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THE COMPARATIVE ADVANTAGE OF REAL OPTIONS: AN EXPLANATION FOR THE US SPECIALIZATION IN BIOTECHNOLOGY

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Comparative advantage based on resource endowments cannot explain United States (U.S.) leadership in biotechnology. Sources of heterogeneity within the process of research and development (R&D) investment, such as international differences in the maximum per-period rate of investment and regulatory uncertainty, offer a plausible explanation that can be incorporated into a real options approach to investment.

Key words: biotechnology; comparative advantage; R&D; real options.

Biotechnology And Comparative Advantage

Comparative advantage is, "the first, oldest, and most basic proposition in the theory of international trade." (Dixit & Norman, 1980). In its standard form, the principle of comparative advantage offers an elegant explanation for the pattern of specialization and trade arising between countries exhibiting sufficient dissimilarities in one or more of the exogenous elements of the neoclassical general equilibrium. More specifically, comparative advantage follows from the presence of some form of international differences, in say technology or resource endowments, which in turn yields an efficient decentralization of global production.

The rapid postwar growth in trade between essentially "similar" industrialized countries suggests a vexing contradiction to the proposition that the pattern of specialization and trade is a result of the exploitation of international differences. United States comparative advantage in biotechnology is an illustrative case of why traditional interpretations of comparative advantage seem to fail. United States firms have long dominated the biotechnology industry relative to firms in other industrialized countries. In 1996, U.S. biotechnology firms numbered 1,287 and employed 118,000 workers, compared to 716 firms and 27,500 workers in all of Europe. United States firms earned $14.6 billion in revenues and expended $7.9 billion on R&D, far exceeding the European totals of $1.4 billion and $1.2 billion, respectively (Ernst & Young, 1997a; 1997b).

Current trade theory typically focuses on international differences in inherited stocks of resources such as human capital and knowledge as the basis for comparative advantage in high technology industries (Grossman & Helpman, 1991). Such theory, however, does not offer a compelling

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explanation for the observed U.S. dominance in biotechnology. Indeed, the post-1945 era has witnessed a convergence in the stocks of such resources among industrialized countries by most relevant measures. Thus, existing trade models can explain why a skilled-labor-rich country such as the United States would specialize in biotechnology, but they cannot explain why the U.S. in particular specializes in biotechnology relative to other industrialized countries.

To cope with the apparent discrepancy between theory and evidence, trade economists have formulated new interpretations of comparative advantage that depart from traditional sources of heterogeneity. One prominent school of thought introduced an element of arbitrariness into the global allocation of industry. Random factors may be responsible for locating an industry, but economies of scale are sufficient to perpetuate the initial pattern of specialization over time (e.g., Helpman & Krugman, 1985). In the same spirit, an explanation for U.S. comparative advantage in biotechnology must also rely on non-traditional interpretations of comparative advantage in order to explain the pattern of specialization in this industry. The following discussion demonstrates how the concept of real options can be applied to a new interpretation of comparative advantage that offers a plausible explanation for the U.S. comparative advantage in biotechnology.

The R&D Process In Biotechnology

In an R&D-intensive industry, such as biotechnology, a natural place to look for sources of heterogeneity is in the R&D investment process itself. Biotechnology R&D can be characterized as follows: 1) R&D programs are lengthy, extending over multiple time periods; 2) time to build for an R&D program is unknown *a priori*; 3) cost to completion is subject to ongoing uncertainty from a number of sources: the physical difficulty of completing the R&D, the external investment environment, and the scientific environment; and 4) R&D costs are made up-front and are at least partially irreversible.

These stylized facts summarize the process by which biotechnology is commercialized. Trefler observes that, "[o]ne facet of national differences … is the ability to commercialize technology. While basic research is internationally available through publications of the scientific community, the translation of basic research into low-cost production processes is both a guarded secret of firms and the comparative advantage of the developed countries." (Trefler, 1993, p.980). Expressed in the context of the community of Northern countries, Trefler's observation can be extended to the idea that commercializing technology may be a comparative advantage of some developed countries *vis-à-vis* other developed countries, as in the case of the U.S. and biotechnology.

A country's comparative advantage in commercializing new technologies can be thought of as the ability to innovate more rapidly than rival countries: in other words, translating the R&D process described above into viable commercial products more rapidly than rivals. Within the R&D process, at least two candidate sources of heterogeneity exist which may serve to create international differences in the pace of biotechnology innovation. First, since biotechnology R&D is lengthy, the rate at which a firm can invest will have important implications for average time to build, or equivalently, the rate of innovation. Secondly, the presence of regulatory uncertainty, and its implications for investment incentives, suggests that a reduction in the level of uncertainty surrounding the regulatory regime will reduce the incentive for firms to delay investment in order to obtain more information about the future path of the regulatory environment.

Empirical evidence suggests that in the U.S. and European biotechnology industries, manifestations of these sources of heterogeneity both favor a more rapid innovation rate in the U.S. In the case of per-period rates of investment, based on 1996 data, the average level of R&D investment by U.S. biotechnology firms was $16 million, compared to an average level for European firms of $6 million.

This suggests that there is a much tighter supply constraint on the availability of investment capital in Europe as compared to the U.S., where there are well-tested capital markets such as NASDAQ. In addition, U.S. biotechnology firms encounter less regulatory uncertainty, compared to their European counterparts (Nelson *et al*., 1999). For example, the U.S. Food and Drug Administration only requires that genetically engineered foods meet the same standards as their conventional counterparts if they are substantially equivalent in content. As a result, over 40 genetically engineered crops/products have been approved for commercial release in the U.S. In contrast, the approval process in Europe is much more protracted and uncertain. For example, by June 1999, only 12 crops/products had been approved in the European Union (EU), and currently a moratorium exists on further approvals due to consumer concerns about their impact on food safety and the environment. In addition, there is evidence that consumer concerns over biotechnology are negatively affecting the levels of public and private investment in biotechnology in the EU (Consumer power, 2000). Given these differences, a more rapid rate of innovation in the US would likely translate into an observed comparative advantage on the part of U.S. biotechnology firms compared to their European rivals.

Real Options And Biotechnology

Given the maintained hypothesis that international differences within the R&D process are responsible for U.S. leadership in biotechnology, what analytical framework is suitable for working out the implications of this hypothesis? Orthodox investment theory applies the net present value (NPV) rule, which compares the present value of the expected stream of revenues from a project with the present value of the expected costs. This approach, however, ignores three key features of many real world investment problems: irreversibility, ongoing uncertainty, and the ability to delay investment after the opportunity to invest is acquired (Dixit & Pindyck, 1994). In contrast, these features are captured in the real options approach to investment, which makes it is well suited for analyzing investment conditions in the biotechnology industry, given the structure of the R&D process summarized in the stylized facts. It can also accommodate the two forms of heterogeneity hypothesized to be the source of comparative advantage in biotechnology.

In the real options framework, the opportunity to invest in a new biotechnology R&D program is likened to holding a financial option, where the firm has the right, but not the obligation, to initiate the first stage of investment - in other words, exercise the investment option (see Pindyck, 1993). If the option is exercised, the firm invests at the per-period rate of investment and completes a portion of the R&D, at which point the firm acquires another option either to initiate the next stage of the R&D, or to abandon the project.

The decision whether or not to initiate the investment, and once initiated, the decision whether or not to continue with the next stage of R&D, is predicated on a comparison of current expected cost to completion with a "critical value". The critical value can be computed by applying pricing techniques for financial options to the biotechnology R&D investment decision, which, as stated above, can be re-stated as a question of optimal exercise of an option to invest. The critical value is the threshold level of cost to completion, in excess of which it is economically infeasible to initiate or continue an R&D investment. A firm's critical value is a function of four key parameters: the value of investment in an R&D project, the per-period rate of investment, the risk-free rate of interest, and uncertainty. The latter consists of *technical* uncertainty relating to the cost of successfully completing the project, *regulatory* uncertainty, and *scientific* uncertainty, which relates to new results from the scientific community indicating that an R&D program should be halted.

Given the critical value, the firm's investment strategy can be summarized as follows. If cost to completion exceeds the critical value, the firm will either delay initiating the project, or terminate it midstream if it has already begun. Conversely, if cost to completion is below the critical value, the

firm will either initiate the investment, or proceed with the next stage of the R&D if the project is already underway. Thus, the firm's investment behavior arises from the evolution of cost to completion over time, relative to the critical value.

Using a real options interpretation, the biotechnology firm's R&D investment can be viewed as the management of a sequence of investment options, a process that continues until the project is successfully completed, terminated midstream, or the initial option to invest is discarded. Therefore, comparative advantage arises from firms in one country, on average, managing their options in such a way that the resulting pace of innovation exceeds that in other countries. Since option management is based entirely on the relationship of current expected cost to completion to the critical value, sources of heterogeneity, which serve to create international asymmetry in the critical value of cost to completion, will be sufficient to identify the pattern of specialization in biotechnology.

In fact, the sources of heterogeneity observed in regard to the European and U.S. biotechnology industries both impact the critical value of cost to completion as noted earlier. Given the structure of the real options model, a higher per-period rate of investment and a lower level of regulatory uncertainty both serve to increase the critical value. A higher critical value in turn imposes a looser decision criterion in the evaluation of investment opportunities, whether in terms of initiating the R&D, or continuing it once begun.

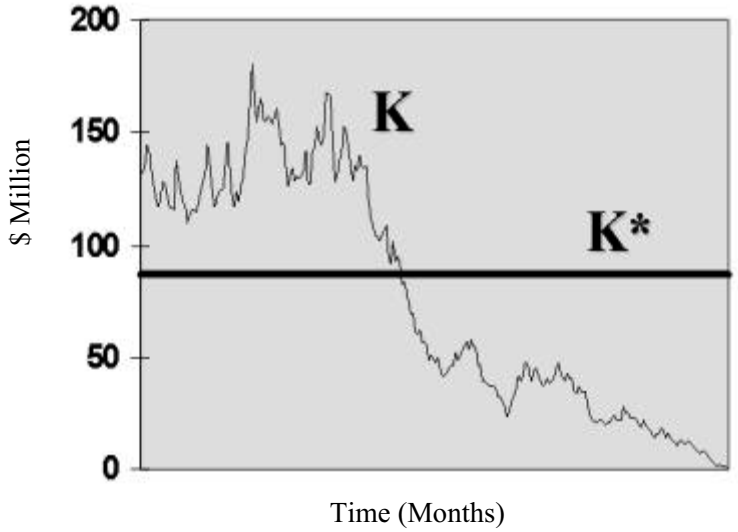
Given that the sources of heterogeneity would imply a higher critical value for U.S. biotechnology firms relative to European firms, the real options framework suggests that in managing their options to invest in biotechnology R&D, U.S. firms would initiate investment earlier, innovate more rapidly, persevere longer in the face of mounting R&D costs, and ultimately, successfully complete more R&D projects than European firms. Lavoie and Sheldon (2000) have examined this hypothesis explicitly. On the basis of data relating to the key parameters determining a firm's critical cost to completion, a computer simulation exercise was conducted in which the investment behavior of representative U.S., and European biotechnology firms was analyzed, given a stochastic investment environment. The two firms were treated as identical except for the two sources of heterogeneity mentioned above, which resulted in the critical cost to completion being $143 million for the U.S. firm and $87 million for the European firm.

In figure 1, a specific iteration from the simulation for the European firm is shown. The firm begins with an initial cost to completion, K, chosen randomly, at time t = 0. At this point, the firm compares this starting value to its own critical value of cost to completion, K*. Since the initial value is greater than K*, the firm delays exercising its option to invest and instead observes conditions in the industry, summarized by the evolution of K over time. In the sample iteration, expected cost to completion, K, driven by stochastic conditions in the investment environment, eventually falls below K*. At this point, the firm exercises its option and invests at the per-period rate until the project is completed. If the degree of regulatory uncertainty facing the European firm were higher, K* would be lower, and this would increase the firm's incentive to delay its investment. In contrast, if the supply of capital constraint facing the European firm were relaxed, the per-period rate of investment would be higher, as a result of which the critical cost, K*, would be higher, thus increasing the firm's incentive to begin investment earlier. The overall results of repeated simulations of this type for both the U.S. and European firm corroborate the inference that the U.S. firm would soon dominate the industry relative to the European firm.

Comparative advantage can thus be interpreted in the language of real options. U.S., and European biotechnology firms acquire opportunities to invest in R&D programs; R&D investment follows a process similar to that summarized in the stylized facts. The opportunity to invest can be likened to a sequence of options, which each firm must manage within the context of the uncertain investment

environment in which R&D takes place. The presence of heterogeneity in the form of a higher U.S. per-period rate of investment and a lower U.S. level of regulatory uncertainty implies that U.S. firms will apply a looser decision criterion in exercising their options than the European firms. This in turn yields the result that, on average, the pace of innovation in the U.S. biotechnology industry will exceed that in the European industry, suggesting that biotechnology R&D and production will eventually concentrate in the U.S..

Figure 1: Simulation of Expected Cost to Completion K Relative to Critical Cost of Completion K*



It should be noted that the real options explanation for the U.S. comparative advantage in biotechnology is best applied to what have been the formative years of the industry, when it has been largely made up of a population of relatively identical start-up firms. More recently, however, the biotechnology industry has been undergoing consolidation, with a growing proportion of the industry captured by multinational corporations forming alliances with, and acquiring, start-ups (Sharp, 1996). For example, German-based Hoechst-Schering AgrEvo recently made a $45 million deal with U.S.-based Gene Logic to discover genes useful for crop protection and improvement products. This suggests that the observed pattern of specialization emerging through sources of heterogeneity in the R&D investment process may be an intermediate state. Competition for external capital, and a more flexible R&D environment, may have pushed the start-ups to be early entrants to the industry relative to the multinationals. Multinationals have delayed exercising their options to invest, preferring instead to wait for more information on the future profitability of biotechnology by observing the performance of the start-ups, perhaps in the form of products reaching the marketplace, or at least steady progress in R&D programs. Now that a certain "critical mass" has been achieved in the industry by the start-ups, multinationals have begun to exercise their investment options by forming alliances or merging with existing biotechnology firms.

Application of the real options framework to biotechnology R&D suggests that even under conditions where traditional interpretations of comparative advantage fail, a world leader in high technology industries like biotechnology may still be identified by analyzing investment behavior as a study in options management. Comparative advantage follows from the impact of heterogeneity within the

R&D process on the option management strategies implemented by biotechnology firms. Based on the observed heterogeneity, U.S. firms on average exhibit a comparative advantage in managing their biotechnology investment options to yield the greatest reward compared to European firms. Analyzing biotechnology R&D from this perspective yields a compelling explanation for the U.S. leadership in the biotechnology industry observed today. However, recent changes in the industry structure suggest that the pattern of specialization in biotechnology may, in the long run, be determined by other factors as described in the economic literature on multinationals (Helpman & Krugman, 1985).

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