The Biotechnology Sector: "Bounds" to Market Structure

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Abstract:

This paper examines whether it makes sense to consider Sutton's "bounds" approach as a candidate theory for explaining the recent evolution of market structure in the biotechnology sector, and to speculate whether market structure will change if the industry begins to introduce second-generation GM products that are of more direct benefit to consumers. A key result is that the market structure is bounded in the presence of endogenous sunk costs, implying care should be taken when inferring any correlation between R&D expenditure and seller concentration in the biotechnology sector.

JEL Classification: L1, L11

Keywords: Biotechnology, market structure, "bounds"

1. Introduction

Since the introduction of genetically modified (GM) crops in the mid-1990s, considerable concern has been expressed about GM food by a wide number of groups, including farmers, consumer groups, retailers and governments (Sheldon, 2002). While much of the discussion has focused on food safety and environmental issues relating to GM foods, some of the public opposition to agricultural biotechnology has been based on the concern that a few large firms will exercise control over the global food supply (Harhoff, Régibeau and Rockett, 2001). Related to this is the concern that firms in the biotechnology sector will not develop products that are beneficial to society, rather there will be systematic biases in the types of GM crops that private firms will select for development. These concerns about the industry revolve around two well-known arguments from the industrial organization literature: first, what determines market structure; and second, to what extent is there a causal link between market structure and the extent and nature of innovation?

In the case of agricultural biotechnology, there is evidence for extensive consolidation in the sector both in terms of both patent and firm ownership (Harhoff *et al*., 2001; Graff, Rausser and Small, 2003; Pray, Oehmke, and Naseem, 2005; King and Schimmelpfennig, 2005; Brennan, Pray, Naseem and Oehmke, 2005; Marco and Rausser, 2008). For example, King and Schimmelpfennig (2005) report that since 1998, just six firms, Dow, Dupont, Monsanto from the US, and BASF, Bayer, and Syngenta from Europe, have accounted for over 80 percent of GM crop trials for release in the US. By 2002, the same six firms also accounted for over 40 percent of private-sector agricultural biotechnology patents issued in the US. Much of this concentration of biotechnology patent ownership has been due to extensive merger and acquisition activity in the sector. Pray *et al*. (2005) report a flurry of mergers and acquisitions between 1994 and 2000

in the five major GM crops in the US, corn, cotton, potatoes, soybeans and tomatoes, with a peak of 22 mergers in 2000. This process of consolidation appears also to have had a significant impact on the concentration of patent ownership in both the US and European Union, where the six-firm concentration ratio for patents rose from 36 to 50 percent, and from 32 to 53 percent, respectively (Harhoff *et al*., 2001). The levels of observed market concentration are even higher when the focus shifts to products approved for inclusion in food, the top three firms, Monsanto, AgroEvo, and Novartis, accounting for 66 percent of approvals by the end of the 1990s (Harhoff *et al*., 2001).

Such concentration ratios are well over the levels that typically trigger concern by the anti-trust authorities about the impact of mergers and acquisitions on market structure. In addition, some analysts have also begun to ask whether such an increase in seller concentration has a negative or positive impact on the degree of innovation in agricultural biotechnology. For example, Brennan *et al*. (2005) argue that the leading biotechnology firms have the *ability* to decrease total industry investment in research and development (R&D) because of the concentration of patent ownership. They also argue though that it is ambiguous whether the same firms have an *incentive* to reduce their innovatory efforts. Counter to this, the intensity of R&D expenditures in the biotechnology sector is clearly very high. Over the period 1996-2000, the ratio of R&D expenditures to product sales for US biotechnology companies averaged 71.4 percent, far exceeding the levels in industries such as drugs and medicines, where the ratio of R&D expenditures to sales was 10.5 percent over the same period (Lavoie, 2004).

While it is clear that the structure of the biotechnology sector has changed in the past decade, and that there may be some connection between market structure and innovation, the key jumping-off point of this paper is that the modern industrial organization no longer subscribes to

the view of early researchers such as Bain (1956) that market structure is determined exogenously by factors such as economies of scale and other barriers to entry, which in turn has a direct impact on the rate of innovation (Kamien and Schwartz, 1982). Instead the direction of causation debate that once raged over whether industries with high concentration generate more R&D activity or that industries in which firms conduct a good deal of R&D tend to become more concentrated, has been replaced with the widespread acceptance of the argument that in fact concentration and R&D intensity are both endogenous variables simultaneously determined within an equilibrium system (Dasgupta and Stiglitz, 1980; Sutton, 1998). This is supported by the fact that there is no empirical consensus in the literature as to the form of the relationship, if any, between R&D intensity and concentration (Cohen and Levin, 1989).

Therefore, the overarching question addressed in this paper is what might be the process that *jointly* determines market structure and innovative activity in the biotechnology sector, and how might it be affected by increasing integration of world markets? A recent paper by Roe and Sheldon (2007), which draws on the earlier work of Shaked and Sutton (1982, 1983), shows that market structure and efforts to improve product quality are jointly determined in a model where the fixed costs of R&D rise sharply with effort and where the distribution of income across the population of consumers takes a particular form. However, in some respects the model is very narrow in that it is quite sensitive to the fact that firms are assumed to play a Bertrand-Nash game in prices, and that in equilibrium, changes in the size of the market have no impact on market structure but simply result in higher quality products in equilibrium. Such a result seems at odds with the possibility that as markets grow due to greater international integration, they will in fact become more fragmented in terms of firm concentration. Consequently, in this paper we explore the relevance of the more general "bounds" approach to market structure laid out by

Sutton (1991, 1998), and summarized in his recent chapter in the third volume of the *Handbook of Industrial Organization* (Armstrong and Porter, 2007). This approach ties down the circumstances under which markets become more fragmented as they become larger, and the conditions under which such convergence breaks down in the presence of endogenous sunk costs of innovation.

In this context, the specific objective of this paper is to examine whether it makes sense to consider Sutton's "bounds" approach as a candidate theory for explaining the recent evolution of market structure in the biotechnology sector, and to speculate whether market structure will change if the industry begins to introduce second-generation GM products that are of more direct benefit to consumers. The remainder of the paper breaks down as follows: in section 2, a brief rationale is given for why analyzing market structure in the biotechnology sector matters, while in section 3, the core ideas in Sutton's "bounds" approach are outlined along with brief discussion about how relevant the model might be for understanding structural change in the biotechnology sector. Finally in section 4, the paper is summarized along with some concluding remarks.

2. Rationale for Analyzing Market Structure in Biotechnology

The very recent evolution of the biotechnology industry and the rapid adoption of GM crops have provoked intense public debate about the future direction of the industry. This paper focuses on one key aspect of this debate: the nature of market structure in the agricultural biotechnology sector and its interaction with innovation, as well as the impact of the GM food regulatory system on market structure. Understanding how market structure is evolving in the

biotechnology sector, therefore, has important implications for the sector itself as well as farmers, consumers and regulators.

Importantly, this paper is the first to suggest applying Sutton's "bounds" approach to analyzing market structure in the biotechnology sector, focusing on the extent to which seller concentration is a function of endogenous sunk costs such as R&D outlays on new products, as opposed to the more traditional argument based on exogenous sunk costs. The beauty of applying this model, as witnessed by Sutton's (1991, 1998) own research, is not only its theoretical rigor, but also that it can be implemented empirically in a fairly straightforward manner through collection of some key parameters, as well as through the use of more traditional case-study analysis. In addition, the model can be used to assess how market structure of the biotechnology industry might change as firms develop second-generation GM crops in an environment of increased regulatory vigilance.

The rationale for a comprehensive understanding of market structure in the development and marketing of GM products is the oft-expressed concern by both farmers and food consumers in the US and Europe that increasing seller concentration in this industry will result in too much control over the food system being vested in the hands of a few multinational firms who may not invest in developing new products with the greatest social benefit, both in terms of increased production in agriculture, as well as the supply of traits beneficial to consumers.

The concerns of farmers and consumers might be dismissed on the grounds that they simply represent the typical fears of the former about other actors in the food marketing chain, and that consumer concerns are those of a small minority with a strong anti-corporate bias. However, the increase in seller concentration in the biotechnology sector has already resulted in serious analysis by some observers of the industry. While there may be perfectly legitimate reasons for

an industry becoming concentrated, there is a concern that there will not only be a static welfare loss associated with this rise in seller concentration, but that firms will also abuse their market dominance by engaging in anti-competitive practices. For example, Harhoff *et al*. (2001) argue that the integration of seed and agricultural chemical firms may have biased the types of GM crops introduced by the sector. In addition, business contracts such as tie-in contracts between GM seeds and complementary products such as herbicides may be exclusionary in nature and therefore grounds for anti-trust scrutiny.

The breadth of the debate about biotechnology and GM food also creates a dilemma for the regulator (Harhoff *et al*., 2001). On the one hand, increased rigor of the regulatory approval process, notably in the European Union, has partly been a response to the concerns of consumers and NGOs about the safety and environmental impact of GM crops. On the other hand, tougher regulation of GM crop approval may create a barrier to entry, affecting seller concentration in two ways: first, large firms with extensive experience of similar regulatory processes will initially own a larger share of approved products, although this "expertise effect" will eventually be dissipated over time; second, costly approval procedures increase sunk costs, and therefore reduce the number of firms actively developing GM products for regulatory approval, an effect that will persist over time.

3. The "Bounds" Approach to Market Structure

Market Structure and Innovation

Early analysis of innovation in industrial organization drew on Bain's (1951) structure-conduct-performance (SCP) paradigm which argued that levels of concentration in an industry (structure), determine pricing behavior of firms in that industry (conduct), which in turn affects dimensions

of market performance such as price-cost margins and R&D outlays relative to sales. A key assumption of this model is that market structure is determined exogenously by given barriers to entry such as economies of scale. This model was widely applied in the industrial organization literature (Schmalensee, 1989), as well as in the agricultural economics literature, notably in the work of the NC 117 Regional Research Committee (see Marion, 1985; and Connor, Rogers, Marion and Mueller, 1985). By the mid-1970s, however, the SCP paradigm began to be questioned generally in the industrial organization literature (Cowling and Waterson, 1974; Jacquemin, 1987), and specifically in the empirical literature on market structure and innovation (Cohen and Levin, 1989).

At this point, the so-called New Empirical Industrial Organization (NEIO) literature evolved, focusing on the econometric estimation of market conduct, with multiple studies in the industrial organization literature (Bresnahan, 1989; Perloff, Karp and Golan, 2007) and the agricultural economics literature (Sexton and Lavoie, 2001; Sheldon and Sperling, 2003). At the same time, several researchers returned to the old question of what actually determines market structure (Baumol, Panzar and Willig, 1982; Baumol, 1982; Panzar, 1989). A key contribution of this literature was the focus on what determines the optimal structure of an industry, both in the single and multiple-product cases.[1]

For example, in the single-product case, given minimum efficient scale of a plant is 10,000 units, and the industry output vector is 30,000 units, then the equilibrium market structure is one of three firms producing at minimum average cost. There was nothing particularly radical about this result, but Baumol and his collaborators drew fire because of their argument that as long as a market is perfectly contestable, firms in that market will produce at minimum efficient scale and

[1] The literature introduced the important concept of sub-additive cost functions to the analysis of both economies of scale and economies of scope.

price at marginal cost, unless they are a natural monopoly, in which case they will adopt second-best Ramsey pricing.[2] Perfect contestability occurs where entry and exit into a market is absolutely costless, such markets being vulnerable to hit-and-run-entry. Much of the criticism of the contestable markets literature focused on the assumption of costless entry, and the pricing reaction of incumbent firms. For example, Schwartz (1986) argues that even with ease of entry and exit, the ability of incumbent firms to change prices rapidly in response to entry could still result in markets being non-contestable. Notwithstanding the criticism, a key contribution of the contestable markets literature was to focus on the endogenous determination of market structure, simultaneously with the pricing, output and other decisions of firms.

The latter insight also carried over into the literature on innovation and market structure. Prior to the late-1970s, the literature in this area was dominated by two key hypotheses, typically associated with Schumpeter (1947): first, there is a positive relationship between innovation and monopoly power; and, second, large firms are more than proportionately innovative than small firms.[3] Counter to this, Arrow (1962) concluded that the incentive to innovate is less under monopoly than competition. Much of the early empirical work focused on seeking a correlation between the intensity of R&D, measured by the ratio of R&D expenditures to sales and some measure of seller concentration, and there was also considerable debate about the direction of causation, i.e., concentration to R&D intensity or vice versa (Sutton, 1996). This dispute was resolved theoretically by Dasgupta and Stiglitz (1980), who showed, that except in the very short-run, both market structure and innovative activity are endogenous. Consequently, the degree of seller concentration could not be taken as given, and is instead dependent on other conditions such as demand, the technology of research and so on. This has been followed up on

[2] See Sharkey (1982).
[3] As noted in Kamien and Schwartz (1982), while the first of these hypotheses is correctly attributed to Schumpeter, the second was probably due more to Galbraith (1952).

extensively in the work of Sutton (1991; 1997; 1998; 2007) has focused on the extent to which firm activities, such as product differentiation and R&D intensity are determined endogenously along with market structure.

Despite the theoretical arguments throwing doubt on the SCP approach, empirical work continued on what Sutton (1996) characterizes as the 'reduced-form' relationship between innovation and seller concentration. This empirical literature has been extensively reviewed by Cohen and Levin (1989), who note that while most studies have found a positive correlation between some measure of R&D intensity and seller concentration, the relationship is considerably weaker when industry-specific effects are controlled for. In addition, other studies find either a negative or a non-monotonic relationship.

In Sutton's (1996) view, the mixed empirical results on the correlation between R&D intensity and seller concentration are not that surprising. Specifically he suggests two reasons for this, which will be explored in the remainder of this paper in the context of the biotechnology sector: first, R&D intensity, as measured by R&D expenditures to sales ratios, is not a very good way of describing the technological characteristics of an industry; and second, any link between R&D intensity and seller concentration involves a "bounds" constraint, which will not be captured in a reduced-form regression specification across a sample of industries.

The Basic "Bounds" Approach

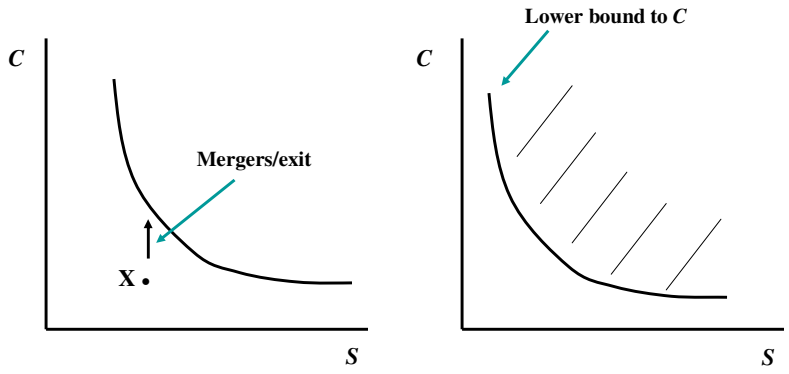
To fix the basic idea of Sutton's "bounds" approach, assume initially that firms in an industry sell a homogeneous product, and to do this they have to incur an exogenous sunk cost of ε, which might be thought of as the cost of acquiring a plant of minimum efficient scale, or the necessary technology to undertake production, after which they compete in price. It turns out that the equilibrium market structure C is a function of the size of the market S relative to sunk costs ε,

and the intensity of price competition. In the case of Bertrand-Nash competition, the market can only sustain one firm in equilibrium, as multiple entry drives price down to marginal cost, firms making a net loss of ε in equilibrium. Nested in this case is the perfectly contestable outcome referred to earlier, where sunk costs $\varepsilon = 0$, and a continuum of equilibria exist, i.e., two or more firms enter, price equaling marginal cost. As Sutton (1991) suggests, this is a "knife-edge" result where sunk costs have to be exactly zero.

In the case of Cournot-Nash competition, market structure becomes more fragmented as market size increases relative to sunk costs. More precisely, assume an iso-elastic demand schedule, $X = S/p$, where p is market price, X is quantity sold, and S is the size of the market, i.e., total expenditure. If N firms have entered the market, firm i's profit is $\pi_i = p_i(\sum x_j)x_i - cx_i$, where c are its constant marginal costs. When maximized with respect to x_i, given the rival firms' output choice, this yields the symmetric equilibrium price and output per firm, $p = c\{1 + 1/(N - 1)\}$ and $x = \{S/c(N - 1/N^2)$, and the equilibrium profit of each firm, $\pi = (p - c)x = S/N^2$. Given the entry decisions of its k rivals, a firm i will incur a sunk cost ε on entering the market, such that it will earn net profits of, $S(k+1)^2 - \varepsilon$. If this is positive, the number of firms entering in equilibrium will be equivalent to $N^* = \sqrt{S/\varepsilon}$. This result is illustrated in panel (a) of figure 1, where market concentration C falls with the size of the market, given a specific level of sunk costs ε. Importantly, due to the fact that firms will not be recovering their sunk costs, a point such as X cannot be an equilibrium outcome. As a result, there will either have to be consolidation by acquisition or merger, or there will be exit of firms as they are unwilling to incur additional fixed costs of replacing their plant as it becomes obsolete.

Alternatively, if we assume that firms are able to horizontally differentiate their products exogenous sunk costs now relate to producing a specific variety and price competition is mitigated in equilibrium. This results in the relationship between market structure and size shifting down to the left in panel (b) of figure 1. In addition, this function is a lower *bound* to equilibrium seller concentration, as there is a possibility of multiple equilibria, due to the fact that, either different firms will enter each sub-market, the same firms may enter all sub-markets, or firms occupy several niche markets.

Figure 1: Exogenous Sunk Costs and Market Structure



(a) Homogeneous Goods **(b) Differentiated Goods**

Now suppose that firms can vertically differentiate their products in the sense that each product has a single quality attribute u which can be enhanced through R&D outlays.[4] All consumers have the same tastes for higher quality, their utility function being of the form, $U = (ux)^{\delta} z^{1-\delta}$, where x is the product of interest, z is a Hicksian composite product, and

[4] Sutton (1991) presented his analysis in terms of advertising, but also notes in his introduction, that it could equally well apply to R&D. Interestingly, the case-studies presented in Sutton's book all relate to the food manufacturing sector.

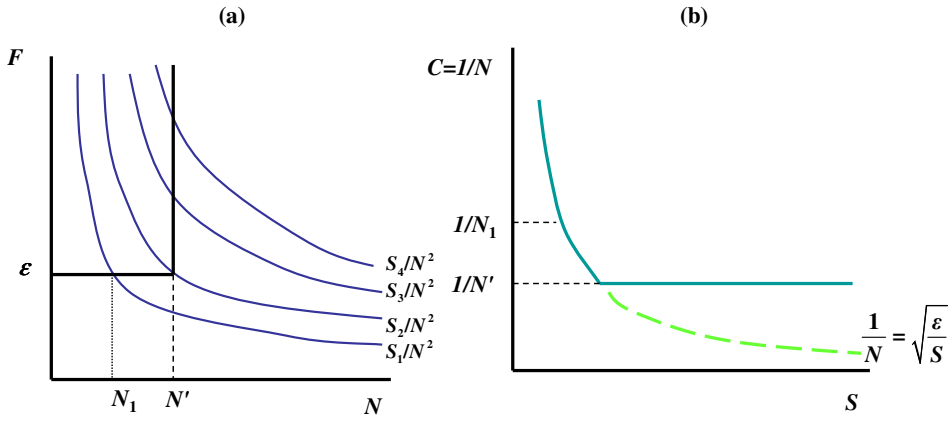
consumers' marginal utility is increasing in u. Firms still incur initial sunk costs of ε, but they now choose a level of u at an additional sunk cost $R(u)$ before competing in price. This setting allows for the possibility that the link between increased market size S and structure C is broken. Specifically, competitive escalation of $R(u)$ raises the equilibrium level of sunk costs $\{\varepsilon + R(u)\}$ as S increases, offsetting any tendency toward market fragmentation, i.e., R&D is an endogenous barrier to entry. If, however there are very rapidly diminishing returns to R&D in terms of consumer response to higher quality, i.e., $R(u)_{\alpha}$, then market fragmentation may still occur as S increases, and R&D is an exogenous barrier to entry.

Sutton (1991) models the additional sunk costs $R(u)$ in terms of perceived quality, via the following function, $R(u) = a/\gamma(u^{\gamma} - 1)$, where a is the cost per unit of R&D activity, and $\gamma > 1$, where higher values of γ reflect more rapidly diminishing returns to increases in R&D outlays. Combining this with the initial sunk costs, a firm's total sunk costs are $F(u) = \varepsilon + a/\gamma(u^{\gamma} - 1)$. The elasticity of $F(u)$ with respect to increases in quality is given as $u/F/dF/du = \vartheta = \gamma\{1 - (\varepsilon - a/\gamma)/F\}$, about which the following can be stated: (i) as $u \to \infty, F(u) \to \infty$, so ϑ tends to γ independent of the initial sunk cost ε and the unit cost of R&D a; (ii) for finite values of u, and hence $F(u)$, then $\vartheta > \gamma$ if $\varepsilon < a/\gamma$, and $\vartheta < \gamma$ if $\varepsilon > a/\gamma$; (iii) when $\varepsilon = a/\gamma$, then ϑ is constant for all levels of u. It turns out that the relationship between the size of the market S and seller concentration C depends on the ratio of ε to a/γ.

At the entry stage, each firm sets the same level of quality u, all firms incurring the same level of sunk costs, so that $\pi = S/N^2 = F^*(N;S)$, where $F^*(.)$ is an implicit value for the level of fixed R&D outlays incurred by firms at equilibrium, given the number of firms entering. The equilibrium values of N and $F^*(.)$ can be solved as functions of ε, S, γ and a. Without deriving it

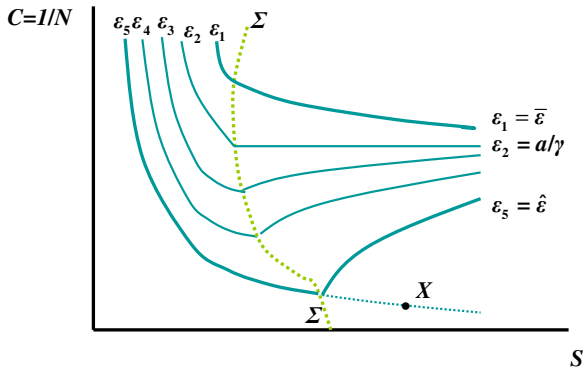
explicitly, solution of the model generates an expression in (*N*,*F*) space, $N + (1/N) - 2 = \gamma / 2[1 - (\varepsilon - a/\gamma)/F]$, which is upward sloping, vertical, or downward sloping depending on whether $\varepsilon > a/\gamma, \varepsilon = a/\gamma$ or $\varepsilon < a/\gamma$, r. Equilibrium R&D is given by the intersection of this locus with the zero profit relation, $F=S/N^2$, which describes a set of downward-sloping curves in (*N*, *F*) space, parameterized by *S*. This in turn impacts the market size-seller concentration relationship. For example, if $\varepsilon = a/\gamma$, and for a sufficiently small value of *S*, the equilibrium involves zero R&D outlays, and the earlier Cournot model applies, with $\pi = S/F^2 = F = \varepsilon$, corresponding to the values S_1 and N_1 in panel (a) of figure. As *S* increases, a value of *N* is eventually reached where R&D begins, and after that point, further increases in *S* involve only increasing levels of R&D, with no additional changes in seller concentration, the market size seller concentration relationship being shown in panel (b) of figure 2.

Figure 2: Endogenous Sunk Costs and Market Structure



In figure 3, the market size-seller concentration relationship is plotted for different values of initial sunk costs, ε relative to a/γ, where $\bar{\varepsilon} = \varepsilon_1 > \varepsilon_2 = a/\gamma > \varepsilon_3 > \varepsilon_4 > \varepsilon_5 = \hat{\varepsilon}$. The locus $\Sigma\Sigma$ traces out the points at which there is a switch from the no-R&D to an R&D regime, defined by where if *N* firms have no R&D, it is just profitable for one firm to deviate. This locus will also shift with increases in the unit cost of R&D, resulting in lower seller concentration for some intermediate market sizes.

Figure 3: Seller Concentration and Market Size



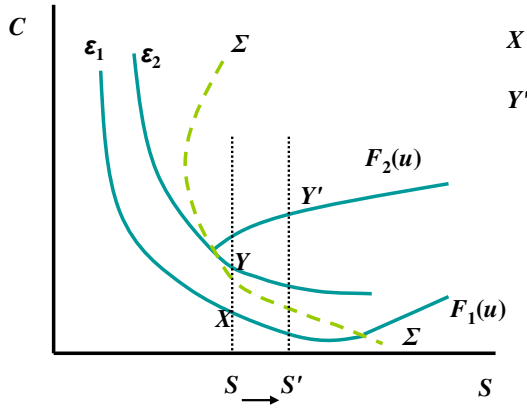
Two comments can be made about this figure: first, increases in market size do not lead to indefinite decreases in seller concentration; second, the market size-seller concentration relationship is not necessarily monotonic. In other words, R&D is not an exogenous barrier to entry as in the traditional literature, whereby the cost of R&D merely shifts the negative relationship between seller concentration and market size. Instead, low sunk costs ε are initially associated with falling seller concentration as the size of the market increases, and then seller

concentration increases. This follows from the fact that R&D only becomes profitable when the market reaches a certain size, which itself varies with the level of seller concentration along $\Sigma\Sigma$, i.e., a lower value of ε implies that the switch-point will be at lower level of seller concentration. In addition, once in the R&D regime, increases in the market size result in increases in R&D expenditure, i.e., market structure becomes independent of the initial sunk costs, and low sunk cost only permits a low degree of seller concentration over a specific range. Finally, if the market is at point *X*, it will require a discrete increase in R&D expenditures to get up to the equilibrium schedule.

The Basic "Bounds" Approach and the Biotechnology Sector

Casual empiricism suggests that evolution of market structure in the biotechnology sector may fit this type of "bounds" model, as illustrated in figure 4.

Figure 4: Market Structure, Sunk Costs and R&D in Biotechnology Industry



X **Initial market structure**

***X* to *Y* mergers/acquisitions**

Y′ **Structure with effective additional R&D**

$F_1(u)$ = sunk costs in 1980s

$F_2(u)$ = sunk costs in 1990s

$\Sigma\Sigma$ = separation no-R&D/additional R&D – function of unit cost of R&D

Initially, in the 1980s, the sector was populated by a large set of small dedicated start-up firms incurring the sunk costs of doing basic research, $F_1(u)$ (Lavoie and Sheldon, 2000). Then in the 1990s, the opportunity arose to tailor the genetic structure of crops, which required firms in the industry to take advantage of complementarities between three types of intellectual assets, relating to plant genetic transformation, genes, and elite germ plasm, driving up industry sunk costs to $F_2(u)$. As a result, there was rapid consolidation via acquisition of start-up firms as the major life science firms attempted to avoid the additional transactions costs of acquiring these assets via arms' length licensing arrangements (Graff, Rausser and Small, 2003), i.e., equilibrium C changes from X to Y. Finally, we can speculate that this also coincided with growth in the size of the market for GM crops as farmers in both North and South America rapidly adopted several key GM crops, causing biotechnology firms to incur additional sunk costs of R&D, equilibrium market structure moving from Y to Y'.

A More General "Bounds" Approach

While the above story seems plausible, it is important to understand that the model makes a key simplifying assumption – a firm's R&D spans all of the products it offers within the industry. Consider instead the case where firms engage in R&D with the objective of improving the attributes of the various products they offer. We can imagine an initial equilibrium characterized by a fragmented industry where all firms have small market share with low R&D outlays. However, there may be a situation where a firm(s) finds it profitable to outspend other firms and capture a larger market share. Sutton (1997; 1998) argues that whether a firm(s) can outspend their rivals and still make sufficient profits to cover their R&D outlays will depend on an escalation parameter α, the value of which will depend on the pattern of technology and tastes, and the nature of price competition in the industry.

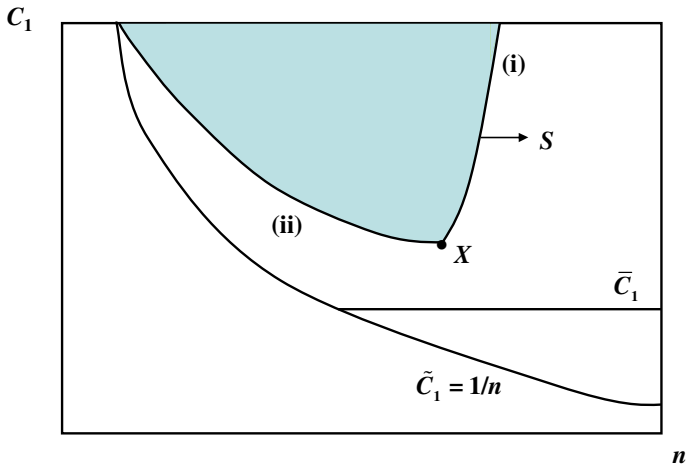
More specifically, the effectiveness of an escalation strategy depends on the success of R&D outlays in raising consumers' willingness to pay for the firm's products within a sub-market. It also depends on supply and demand linkages between different R&D trajectories and different sub-markets. Where these linkages are strong due to economies of scope in R&D and/or a high degree of substitution in demand, α will be high, while it is low with no economies of scope in R&D and a low degree of substitution across sub-markets.

Following Sutton (1997; 1998), the escalation mechanism can be illustrated with use of a linear-demand example and Cournot-Nash behavior by firms. There are n varieties of some product all consumers having the same utility function over these products, with S consumers in the market, so that output of a given good k is Sx_k. The utility function is given by, $U = \sum_k \left(x_k - \frac{x_k^2}{u_k^2} \right) - 2\sigma \sum_k \sum_{l<k} \frac{x_k}{u_k} . \frac{x_l}{u_l} + M$, for $u_k > 0, u_l > 0$, where M denotes consumption of an outside product(s), $0 \le \sigma \le 1$, and the inverse demand function is, $p_k = 1 - \frac{2x_k}{u_k^2} - \frac{2\sigma}{u_k} \sum_{l \neq k} \frac{x_l}{u_l}$. Each firm operates along a single technological trajectory, where σ measures the degree of substitution between products associated with different trajectories. Marginal costs are assumed zero, and there are sunk costs, F(u), of producing quality u, where $F(u) = \varepsilon u^{\beta}, u \ge 1, \beta > 2$. If all qualities are unity, sunk costs are ε. Following Sutton (1997), the equilibrium configurations are shown in figure 5 in (n, C_1) space, bounded by functions (i) and (ii) – the shaded area. The former is a viability function, ensuring each firm's product covers its fixed costs; the latter is a stability function, such that there is no profitable gap in the configuration of products.[5] Note that the stability function starts from a point where a the seller concentration ratio is 1, i.e., as long as

[5] The viability function can be seen in terms of the "survivor" principle as discussed by Alchian (1950), and Stigler (1968), *inter alia*. The stability function is based on the principle that if there is a gap in the market, there will be one "smart" agent that fills it. See Sutton (1997; 1998) for further discussion of these functions, as well as a formal proof of the results.

σ is strictly positive, a monopolist can deter entry by setting u sufficiently high. The stability function (ii) also cuts the viability function (i) above $\overline{C}_1$, the minimum level of seller concentration X being bounded away from zero as $S \to \infty$. For any $\beta > 2$, the seller concentration ratio is bounded below by $\overline{C}_1 = 1 \Big/ 1 + \frac{2}{\sigma}\left[\left(\frac{2}{\sigma}\right)^{\beta-2} - 1\right]$.

Figure 5: Equilibrium Configurations



The key parameters in the equilibrium are β and σ, generating the two core ideas in Sutton's (1998) more general "bounds model: (i) where β is low, i.e. R&D is effective, and σ is high, i.e., progress on one research trajectory results in one firm gaining customers from other firms' trajectories, then the escalation parameter α is high, and there will be high levels of R&D expenditures as well as a high level of seller concentration; (ii) where β is low, but there are

many technically independent research trajectories generating products that are poor substitutes, i.e., σ is low, there can be a high level of R&D expenditures consistent with a low degree of seller concentration. So where σ is high, high R&D on one research trajectory can eliminate low spenders on other trajectories, and over time new trajectories eliminate older trajectories.

From Theory to Empirics

While α cannot be measured directly, the theory basic places constraints on two observable variables whose joint interaction implies a value for α, thereby placing a lower bound on market structure C. One of these variables is the R&D to sales ratio, the second is the degree of proliferation of distinct R&D trajectories in the industry which can be measured by what Sutton (1998) terms the h index which can be proxied by the fraction of industry sales revenue accounted for by the largest product class. Consequently, Sutton's (1991) earlier model is nested in this more general model as the special case of $h = 1$.

From this more general theory, predictions about R&D intensity and market structure can be derived. If R&D outlays are ineffective in raising consumers' willingness to pay for a firm's products, R&D intensity will necessarily be low. Consequently if we observe a high R&D to sales ratio, it implies that R&D outlays are effective. Seller concentration will then be determined by the strength of the linkages between sub-markets, i.e., it will tend to be high where the linkages are strong, making an escalation strategy profitable, and the h index will tend to be high. With weak linkages on the demand and supply side, even if R&D outlays are effective, seller concentration will be low, as will the h index. As a result, a joint restriction can be placed on the observable parameters: in an industry with a high R&D to sales ratio, seller concentration C should increase with h. Alternatively, an industry with a low R&D to sales ratio will converge to a fragmented market structure independent of h. In addition, if sunk costs ε

increase, seller concentration will increase irrespective of R&D intensity, but with low R&D intensity, this increase in concentration will be eroded over time as the market grows.

In the case of high R&D intensity, the impact of an increase in sunk costs on seller concentration has to be separated out from the effects of escalation in R&D outlays. Returning to the stylized facts of the biotechnology industry described in figure 4, the increase in sunk costs was the initial mechanism for the biotechnology sector to become more concentrated in the 1990s as start-up firms were acquired by larger life-science companies, but the complementarities between the different intellectual property rights they acquired, along with the willingness of a growing number of farmers to purchase GM crops, resulted in an R&D escalation strategy that has led to further increases in seller concentration.

4. Summary and Conclusions

In this paper, the potential relationship between R&D and seller concentration in the biotechnology sector has been addressed through consideration of a "bounds" approach due to Sutton (1991; 1998). In particular, it has been shown that the evolution of a concentrated market structure is entirely consistent with an endogenous sunk cost story. Specifically, if firms are able to adopt an R&D escalation strategy either when market size increases or when they are able to outspend other firms on different research trajectories, there is a key non-convergence result, i.e., seller concentration declines initially over some range, as in the presence of exogenous sunk costs, and then is either bounded from zero or even increases. Consequently, the presence of such a bound explains why only a weak correlation has been found between R&D intensity and seller concentration in cross-sectional studies.

In purely theoretical terms, using Sutton's approach to analyzing market structure and innovation is both rigorous and logical: it allows the derivation of very clear and testable hypotheses concerning the extent to which seller concentration is related to exogenous sunk costs and/or endogenously determined along with R&D activity. However, in applying Sutton's model, a key issue is to establish overall whether it is a good description of what has and is happening in the biotechnology industry, and in particular whether the industry's h index is equal to or less than one, as this impacts the complexity of both theoretical and empirical analysis. Importantly, a real test of the model's validity will be whether recent introduction of GM crops containing stacked traits will be accompanied by further changes in market structure – presumably these can be regarded as products on new research trajectories compared to single-trait GM crops which are on older research trajectories, i.e., the value of σ may be high. Likewise, as R&D expenditures are devoted to GM products containing traits considered beneficial by consumers, it is not clear whether this will result in high seller concentration in this sector or product proliferation, i.e., high levels of R&D intensity may actually be accompanied by modest levels of seller concentration. What is clear though from this analysis is that assuming a direct correlation between R&D intensity and seller concentration in the biotechnology industry may be misleading both in terms of understanding the evolution of the sector's market structure, as well in terms of drawing normative conclusions about the impact of market structure on innovation in the sector.

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