Staff Paper

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A Neo-Schumpeterian Model

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Abstract

Several characteristics of biotech industry structure follow cyclical patterns. Mergers and acquisitions activity shows cyclical behavior, with peaks from 1988-92 and 1996-97 and a valley from 1993-95. The ratio of large-firm to small-firm field trials, and the Herfindahl-Hirshmann concentration index, move pro-cyclically with M&A activity. This paper develops a formal, dynamic, neo-Schumpeterian model of endogenous R&D and innovation. The model generalizes and extends the literature on biotech industry concentration. For specified parameter values, the out-of-steady-state dynamics are examined, and shown to generate model behavior which is consistent with empirical descriptions of biotech concentration and R&D-activity cycles.

Cyclical Fluctuations in the Level of Plant Biotech R&D: A Neo-Schumpeterian Model

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Introduction

Since 1995, the outstanding feature of the agricultural biotech industry structure is its increasing concentration, accomplished primarily through mergers and acquisitions (M&A). Kalaitzandonakes (1999) describes the M&A activity as following a cyclical pattern, with peaks from 1988-92 and 1996-97 and a valley from 1993-95 (Figure 1). In separate work Brennan, Pray and Courtmanche examine industry concentration and its relationship with U.S., plant, biotech, field-trial activity by large and small firms. Comparative analysis shows that the ratio of large-firm (four largest firms) to small-firm (other firms) field trials, and the Herfindahl-Hirshmann concentration index, move pro-cyclically with M&A activity (Figure 1).

This paper provides an innovative theoretical model of small- and large-firm R&D activity. For specified parameter values, the model generates cyclical patterns of behavior, which are consistent with empirical observation. These cyclical patterns emerge as the outcome of endogenous R&D investment decisions. The model generalizes earlier theoretical work by Oehmke et al. (1999a, 1999b), who model R&D and industry concentration cycles as the result of unanticipated changes in the costs of R&D and/or in the profits earned from successful innovation. In addition to providing a more general framework, this paper extends those models to the case in which a single shock can affect the profit levels of both small and large innovators. Numerical

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solutions to the dynamic equilibrium conditions exhibit the same patterns of behavior noted empirically in figure 1.

The next section of the paper develops a neo-Schumpeterian model of R&D activity and industry structure. The third section presents the results of numerical solutions to the model. The paper concludes with policy implications and suggestions for further work.

A Model of R&D-Industry Structure and R&D Activity

The model draws from and generalizes previous neo-Schumpeterian models of biotech industry structure. The defining characteristics of the neo-Schumpeterian approach are that R&D is inherently a risky investment, that products are made obsolete and replaced by the next generation of higher-quality products, that successful researchers obtain some degree of monopoly power and rents from their discovery of the next generation of products, and that the lure of monopoly profits draws firms into the R&D process (Dinopoulos, 1994). Each of these assumptions accurately represents a part of the agricultural biotechnology industry.

In previous applications of neo-Schumpeterian modeling to the biotech industry, Oehmke et al. (1999a) present a model with heterogeneous (large and small) firms. Each type of firm targets a different, unrelated output in their R&D activities. The Oehmke et al. (1999a) model is capable of generating cycles in industry concentration in the large-firm or small-firm sub-industries. However, there is no systematic relationship between the possible cycles in the two sub-industries. Oehmke et al. (1999b) provide a more in-depth analysis of the nature and possible causes of concentration cycles for a biotech industry with homogeneous firms.

The current model extends this literature by i) generalizing the Oehmke et al. (1999b) model of concentration cycles, ii) adapting the Oehmke et al. (1999b) model to a heterogeneous industry with large and small firms, and iii) generalizing the profit structure of Oehmke et al. (1999a) to allow for systematic relationships between unanticipated changes in large-firm profits and unanticipated changes in small-firm profits: that is, both large and small firms may be subject to the same exogenous shocks.

In the model, large firms represent the major life-sciences corporations involved in agricultural biotech R&D. Small (including middle-sized) firms represent start-up and young companies whose assets consist largely of intellectual property and/or low-cost R&D capacity. All firms engage in R&D to discover the next-generation technology in a particular market, and to earn (limited) monopoly rents from being the sole owner of this technology. The differences between the two firm types is in their cost and profit structures. Small firms are assumed to have lower fixed costs of R&D, but more rapidly increasing marginal costs. Large firms have higher fixed costs, but more slowly increasing marginal costs.

Inventive Activity and Firm Profits

Each firm invests in R&D to discover the next generation technology. For firm i, the R&D costs are determined by:

$$C_j(R_{i,j}) = F_j + \gamma_j R_{i,j}^{\alpha_j}, \quad \alpha_j > 1.$$

$$C_k(R_{i,k}) = F_k + \gamma_k R_{i,k}^{\alpha_k}, \quad 1 < \alpha_k < \alpha_j,\ F_k > F_j.$$

where the subscript j denotes the technology targeted by small-firm R&D, and the subscript k denotes the technology targeted by large-firm R&D. F represents fixed costs, γ is a productivity parameter, and α is a parameter that represents decreasing returns to scale as the level of research activity gets large relative to the fixed costs (for low levels of $R_{i,j}$, amortizing fixed costs over $R_{i,j}$ results in increasing returns to scale), so that the firm has the usual U-shaped average cost curve. The fixed costs represent the costs of maintaining physical plant, starting and maintaining research activities, etc. Large firms have higher fixed costs of R&D ($F_k > F_j$), but more slowly increasing marginal costs ($\alpha_k < \alpha_j$).

The successful firm 'wins' the R&D race to discover technology j or k. This firm becomes the sole owner of that technology, and can thereby earn monopoly rents. For brevity, this paper simply specifies the profit functions for successful innovators (well-specified output markets and derived profit specifications are found in Oehmke et al. (1999a, 1999b)). The small-firm innovator earns instantaneous profits $\Pi_j = \Pi_j(Z; \zeta)$ for the duration of its monopoly power; the successful large-firm earns instantaneous profits $\Pi_k = \Pi_k(Z; \zeta)$. Z represents market and technological parameters, such as supply and demand elasticities, market size, and cost reduction or quality improvement due to innovation. The shift parameter ζ represents exogenous shifts. Changes in this parameter affect the expected profits of both small and large firms. The innovating firms earn these profits until the next-generation technology is discovered, making the current-generation technology obsolete and destroying the current-generation innovator's market power. By making the profits and profit response to ζ vary by firm size, this model generalizes the heterogeneity assumption introduced by Oehmke et al. (1999a).

For each R&D race, the firm and industry instantaneous innovation probabilities are

$$\varphi_j(R_{i,j}) \equiv \frac{R_{i,j}}{K_j + R_j}, \quad \text{and} \quad \Phi_j \equiv \Phi_j(R_j) \equiv \frac{R_j}{K_j + R_j},$$

respectively, where $R_j = \Sigma_i R_{i,j}$ is the aggregate level of R&D activity in the industry, and $K_j > 0$ is simply a parameter of the research production function. Equation 3 implies increasing returns of research activity on innovation probabilities, but at a diminishing rate. Large-firm innovation probabilities are defined analogously by replacing the subscript j with the subscript k.

The values of the innovating firms are determined by the arbitrage equations

$$\left(r + \Phi_{j+1}\right) V_j = \Pi_j, \quad \left(r + \Phi_{k+1}\right) V_k = \Pi_k .$$

In equations (3) the subscripts refer not just the type of technology target, but to the technology level of that target. V_j and Π_j represent the expected value and instantaneous profits of the firm discovering the j^{th}-generation technology; Φ_{j+1} represents the probability that the small-firm sub-industry will discover the $j+1^{st}$-generation technology. Equations (3) state that the profits earned by the winner of the j^{th} or k^{th} race equal the risk-free rate of return, r, plus a risk premium (per unit) equal to the probability, Φ_{j+1} or Φ_{k+1}, respectively, that the next-generation innovation will be discovered and make the current technique obsolete.

Equilibrium

Firms will invest in R&D until the expected marginal return from R&D–the probability that the firm will innovate successfully times the value of being the innovator–equals the marginal cost of R&D. The relevant small- and large-firm conditions are:

$$\varphi_j'(R_{i,j})\, V_j = C_j'(R_{i,j}) \qquad \varphi_k'(R_{i,k})\, V_j = C_k'(R_{i,k})$$

The zero-profit conditions state that for each firm participating in race j or k, the expected returns equal the costs:

$$\varphi_j(R_{i,j})\, V_j = C_j(R_{i,j}) \qquad \varphi_k(R_{i,k})\, V_k = C_k(R_{i,k})$$

Algebraic manipulation of equations (2) through (5) results in a relationship between current and future R&D activity,

$$\frac{\Pi_j}{\kappa_j(K_j + R_j)} = \frac{R_{j+1}}{K_j + R_{j+1}} + r.$$

where $\kappa_j \equiv \alpha_j\, (\alpha_j - 1)^{\frac{1-\alpha_j}{\alpha_j}}\, \gamma_j^{\frac{1}{\alpha_j}}\, F_j^{\frac{\alpha_j - 1}{\alpha_j}}$ is an expression containing only market and technological parameters. Equation (6) is a reduced-form, dynamic equilibrium condition determining the time-path of small-firm R&D activity. An analogous condition holds for large firms. In equation (6), when Π_j is constant for all technology levels j, a steady-state exists under general parameter values and can be found by setting $R_j = R_{j+1}$. However, to examine cyclical behavior we focus on out-of-steady-state behavior.   Since equation (6) is a nonlinear difference equation, it is difficult to find closed form solutions, and so out-of-steady-state results are generated by solving the equation numerically.

Results

Numerical Results

The numerical solutions to equation (6) and its large-firm analog depend on the parameterization of the model and the selection of initial conditions. The specified parameter values are Π_j,=2000, K_j = 1,000, κ_j = 3.8, Π_k = 60,000 K_k = 5,000, κ_k = 12 and r = 0.1. The initial conditions are R_j = 696 and R_k = 6,200. These initial conditions are approximately the steady-state levels of R&D activity when Π_j and Π_k are constant across R&D races. The parameter values and initial conditions are selected so that i) based on equation (2), the duration of an R&D race–that is, the time it takes to develop a patentable innovation–ranges from 2 to 4 years (field trials, regulatory clearance, etc. add to the time it takes to develop and commercialize the innovation); and ii) the initial ratio of large-firm to small-firm R&D activity, R_k/R_j, is between 8 and 9, which is close to the observed 1988-90 ratio. The values of κ_j and κ_k reflect a variety of market and technological parameter choices, details are available from the authors.

Cycles are induced by shocking the levels of profits. Of particular interest are shocks which decrease large-firm profits significantly. The effect on large-firm profits is to reduce these profits to 40% of their steady-state levels. The choice of 40% is from anecdotal evidence, which suggests that actual profits in the year 2000 will be about 40% of anticipated profits. For example, In 1990, "Monsanto executives believe[d] the combined sales and royalties [from bovine and porcine growth hormone and 13 other genetically engineered products] could approach $1 billion a year by the end of the decade" (Schneider, 1990). However, in fiscal 1998 Monsanto had revenues of only $209 million from their biotech 'traits' businesses, and is projecting revenues of about $400 million in 2000 (Monsanto, 1999).

It is assumed that the change in ζ on small-firm profits is to increase Π_j by 10%. This is consistent with an idea that large firms with a multinational focus are hurt significantly by EU and consumer rejection of genetically modified organisms, but that small firms have a greater domestic/North-American focus and so are hurt less by EU rejection. Moreover, small-firm profits may increase if large firms turn their attention to issues of EU consumer reaction rather than competing against smaller rivals. Finally, the assumption of an increase in small-firm profits is not strictly necessary: similar cyclical patterns in the ratio of large-to-small firm R&D activity can be generated if small-firm profits decrease, but by an amount proportionately less than the decrease in large-firm profits. Additional numerical solutions are available from the authors.

The results show that shock to profits induces cyclical behavior in large-firm R&D activity, and counter-cyclical behavior, of a much smaller magnitude, in small-firm R&D activity (Figure 2). These results are consistent with de-trended evidence on the number of GMO field trials conducted by large and small firms. The ratio of large:small firm R&D activity plunges to 2.3 initially, but recovers to 3.8 by the next R&D race (Figure 1). Since the parameterization has R&D races lasting from 2-4 years, this is very close to the pattern of relative field trial activity found empirically by Brennan, Pray and Courtmanche over the period 1990-98 (Figure 1).

The main result in this paper is that unanticipated changes in innovator profits can generate cyclical patterns in the level of large-firm R&D activity relative to small-firm R&D activity. It is straightforward to show that this R&D cycle matches the model's cycle of R&D industry concentration (since firms produce R&D at the minimum of their average cost curves, a decrease in industry R&D levels reduces the number of firms in the innovation race and hence increases concenration), as is consistent with empirical observation.

Conclusions

The paper's model and results extend the biotech industry concentration literature to co-generated cycles among the large- and small/medium-firm sub-industries. This is an important contribution to a young literature that has not previously grappled with relationships between large and small/medium firms in formal algebraic models.

The results are largely correlative in nature. That is, the results generate correlated cyclical patterns, cut do not provide a detailed examination of causal relationships. In particular, the model allows for indirect feedbacks between industry concentration and R&D activity through firm- and industry-level innovation probabilities, but does not consider that firms may take concentration directly into account when making R&D investment decisions. Nor does the model allow for R&D activity to guide firm actions which might influence their product-market share (and hence product-industry concentration), such as advertising. Including such direct causal relationships and deriving empirically testable results is an important consideration in the future research agenda.

Finally the model contains no direct representation of M&A activity. Although firms exit the R&D industry in the model, the winner-take-all nature of the innovation race precludes discussion of what happens to the assets of firms exiting the industry. Extension of the model to include explicit representation of M&A activity is a second important issue for future work.

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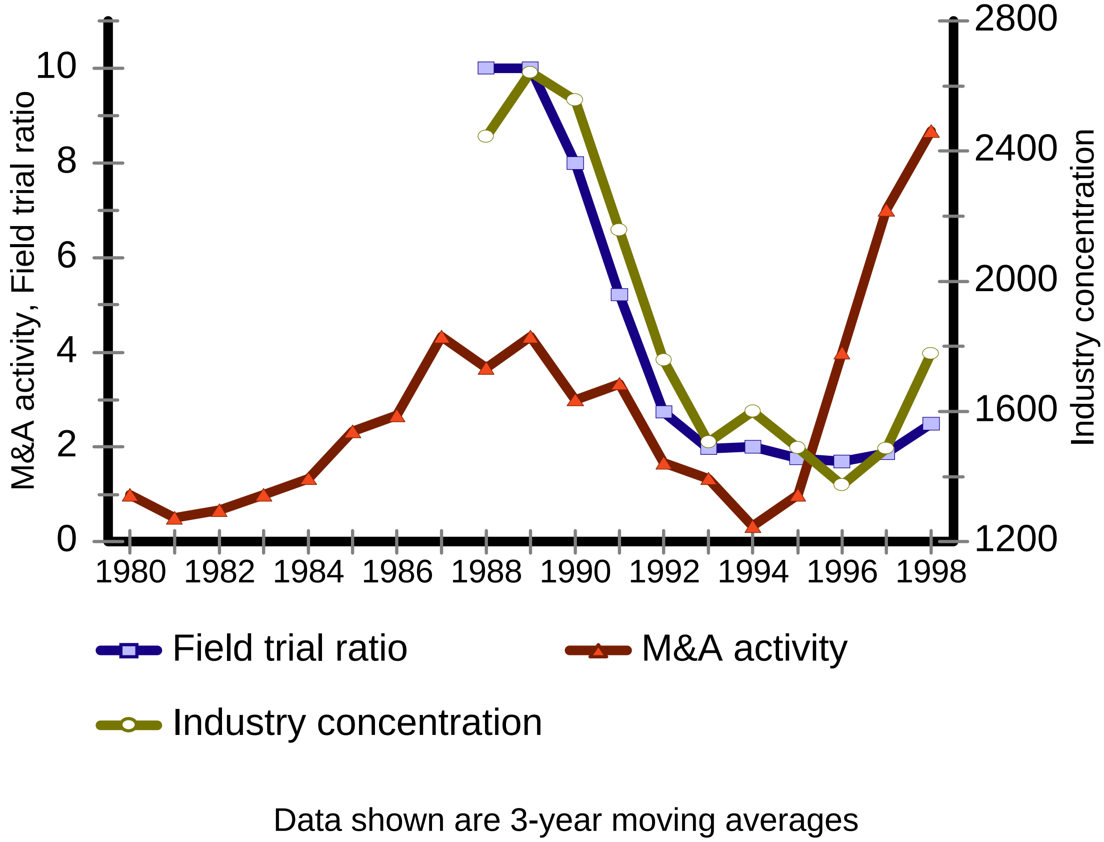

Figure 1. Patterns of cyclical behavior in biotech M&A activity, industry concentration, and ratio of large:small firm GMO field trials.

Sources; M&A activity calculated from Kalaitzandonakes, field trial ratio and industry concentration from Brennan, Pray and Courtmanche.

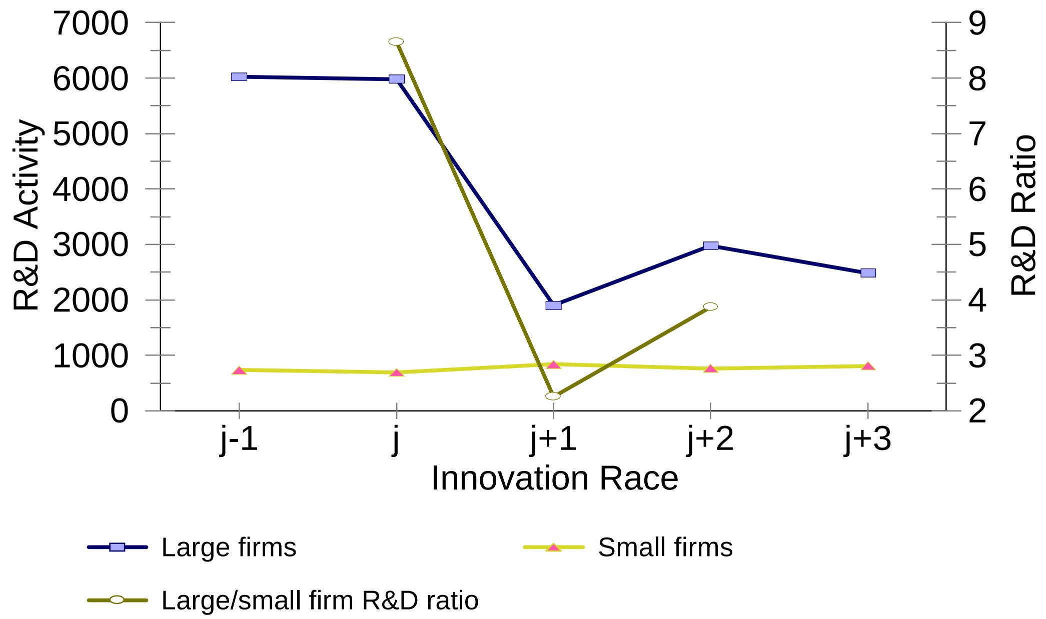

Figure 2. Numerical solution to the model, showing cyclical behavior in large-firm R&D activity, counter-cyclical behavior in small-firm R&D activity, and pro-cyclical behavior in the ratio of large:small firm R&D activity.