (R&D firms), while the downstream stage consists of the users of the innovation (i.e., farmers)

R&D firms ("seed suppliers" from here onwards) incur research and development (R&D) cost in their effort to produce a better or improved version of bio-tech seed. Consumers of the innovation ("farmers" from here onwards) see the price of the bio-tech and make their purchasing decisions. It is assumed that the better the quality of bio-tech seed (in terms of its efficacy, etc.), the more it is demanded by farmers. It is also assumed that this improvement in the quality of the bio-tech seed is directly proportional to the amount of R&D investment made by the bio-tech firms to produce a better quality bio-tech seed.

The research question that we address in this paper is whether demand for bio-tech seed gets translated into investment in R&D by bio-tech firms? This is not an easy question to answer and we make several simplifying assumptions (for this article) on our way to answer that question. Note that such assumptions will be relaxed in the future (see the Conclusion section for details).

Our assumptions include, (a) instead of individual firm behavior, we consider an aggregate bio-tech seed industry behavior, (b) similarly, we consider an aggregated farmers' behavior, (c) we assume that the bio-tech firms are operating in the long-run and (d) the R&D investment is considered as a lump-sum cost, i.e., something like fixed costs

The upstream bio-tech industry's objective function is given by -

(1) $$\max \Pi^{Bio}(q,z) = Pq - cq - z$$

where P is the price of bio-tech seed per unit (charged by the bio-tech firms and paid by farmers), q is the amount of bio-tech seed produced by the bio-tech industry in a given year, c is the marginal cost (constant) of producing an unit of bio-tech seed, and z is the lump-sum investment in R&D by the bio-tech seed industry in order to produce better quality seed, and z. We assume that $P > 0$, $q > 0$ and $z \geq 0$. Note investments in R&D by the biotech firm results in a product innovation rather than a product innovation.

In the long run, the input demand for the biotech product is derived as follows

$$
\begin{aligned}
&\Pi^{Bio}(.) = 0 \\
&or\ (P - c)q - z = 0 \\
&or\ P = c + z / q \\
&or\ w1 = c + z / v_1,
\end{aligned}
\qquad \textbf{(2)}
$$

where, v_1 = amount of bio-tech seed demanded by farmers which equals to the amount of bio-tech seed produced by the seed suppliers, ie., $v_1 = Q.$ Similarly, w_1 = per unit price bio-tech seed paid by farmers which equals the per unit price charged by the seed suppliers, i.e., $w_1 = P.$ From equation (2), we obtain the price for bio-tech seed as follows:

(3) $$P = w_1 = c + (z / v_1)$$

The downstream farmers' conditional input demand for the bio-tech seed is given by

(4) $$v_1 = f\ (w_1, w_2, Y),$$

where, w_2 = per unit price paid by farmers for non-seed inputs, e.g., pesticides, and Y = aggregate farm output, and $Y = f\ (v_1, v_2)$, where v_2 = amount of non-seed input used by farmers. We assume that for a given amount of Y, inputs v_1 and v_2 are substitutes, i.e., an increase in the use of one would result in a decrease in the use of the other.

Assuming a Cobb-Douglas production function for farmer's output, we can rewrite equation (4) as follows:

(5) $$v_1 = y\left(\frac{w_2}{w_1}\frac{\alpha}{1-\alpha}\right)^{1-\alpha}$$

and

(6) $$v_2 = y\left(\frac{w_1}{w_2}\frac{1-\alpha}{\alpha}\right)^{\alpha}$$

Substituting equation (3) for w_1 and solving for v_1 and v_2 (assume $\alpha = 0.5$), we obtain,

(7) $$v_1 = \frac{-z + \sqrt{4cw_2 y^2 + z^2}}{2c}$$

and

(8) $$v_2 = y\left(\frac{c}{w_2} - \frac{2czw_2}{\sqrt{4cw_2 y^2 + z^2} - z}\right)^{1/2}$$

Equation (7) yields the amount of bio-tech seed demanded by farmers and can be written in its generic form as follows:

(9) $$v_1 = f\ (w_1,\ w_2,\ Y,\ z,\ c),$$

that is, bio-tech seed demand is a function of farmers' input prices (because bio-tech seed is substitutable with farmers' other non-seed input), farm output, R&D investment (impacts the demand for bio-tech seed by improving quality of bio-tech seed), and bio-tech firms' cost of production (which impacts the price of bio-tech seed, w_1).

It is clear from equation (9) that although farmers' only see the price of bio-tech seed and use their knowledge of seed quality to purchase such seed, their decision to purchase influences the R&D investment by bio-tech firms. Thus, through equation (9), we are able to establish a relationship between farmers' demand for bio-tech seed and R&D investment by bio-tech firms. Now, to address the question as to how farmers' demand for biotech seed influences R&D investment by biotech firms, we resort to comparative static analysis. We use equations (7) to address this question. In addition, we also explore the impact of an increase in competing input prices on seed demand as well as other variables of economic interest.

Comparative static analysis shows that

(10) $$\frac{\partial v_1}{\partial z} = -\frac{1}{2c} + \frac{cz}{2\sqrt{4cw_2 y^2 + z^2}}$$

(11) $$\frac{\partial v_1}{\partial w_2} = \frac{y^2}{2\sqrt{4cw_2y^2 + z^2}} > 0$$,

(12) $$\frac{\partial v_1}{\partial c} = \frac{z}{2c^2} - \frac{c^2\left(cw_2y^2 + 0.5z^2\right)}{\sqrt{4cw_2y^2 + z^2}}$$

(13) $$\frac{\partial v_2}{\partial z} = -\frac{c^2x^3F}{\left(cw_2y^2 + 0.25z\right)\left(z - F\right)^2\left(\frac{c}{w_2} - \frac{2czw_2}{-z + F}\right)^{1/2}} < 0$$

where $F = \sqrt{4cw_2y^2 + z^2}$.

From equation 10, we note that the input demand for the biotech seed with respect to R&D is ambiguous. At low levels of R&D, input demand for the biotech seed is decreasing but with increasing levels of research, the demand is increasing. Our simulation (Table 1) however suggests that R&D decreases the demand for biotech seed for a large range of research levels. Our interpretation of this result is that R&D increases the productivity of the input and therefore farmers decrease its per unit use. On the other hand research unambiguously decreases the need for the substitute as the productivity of the other input has increased. Our comparative results also shows, as per standard theory, the demand for biotech input increases as the price of the substitute increases. Simulation analysis was conducted to test our model. For this purpose, we assume ad-hoc values for various variables that are present in equations (7) and (8). Note that regardless of the ad-hoc nature of the values assumed for simulation, the robustness of the model presented earlier is sustained.

III. Simulation Results

We summarize the simulation and comparative static results as follows:

- Demand for biotech innovation is decreasing with increasing research as well as with increasing marginal cost of production. It is increasing with increasing output and a rise in the price of the substitute.
- Price of the biotech seed is increasing with higher research and increasing marginal cost. The price of biotech seed is decreasing with increasing output and price of the substitute.
- The demand for the substitute is increasing with higher amounts of research (comparative static result shows otherwise), increasing in the marginal cost of production of the biotech seed, and final output. It is however decreasing in own price.

Table 1: Simulation Results

$c=10; y=1000; w_2=10$	z =0	z =5	z =10	z =100	z =500	z =1000
v_1	1000.	999.75	999.5	995.012	975.312	951.249
v_2	1000.	1000.25	1000.5	1005.01	1025.31	1051.25
P	10	10.005	10.01	10.1005	10.5127	11.0512
$z=10; y=1000; w_2=1$	c =0.05	c =0.5	c =1.0	c =2	c =5	c =10
v_1	14042.5	4462.15	3157.28	2233.57	1413.21	999.5
v_2	71.2124	224.107	316.728	447.714	707.607	1000.5
P	0.0507121	0.502241	1.00317	2.00448	5.00708	10.01
$c=10; z=10; w_2=10$	y =0.05	y =10	y =100	y =500	y =1000	y =10000
v_1	0.00249378	9.51249	99.5012	499.5	999.5	9999.5
v_2	1.00249	10.5125	100.501	500.5	1000.5	10000.5
P	4019.98	11.0512	10.1005	10.02	10.01	10.001
$c=10; y=1000; z=10$	w_2 =.05	w_2 =.5	w_2 =1	w_2 =2	w_2 =5	w_2 =10
v_1	70.2124	223.107	315.728	446.714	706.607	999.5
v_2	14242.5	4482.15	3167.28	2238.57	1415.21	1000.5
P	10.1424	10.0448	10.0317	10.0224	10.0142	10.01

IV. Concluding Remarks

In this paper we have made a modest effort to examine the relationship between the farmer's demand for a biotech seed and how that demand affects the incentive to innovate at the firm level. We have taken a long run perspective to examine this relationship and understand the implication of the Schumepeterian tradeoff in the long run. Given our long-run assumption in the model presented here, we plan to develop a more realistic model of the bio-tech seed industry which will capture strategic oligopoly behavior. However, without a functional form for z as a function of farm demand for biotech seed, i.e., $z = f(q)$, it is *mathematically* not possible to solve for market clearing solutions (we tried). We hope to study this issue of functional form and solve this problem over the summer. This will also cure the problem of our current assumption of R&D as lump sum cost to the biotech firms and would allow us to develop a more realistic model of R&D investment. Once the issue of functional form is resolved, we hope to revise this article and report new results. We welcome suggestions and comments from the readers and offer our thanks in advance.

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