Staff Paper

CYCLICAL CONCENTRATION AND CONSOLIDATION IN BIOTECH R&D: A NEO-SCHUMPETERIAN MODEL

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Staff Paper 99-50 October 1999

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22 pages

ABSTRACT

Over the past fifteen years, the agricultural biotechnology industry has exhibited cyclical behavior in concentration and consolidation. This paper provides a theoretical model of endogenous R&D, in which industry concentration exhibits cyclical behavior. The model also generates additional testable hypotheses, and policy implications.

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Draft, September 8, 1999

ABSTRACT: Over the past fifteen years, the agricultural biotechnology industry has exhibited cyclical behavior in concentration and consolidation. This paper provides a theoretical model of endogenous R&D, in which industry concentration exhibits cyclical behavior. The model also generates additional testable hypotheses, and policy implications.

KEYWORDS: R&D, Biotech, Life- Science, Concentration, Consolidation, Mergers and Acquisitions, Innovation, Schumpeter.

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Cyclical Concentration and Consolidation in Biotech R&D: A Neo-Schumpeterian Model

Since 1995, the outstanding feature of the agricultural biotech industry structure is its increasing concentration. Consolidation in this industry is accomplished primarily through mergers and acquisitions (M&A). In 1996 and 1997, Monsanto alone acquired 16 biotech or related companies. Several explanations of this M&A activity have been offered (Artuso, 1999; Johnson and Melkonian, 1999; Graff, Rausser and Small, 1999; Rausser, Scotchmer and Simon, 1999).[2] Each of these articles provides meaningful examination of forces contributing to industry consolidation, but focuses on the M&A activity of the past five years. In other words, these explanations focus on explaining the recent flurry of M&A activity.

Kalaitzandonakes (1999) contends that a longer-term perspective on the agricultural biotech industry shows that the recent flurry of M&A is neither unprecedented nor sustainable. In his view M&A activity exhibits a natural cyclical pattern, with the previous cyclical peak corresponding to the 1988-92 consolidation in the seed industry, and the most recent peak corresponding to the 1996-1997 purchasing of seed companies or divisions by biotech companies, most notably Monsanto and DuPont. Limited empirical evidence to date provides crude support for this explanation (Figure 1). Particularly noticeable are the peak levels of M&A activity in the

[2]Artuso argues that "the consolidation underway in the industry is simply a reflection of the increasing costs of developing and obtaining regulatory approval for transgenic crops (p. 1)." Johnson and Melkonian examine "technology and policy factors responsible for consolidation" (p. 2), and go on to argue that the relatively high level of 'incompleteness' in agri-biotech contracts makes M&A cost-effective relative to partnering. Graff, Rausser and Small argue that "at least one key driver behind the recent restructuring of the agronomic systems industry is the desire to exploit complementarity between intellectual assets (p. 2)" of previously independent firms. Rausser, Scotchmer and Simon merge the incomplete contracts and complementary assets arguments to explain the use of M&A rather than other restructuring options.

late 1980s and in 1996-97; the valley in the early 1990s is also conspicuous due to the absence of M&A activity. The recent spate of M&A activity has led to an increase in industry concentration: there are now four agricultural firms with significant revenues from seed and enhanced genetic traits (Monsanto, 1999).

This paper provides a theoretical model of the cyclical concentration pattern as the outcome of endogenous R&D investment decisions. The development of a rigorous theory of cyclical biotech concentration, with accompanying empirical and policy implications, are unique contributions of this paper to the literature.

The next section of the paper develops the neo-Schumpeterian model of R&D, innovation, and industry structure. The third section derives implications on R&D activity and industry concentration. Empirical implications are presented in the fourth section. The paper concludes with policy implications.

A Model of Innovation and R&D-Industry Structure

The model is built around neo-Schumpeterian endogenous innovation fueled by investment in R&D. 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.

The representation of R&D and innovation in this paper follows the neo-Schumpeterian approaches of Segerstrom, Anant and Dinopoulos, Grossman and Helpman, Aghion and Howitt (1992, 1998) and Barro and Sala-i-Martin, in modeling R&D as a sequence of stochastic innovation races. In each race, firms conduct R&D in an effort to be the first to discover the next-generation product. The winner is granted an exclusive patent on this product, and earns monopoly rents. Schumpeter's 'creative destruction' occurs as the 'creation' of each successive product 'destroys' the competitive advantage held by the previous-generation product.

The current model has a single agricultural life-science product, which faces inelastic demand. The cost of producing this output is constant at each instant in time. Firms invest real resources in R&D to discover innovations which reduce production costs. R&D activity is modeled as a race, in which the winner of the race discovers and becomes the sole owner of the next-generation production technology. This firm is able to earn a degree of monopoly rents from its discovery, but the price which the firm can charge is limited by the availability of the previous-generation technology. Immediately at the end of one R&D race a new race starts, to find the next innovation. The discoverer of this new innovation becomes the new monopolist. The prior winner's market power is effectively destroyed. The number of firms entered in each R&D race is determined endogenously by a zero-expected-profit condition. Each firm's level of R&D activity is the outcome of an optimization process. The evolution of R&D activity over time is driven by an inter-temporal arbitrage equation, which relates firm value to the level and expected duration of monopoly rents. The summation of this modeling process is the derivation of a difference equation which governs the evolution of R&D activity–and hence the evolution of R&D industry concentration–over time. The remainder of this section formalizes the model.

The Output Market

Assume the demand for the single agricultural life-science output is given by the constant elasticity demand function

$$Q = \delta P^{-\varepsilon}, \quad 0 < \varepsilon < 1$$

where Q is the quantity demanded, P is the price, δ, is a parameter, and ε is the absolute elasticity of demand. The assumption that ε<1 means that demand is inelastic, which corresponds to many agricultural and pharmaceutical products.

The total cost of producing Q is defined for all technologies by

$$C_Q = AQ,$$

where A is the unit cost of production, and will be influenced by R&D and innovation. The evolution of unit costs is governed by the stochastic differential equation

$$dA = \lambda^{-1} A ds, \quad \lambda > 1$$

where s is a stochastic variable that takes the value of unity with instantaneous probability Φdt and the value of zero with probability (1-Φ)dt (t represents time). The case s=1 denotes the discovery of an innovation which decreases unit costs by a factor λ. In other words, the probability that an innovation is discovered in any time interval (t, t+dt) is Φdt. Equation 3 describes a memory-less Poisson process for the arrival of innovations, with intensity Φ (see Tolley, Hodge, Thurman and Oehmke for a discussion of the Poisson process with respect to R&D). This particular Poisson specification is borrowed from Dinopoulos and Oehmke, and is

consistent with empirical work conducted by Graff, Rausser and Small). Thus, after the j^{th} innovation is applied, the cost function can be rewritten as

$$C_{Q,j} = A_j Q = \lambda^{-j} A_0 Q,$$

where $C_{Q,j}$ represents the production costs using the j^{th} innovation, A_0 is an initial unit-cost figure and A_j represents unit costs when using the j^{th} innovation in production.

The innovating firm earns monopoly rents by charging a price in excess of production costs (equivalently, the firm licenses the technology to farmers for a technology fee). However, the price which the monopolist can charge is limited by the availability of the previous generation of technology. Bertrand competition between the current and previous monopolists thus determines the limit-price to be

$$P = \frac{\partial C_{Q,j-1}}{\partial Q} = \lambda^{-j+1} A_0$$

The price which the innovator charges is thus limited by the degree of competitive advantage afforded by the innovation, λ. This result is standard in neo-Schumpeterian growth models (see Dinopoulos).

Equations 1, 4, and 5 can be combined to determine an expression for the instantaneous profits earned by the winner of the j^{th} race:

$$\Pi_j = (\lambda - 1) A_0^{1-\varepsilon} \delta \lambda^{j(\varepsilon-1)-\varepsilon}.$$

R&D and Innovation

For each firm i, the cost of research activity $R_{i,j}$ directed to discovering innovation j is:

$$C_R(R_{i,j}) = F + \gamma R_{i,j}^{\alpha}, \quad \alpha > 1.$$

F represents fixed costs, δ 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.

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

$$\varphi(R_{i,j}) \equiv \frac{R_{i,j}}{K + R_j}, \quad \text{and} \quad \Phi(R_j) = \frac{R_j}{K + R_j},$$

respectively, where $R_j = \sum_i R_{i,j}$ is the aggregate level of R&D activity in the industry.

Equation 8 implies increasing but diminishing returns of research activity on innovation probabilities (Dinopoulos (1994) and Segerstrom(1995) provide alternative specifications of instantaneous diminishing returns to R&D.). At the industry level, the instantaneous probability of innovation approaches unity as the level of research activity approaches infinity, but there is a

nonzero probability of failure (not discovering the next-generation product) for any finite level of R&D.

The value of the firm that wins race j is determined by the arbitrage equation

$$\left(r + \Phi(R_{j+1})\right) V_j = \Pi_j .$$

Equation 9 states that the profits earned by the winner of the j^{th} race equal the risk-free rate of return, r, plus a risk premium (per unit) equal to the probability that the next-generation innovation will be discovered and make the current technique obsolete.

Firm i will invest in race j until the expected marginal return from R&D–the probability that firm i will innovate successfully times the value of being the innovator–equals the marginal cost of R&D:

$$\varphi'(R_{i,j})\, V_j = C'_R(R_{i,j})$$

The zero-profit condition for the R&D industry is

$$\varphi(R_{i,j})\, V_j = C(R_{i,j})$$

The zero-profit condition is that for each firm i participating in race j, the expected returns equal the costs.

Equations 7, 8, 10 and 11 are sufficient to ensure that each firm engaged in the R&D race is producing R&D activity at the minimum of their average cost curve. The average-cost minimizing level of R&D and the associated total cost are

$$R_{i,j}^{*} = \left(\frac{F}{(\alpha-1)\gamma}\right)^{1/\alpha} \quad \text{and} \quad C_R(R_{i,j}^{*}) = \frac{\alpha}{\alpha-1} F,$$

where the superscript * denotes the optimized value of the variable.

Algebraic manipulation of Equations 9, 11 and 12 results in a relationship between current R&D activity and firm value,

$$V_j = \alpha(\alpha-1)^{\frac{1-\alpha}{\alpha}} \gamma^{\frac{1}{\alpha}} F^{\frac{\alpha-1}{\alpha}} (K + R_j),$$

and between R&D activity in the next race and current-race firm value,

$$\frac{R_{j+1}}{K + R_{j+1}} = \frac{\Pi_j}{V_j} - r.$$

Substituting for V_j from equation 13 reveals that equation 14 is a nonlinear difference equation in R&D, for which it is at best extremely difficult to find a closed form solution. We pause only to note that there is no non-zero, steady-state solution to 14, since inelastic demand causes Π_j decrease with each subsequent R&D race.

Since it is difficult to find closed form solutions to equation 14, results are generated by solving the equation numerically.

Results

Results on R&D activity, firm value, and time to innovate

Solving the difference equation 14 for varying parameter values and initial conditions yields results on R&D activity and expected duration of the innovation race (Figures 2 and 3).

Figure 2 depicts a numerical solution to the difference equation 14 with monotonically declining R&D activity (parameter and initial values: r = 0.1, F = 50, λ = 1.1, γ = 3, K = 1000, α = 1.5, Π_0 = 10,000, R_0 = 1040). This solution has very intuitive characteristics. Since profits decrease each race (due to the inelastic demand), it seems likely that firms would have less incentive to engage in R&D, so that R&D activity would also decline monotonically. Lower levels of R&D activity in turn imply that the expected time at which the innovation is discovered increases with each race.

Figure 3 depicts a numerical solution which exhibits large cyclic swings in R&D activity (parameter and initial values: r = 0.1, F = 100, λ = 1.1, γ = 0.75, K = 1000, α = 2, Π_0 = 10,000, R_0 = 2000). These swings are also caused by firms' expectations about profits (which in this model are always correct), but both the level and duration of instantaneous profits are important. Even though the level of profits is declining, if the firm is able to capture those profits for a longer period of time, then the present value of the profit stream may increase. The duration of the profit stream for the j^{th} innovator is determined by the time to innovate in race j+1. If it takes longer to innovate in race j+1, then the present value of the j^{th} innovator increases, ceteris paribus. Consequently, the level of R&D rises in race j. This in turn has a feedback effect, through equation 14, which further decreases the R&D level in race j+1.

It is quite easy to find parameter values which generate cycles. As the above intuition suggests, under- or over-investment in any race (relative to the trend) generates cyclic behavior. For example, changing the initial level of R&D activity in Figure 2 by as little as ±5% generates a cyclic pattern centered around the downward trend depicted in Figure 2. For all parameter values the authors tried, it is more difficult to find an initial value for R&D activity that results in

smoothly declining levels of R&D activity than to find some degree of cyclic behavior. The parameter values represented in Figure 3 were chosen to provide what is likely an exaggerated cycle.

Results on industry concentration

The simplest measure of R&D industry concentration is the number of firms in the industry. Ignoring the integer problem, the number of firms in R&D race j is determined by $n \equiv R_j / R_{i,j}^*$.

Since the difference equation 14 is solved numerically, the number of firms in any given R&D race must also be determined numerically. R_{ij}^* does not depend on the industry-wide level of R&D, so that the behavior of n is similar to the behavior of R_j. That is, when R_j declines monotonically, so does n; when R_j cycles, so does n. For illustrative purposes, extreme cycles are depicted in Figure 4, generated by the same parameter values which generate the cyclical R&D activity depicted in Figure 3. In these extreme cycles, the number of participants in an R&D race can fluctuate between several hundred firms and only a handful. This extreme fluctuation is presented only for illustrative purposes: a range of parameterizations lead to more believable cyclic patterns of industry concentration.

Interpretation of Results

Cyclical Concentration

The driving force behind the cyclical pattern in the model is initial over- or under-investment in biotech R&D. There is some casual evidence of over-investment. For example,

since its inception on Dec. 16, 1985, the Fidelity Select Biotechnology Fund has performed about at par with the Standard and Poor's 500 index (S&P 500).[3] The S&P 500 is more diversified and so presumably less risky than the Biotechnology Fund. Thus, in a risk-adjusted sense, biotech stock prices are underperforming (at least by this measure). This is consistent with the idea of historical over-investment.

Over-investment occurs, within the context of the model, when profits are lower than expected, or when R&D costs are higher than expected. A primary reason why profits may be lower than expected is consumer resistance to genetically engineered products. 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 (Monsanto, 1999). The current European Union proscription on all genetically engineered products is placing a further damper on potential profits. For example, Monsanto projects 'trait' revenues to be $760 million in 2002, all from the U.S. and Latin America, substantially less than the $1 billion originally projected by 2000.

A second, key reason why profits may be lower than expected is that companies have not been able to extract the expected level of monopoly rents from producers. "Seed companies have captured less than 25% of the value of yield increases attributable to genetic improvement (Artuso, p. 3) ."

[3]The Fidelity Biotechnology Fund is the oldest biotechnology fund or stock index. Data on the NASDAQ biotechnology index are unavailable prior to January, 1995.

Profits also may be lower than expected if R&D and commercialization costs exceed expectations.

Technological difficulties may lengthen the duration of the R&D process, increasing costs. In 1990, Monsanto's Robert Fraley was quoted as saying "Two years from now every crop in the world will be easily manipulated. Ten years from now, in some plant we'll know every gene, every protein, every function. There are no longer any technical restraints" (Schneider, 1990). Despite the long time lag involved in biotechnology R&D (Fraley created the first transgenic plant in 1983), R&D firms appear to have forecast this time lag more accurately than some of their scientists. For example, in 1990 Monsanto chairman Richard Mahoney projected that the first of Monsanto's genetically engineered plants would appear on the market by 1994 or 1995 (Schneider); the first transgenic plants (bT corn and cotton and Roundup-ready soybeans) were planted commercially in 1996 (Kalaitzandonakes). However, the vision of unrestricted technology has clearly not been realized to date.

Commercialization costs are also higher than might have been anticipated. Arutso contends that "it is quite likely that cost considerations are also influencing consolidation of the agricultural biotechnology industry. ...Regulatory oversight of transgenic crop varieties has also undoubtedly added new product development costs by requiring closely monitored field trials, environmental assessment, and food safety analyses" Artuso, (p. 10). John Stafford, chairman of American Home Products, has been quoted as saying "It is becoming more and more costly to take advantage of the new technologies" (The Financial Times Limited, 1998). The result is likely commercialization costs higher than were expected even a few years ago.

M&A Activity

The model exhibits cyclical behavior in industry R&D levels, which leads to cyclical behavior in industry concentration. Although the model does not make this assumption explicitly, it is reasonable to interpret concentration to be accomplished in part through M&A activity. This is certainly the case in the agricultural biotech industry. Allowing this interpretation, the model suggests that M&A activity also exhibits a cyclical pattern. The relationships among the various cyclical patterns allow the derivation of empirically testable hypotheses.

Implications for empirical work

The model exhibits behavior in which industry R&D activity moves counter-cyclically to industry concentration. This is a testable hypothesis, given a good data set on private agricultural biotech R&D.

If the model's predicted cyclical pattern of industry concentration is correct, the next few years should witness a reversal of the current pattern of increasing industry concentration. Assuming that M&A moves pro-cyclically with concentration and counter-cyclically to industry R&D activity, M&A activity in the industry should diminish significantly over the next few years, also reversing the behavior of the past few years. As time unfolds, these implications will be testable.

The pro- or counter-cyclicity of R&D investment distinguishes among competing explanations of concentration. For example, the complementary asset argument suggests that as M&A activity increases, so too would the productivity of R&D assets, because they are now paired with complementary assets (Graf, Rausser and Small; Rausser, Scotchmer and Simon).

This suggests that investment in R&D would move with M&A activity . A pure transactions cost approach (without complementary assets) would suggest that if the purpose of the M&A is to reduce transactions costs in linked R&D activities (Artuso, Johnson and Melkonian, Kalaitzandonakes), then M&A activity would move contrary to R&D. The current model is consistent with the latter explanation. Brennan, Pray and Courtmanche have examined empirically whether M&A activity increases or decreases R&D activity, but were unable to reach conclusive results.

Conclusions: Policy Implications

Increasing industry concentration typically raises concerns about monopoly power and non-competitive behavior. Such is the case with the agricultural biotech industry. For example, the EU afforded patent protection to biotech innovations starting only in 1998, 18 years after the US Federal Court of Appeals allowed patents of living tissue in Diamond v. Chakrabarty. A large part of this delay was due to environmental opposition, which in 1995 prevented passage of a similar act and opposed the 1998 act: "The Green lobby claims that it will give industry monopoly rights over genes, cells, plant, animal and human body parts" (BBC, 1998).

The policy implications stemming from the cyclical model mitigate concerns about concentration for two reasons. First, the availability of monopoly rents motivates investment in R&D. Hence there is a tradeoff between static efficiency in the sense of pure competition, and dynamic efficiency in the sense of an ongoing flow of welfare-improving innovation (see Aghion and Howitt for a more general discussion of this issue). Second, the cyclical nature of concentration suggests that policy makers need not be overly concerned with the high level of

M&A and increasing industry concentration, because as the cycle is completed the increases in concentration may be reversed.

The policy implication is not a complete laissez-faire attitude, however. The potential existence of negative externalities from agricultural biotechnology, particularly on human health and/or the environment, has been raised by many environmental, consumer and health groups. Coupled with the need to 'win' the R&D race by being the first to discover a new technology, potential negative externalities raise the possibility that, in the rush to innovate, firms may commercialize agricultural bio-technologies before taking proper (socially optimal) precautions against negative externalities. That is, firms acting solely from a private profit motive will commercialize technologies before the socially optimal time.[4] This suggests the need for regulation or other policy which reduce the potential for negative externalities. Naturally, determination of 'the socially optimal time' is a complex issue. This issue is at the heart of the biotechnology debate between the U.S. and the European Union (EU). The U.S. essentially takes the position that biotechnologies which meet certain bio-safety requirements are legitimate candidates for commercialization; whereas the EU takes a position based on the precautionary principle, namely that biotechnologies are suspect until proven safe over a long period (Caswell). The current model is consistent with the need for bio-safety protocols. A thorough discussion of the socially optimal nature and level of bio-safety standards remains a topic for future research.

[4] This result is not specific to the current model. Similar findings in different contexts date from Barzel, 1968 and Kitti, 1985.

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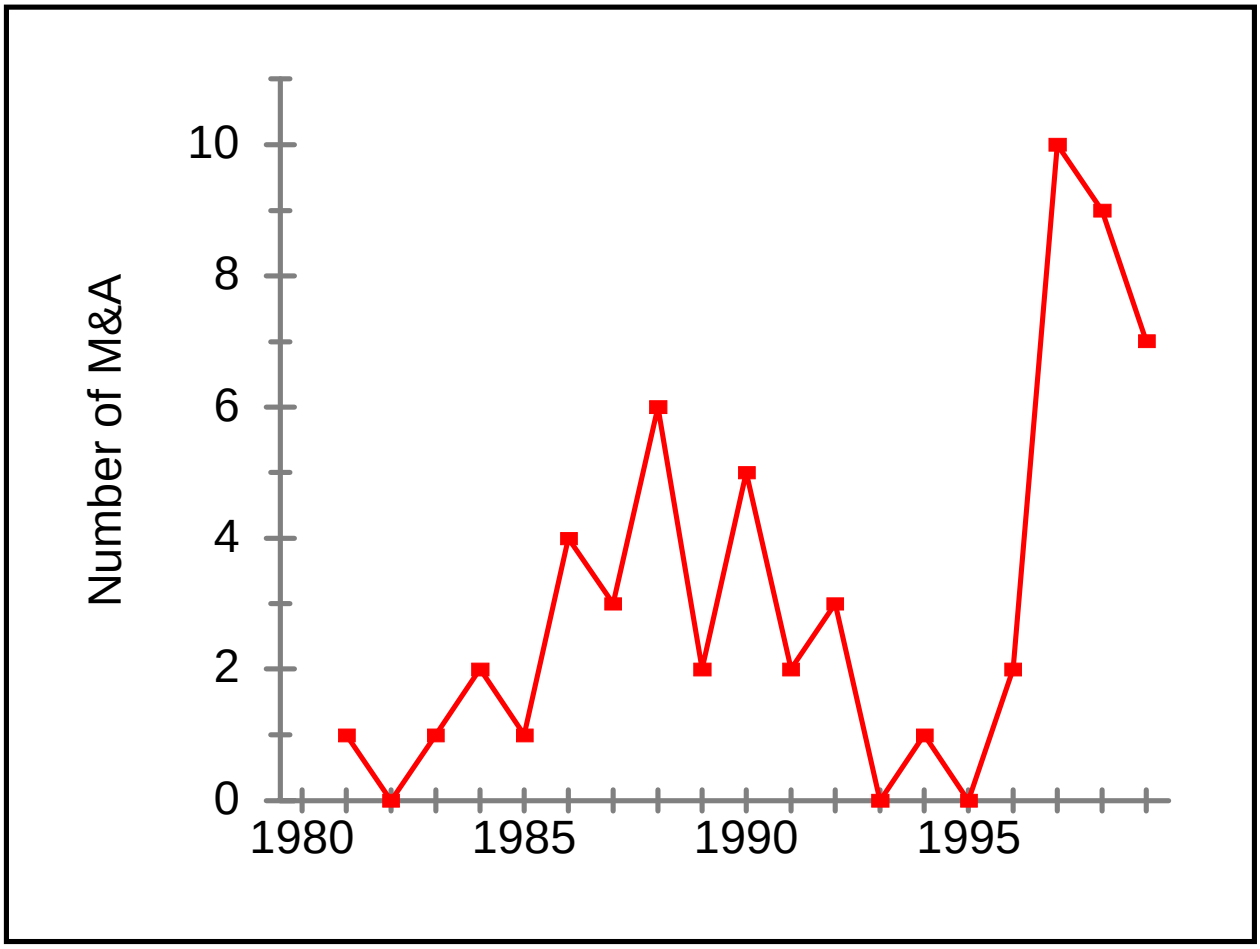

Figure 1. Mergers and Acquisitions by Diversified Biotech Companies and Seed/Biotech Companies (Source: Kalaitzandonakes).

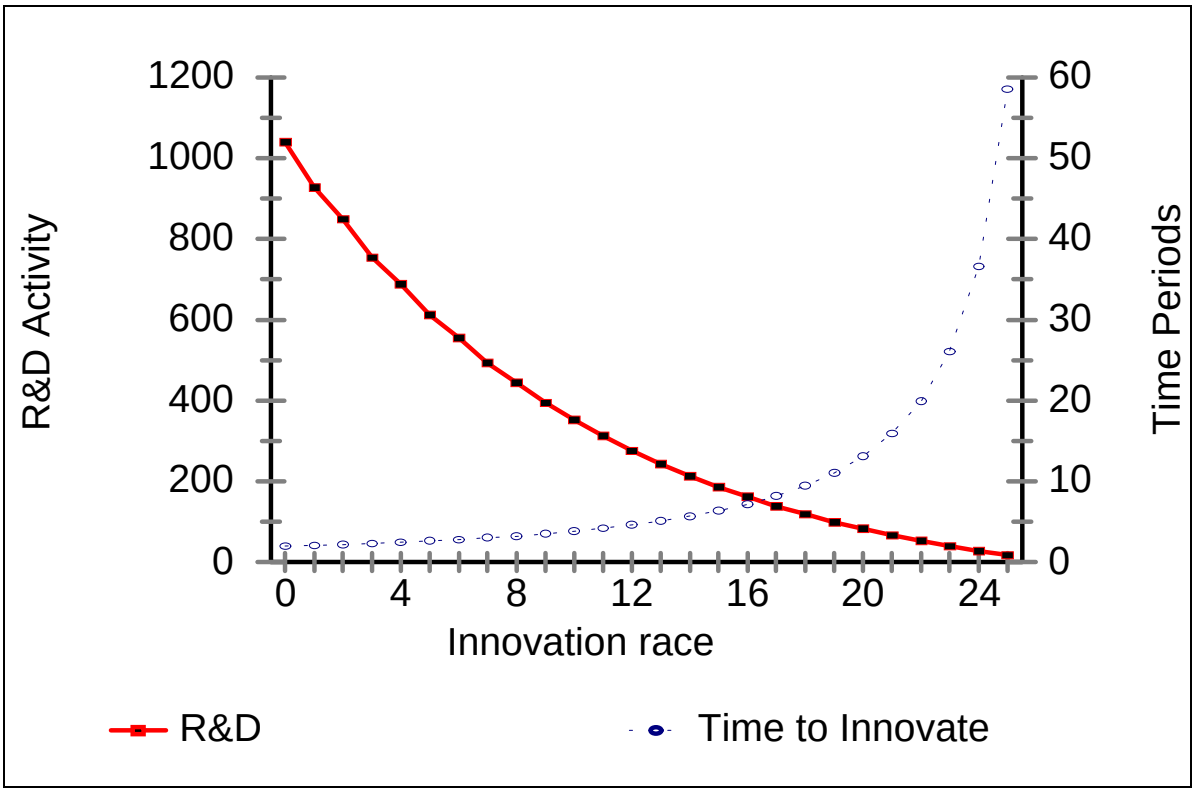

Figure 2. Monotonically declining R&D activity, with monotonically increasing time to innovate (source: numerical solution to equation 14).

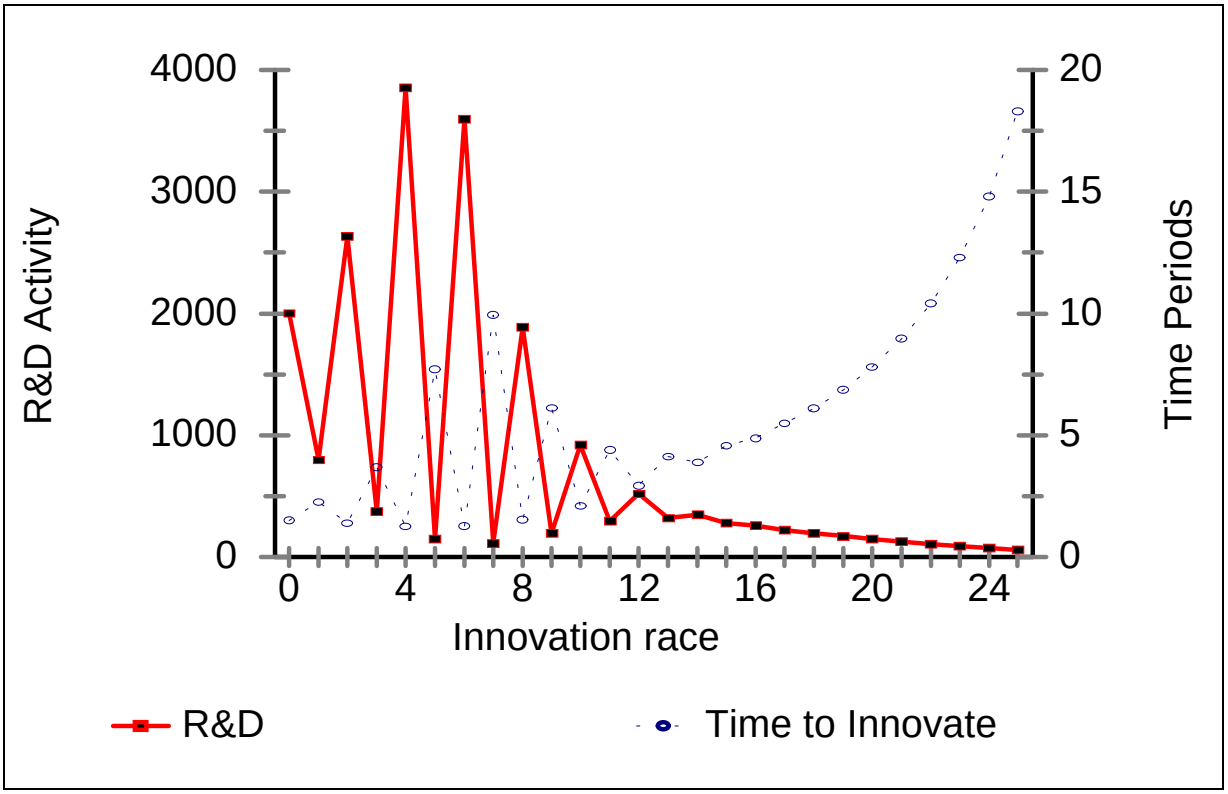

Figure 3. Cyclical pattern of R&D activity, with counter-cyclical time to innovate (source: numerical solution to equation 14).

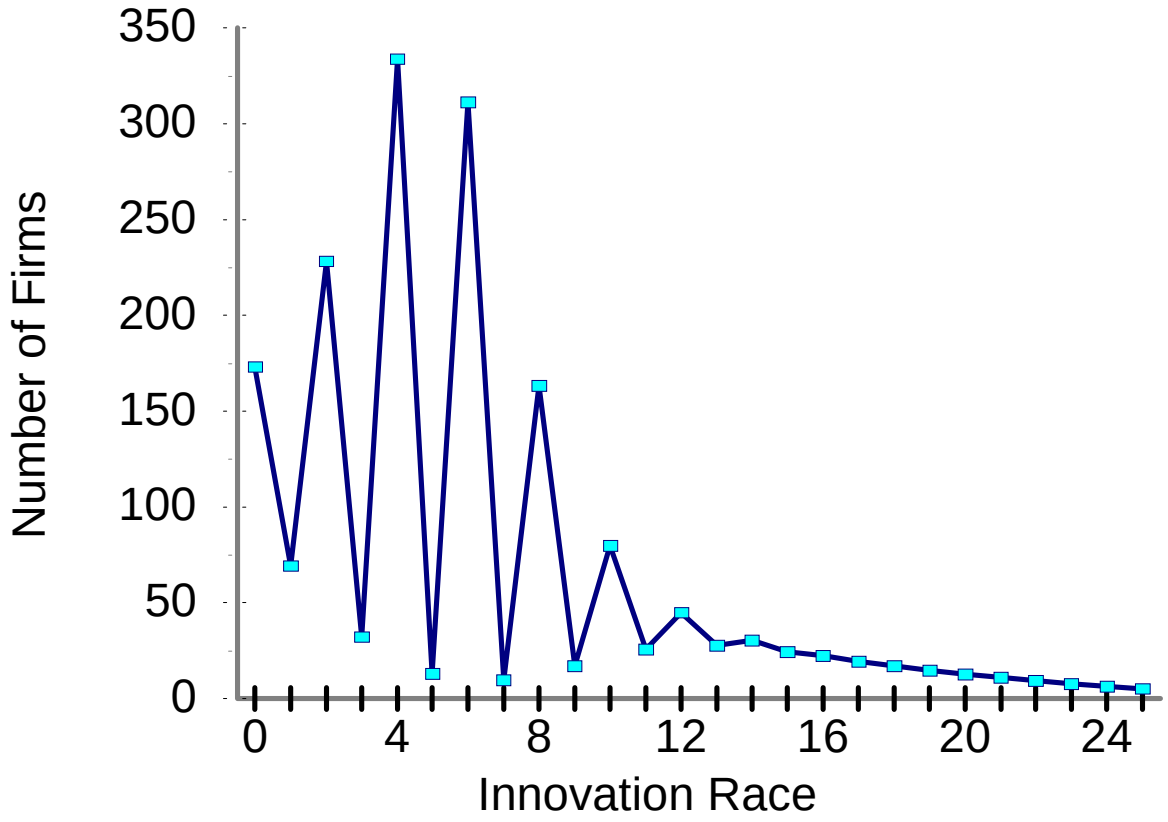

Figure 4. Cyclical Pattern of Industry Concentration, as Measured by Number of Firms in Each R&D Race (source: calculations based on the numerical solution to equation 14, as represented in Figure 3).