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Untangling the Origins of Competitive Advantage

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I. Introduction

Strategy studies... is systematic, like the system of touts at the race track...

(Stinchcombe, 2000)

What are the origins of competitive advantage? Although this question is fundamental to strategy research, it is one to which we lack a clear answer. As strategy researchers we believe that some firms consistently outperform others, and we have some evidence consistent with this belief (Rumelt, 1991; McGahan and Porter, 1997). We also have a number of well developed theories as to why, at any given moment, it is possible for some firms (and some industries) to earn supranormal returns. As of yet, however, we have no generally accepted theory C and certainly no systematic evidence C as to the origins or the dynamics of such differences in performance. We know, for example, why high barriers to entry coupled with a differentiated product positioning obtained through unique organizational competencies may provide a firm with competitive advantage. But we know much less about how barriers to entry are built: about why this firm and not that one developed the competencies that underlie advantage, and about the dynamic process out of which competitive advantage first arises and then erodes over time.

This conceptual ambiguity has always been problematic for many economists, who have tended to view persistent differences in performance as a function of Aunobserved heterogeneity@ (Mundlak, 1961; Griliches, 1986). For example, empirical work in industrial organization routinely controls for Afirm fixed effects.@ These are usually statistically significant and often account for a substantial fraction of the total variation in firm productivity or performance. Whereas strategy researchers tend to emphasize the degree to which these kinds of results offer support for the importance of Acapabilities@ or Apositioning@ (Rumelt, 1991; Henderson and Cockburn, 1994; McGahan and Porter, 1997; Lieberman and Dhawan, 2000), economists tend to emphasize the possibility that fixed effects are simply controlling for a series of much more mundane measurement problems, ranging from the difficulty of computing appropriately depreciated capital stocks and of measuring firm-specific input and output price schedules, to the problem of controlling for difficult-to-observe factors such as worker effort or worker quality. In short, the evidence which strategy researchers view as the motivation for their intellectual agenda are interpreted by many economists in terms of Anuisance@ parameters C things which must be controlled for but which are not of intrinsic interest.

This implicit critique has been reinforced by theoretical and empirical research in the tradition of population ecology (see for example Hannan and Freeman, 1989). In summarizing the contributions of this literature and its application to strategy, Stinchcombe (2000) charges that the preponderance of

strategy scholars have simply failed to understand (and certainly to systematically account for) the implications of population dynamics for performance heterogeneity. Stinchcombe suggests that if superior performance arises from the degree to which a firm=s resources and/or strategy Amatch@ the competitive environment, and if resources are randomly distributed at Abirth@ (or if the environment which firms face at the time strategies are chosen and resource investments are made is sufficiently uncertain), then performance heterogeneity simply reflects the fact that the realized competitive environment favors some strategies and some resource bundles over others. Such a critique implies that the cases which motivate so much of strategy research, and indeed even some of our theoretical frameworks, are roughly equivalent to ex post accounts of the way in which a winning gambler chose to put her money on red rather than on black at the roulette table.

In this paper we argue that grappling with this problem should be of central concern to strategy researchers: that while many of us are aware of the issue that Stinchcombe raises, without a more detailed understanding of the origin and dynamics of the development of competitive advantage we run the grave risk of meriting Stinchcombe=s taunt that we are indeed Atouts at the racetrack.@ We suggest that empirical strategy researchers need to move beyond studies of differential performance to more integrated studies which not only identify those factors which are correlated with superior performance but also attempt to explore the origins and the dynamics of their adoption.

We begin the paper with a brief literature review. By and large, Stinchcombe=s critique C and population ecology more generally C suggests that most performance differentials, particularly differences in the probability of survivorship, can be explained by differences in a firm=s initial conditions, and, moreover, that differences in initial conditions are largely the result of difficult-to-explain (and even harder-to-measure) differences in each firm=s initial allocation of resources and capabilities. In contrast, strategy is centrally concerned with the process of how firms and managers *respond* to and exploit environmental signals. For example, in the last twenty years, there has been an explosion of powerful frameworks for evaluating the determinants of differential performance, from Porter=s five forces framework to the resource-based view to transaction-cost economics. While each of these frameworks offers a somewhat different explanation for heterogeneous performance, all share two assumptions: that competitive advantage arises through earlier or more favorable access to resources, markets, or organizational opportunities; and that exploiting such opportunities reflects some degree of active interpretation of internal and external environmental signals by managers. Indeed, we argue that these literatures often share the implicit view that the *origins* of competitive advantage lie in the unusual foresight or ability of the firm=s managers.

Of course, this characterization of the two schools of thought is unrealistically stark: population ecologists recognize the possibility that firms may be able to adapt to their environment and their competitive experience (Barnett and Sorenson, 1998), and strategy researchers understand that firm strategy and capabilities are subject to powerful inertial forces (Christensen and Bower, 1994). But as we discuss in some detail in Section II, substantial differences in focus do exist: while population ecology is principally focused on exploring the performance implications of strong organizational inertia, one of the core agendas of strategy is understanding which organizational structures allow firms to first identify and then exploit opportunities offered by their environment and so (potentially) overcome organizational constraints.

We then turn in Section III to a discussion of an empirical methodology that might enable us to explore the relative importance of initial conditions and strategic choice in shaping competitive advantage. Our goal is to lay out an empirical framework that might allow us to compare and contrast the distinctive implications of the strategic perspective alongside the predictions of the population ecology literature, and thus to both offer a preliminary response to Stinchcombe=s critique and to begin disentangling the origins of competitive advantage.

We begin by distinguishing between differences among firm in terms of their Ainitial conditions@ versus differences in the rate at which they adopt a particular performance-enhancing practice (or strategy) that has been linked to superior performance. Using Stinchcombe=s analysis, we would expect the primary determinant of each firm=s degree of adoption at any particular point in time to be the initial condition or founding state of that firm. This is not to imply that Stinchcombe=s analysis suggests that firms cannot change, only that we believe that in general he would argue that change will not be systematically tied to the kinds of environmental cues which would be readily amenable to empirical analysis by strategy researchers.

We contrast this hypothesis with two explanations for diffusion which are consistent with a strategic perspective, and are more difficult to reconcile with Stinchcombe=s hypothesis. First, a strategic orientation would suggest that, in the absence of organizational failure, those firms whose early history places them in a particularly unfavorable position will tend to be the firms that respond most aggressively in terms of the rate at which they adopt particular performance-enhancing practices or strategies. We label this the Aconvergence@ hypothesis, under which the key empirical question is not somuch whether differences between firms will persist but how long they take to erode. From this perspective, the dynamics of competitive advantage are driven by two distinct processes: the exploitation of particularly favorable combinations of practices and/or market positions by firms whose initial positions Amatch@ their

environment, and the erosion of these rents as competitors Acatch up@ by mimicking the successful strategies of market leaders.

Second, we suggest that, beyond initial conditions and the process of convergence, adoption rates may be associated with environmental cues which are more intensively experienced by some firms rather than others. Firm strategy may thus be responsive to factors which provide information about a distinctive opportunity to invest in resources or strategies which will ultimately be associated with competitive advantage. For example, if firms are in different Aniche@ markets during the early stage of an industry, then the information these firms will possess about the future evolution of the industry may be different and their strategy should in principle respond to these signals. From an empirical perspective, this hypothesis suggests that strategy will be a function of the firm=s *current or recent* environment; of course, a second issue exists as to whether we should focus on environmental cues which tend to be associated with internal (organizational) factors, external (market) factors, or both.

To illustrate these ideas, we then turn in Sections IV and V to an application of this empirical framework through the evaluation of the adoption and diffusion of one particular strategy C the use of science-driven drug discovery C in the context of the worldwide pharmaceutical industry. We begin by briefly motivating the study of the adoption of science-driven drug discovery as a useful context in which to think about the origins of competitive advantage, and then turn to a discussion of our data sources and variable construction. We explore the measurement of both initial conditions and convergence, and then use our qualitative knowledge of the industry to identify five distinct Aenvironmental cues@ that might drive Astrategic@ adoption: a firm=s distance from public science, whether or not the CEO is a scientist, its accumulated stock of scientific knowledge, its market position, and the composition of its sales portfolio.

Our analysis is by no means definitive. We offer it as a preliminary descriptive analysis of a complex phenomenon that raises as many questions as it answers. However we believe that it illustrates concretely one approach to taking Stinchcombe=s hypothesis seriously while also evaluating the origins of competitive advantage in a systematic manner.

Our findings are consistent with a perspective in which both population ecology and strategy have an important role to play in explaining patterns of organizational heterogeneity. On the one hand, Ainitial conditions@ C or the position of each firm at the beginning of the period covered by our data C play an important role. Firms differ very significantly in the degree to which they had adopted the techniques of science-driven drug discovery in the first years of our period, and these differences persisted for many years. But there is also evidence for a powerful convergence effect, with the firms which were furthest from best practice at the beginning of the period moving most aggressively to adopt it. Finally, after

controlling for initial conditions and convergence, additional time-varying characteristics of the firm play a modest role in explaining patterns of diffusion: both the composition of the firm=s sales portfolio and its market share are significantly correlated with the rate at which the practice of science-driven drug discovery is adopted by the firm. Our results therefore provide substantial support for both Stinchcombe=s view of the sources of competitive advantage and for a more traditional, Astrategic@ view, the implications of which are addressed in the concluding section of the paper.

II. The Origins of Competitive Advantage.

Early studies of competitive advantage were rooted firmly in historical analyses and careful qualitative research. This work could be interpreted as suggesting that competitive advantage was a complex phenomenon, that depended crucially on the active presence of superior leadership (Andrews, 1971; Selznick, 1957; Chandler, 1962). For example, Chandler=s early work can be read as implying that those firms who adopted the new M-form before their competitors gained a strategic advantage, and, moreover, that the choice to adopt the new organizational form reflected the structure and leadership qualities of a company=s top management. Through the 1960s and 1970s, the study of Astrategy@ was thus the study of what general managers or Aleaders@ should do and it was generally assumed that doing these things would make a difference: firms with better leaders would make better choices and would ultimately do better than their competitors.

Porter turned this paradigm on its head (Porter, 1980). In transforming the study of Aimperfect competition@ into the analysis of Acompetitive advantage,@ Porter shifted the focus of strategy research *outward*, towards the analysis of the firm's microeconomic environment. Porter's approach yielded sharply defined tools for understanding exactly why some firms (and industries) were likely to be more profitable than others. A Afive forces@ analysis is essentially a structural map of the underlying economics of an industry: a map of the degree to which competitors, entrants, substitutes and vertical bargaining power exert pressure on the margins of a firm in a particular industry. A firm operating in an industry in which there are substantial returns to scale coupled with opportunities to differentiate, that buys from and sells to perfectly competitive markets and that produces a product for which substitutes are very unsatisfactory (e.g. the US soft drink in the 1980s), is likely to be much more profitable than one operating in an industry with few barriers to entry, and a large number of similarly sized firms who are reliant on a few large suppliers and who are selling commodity products to a few large buyers (e.g., the global semiconductor

memory market).[1]

[1] Structural analysis has, of course, moved much beyond Porter=s original book, and we do not even attempt to summarize this literature here. For some recent contributions, see, Brandenberger and Nalebuff (1998) and Besanko, Dranove and Shanley (2000).

Structural analysis is a powerful tool for understanding why a particular strategic action (e.g., branding or investment in complementary product areas) may be associated with supranormal returns, but in and of itself says nothing about the role of senior management C or the process of strategic choice C in determining profitability. Consider the case of Crown Cork and Seal. [2] This classic HBS case describes the metal can industry: an industry that has a classically unfavorable structure and in which, in consequence, the vast majority of firms are relatively unprofitable. A structural analysis provides concrete insight into why it is so difficult for most firms to make supranormal returns in steel can production. In addition, the case can be read as suggesting that Crown itself earns supra normal returns because it has developed unique capabilities that have allowed it to differentiate its product in a way that is difficult for competitors to imitate. Does the case therefore imply that Crown was particularly well managed or that it had chosen a Agood@ strategy? Analogously, does it also imply that those metal can producers that are not performing well are managed by Abad@ managers who have chosen Abad@ strategies? Certainly this is the way that the case is often taught: as if the vision and determination of John Connelley, who developed Crown=s strategy, was a critical determinant of its success. To take Stinchcombe's critique seriously, however, is to wonder whether Crown was simply lucky: whether it happened to be to be managed by Connelley, who happened to be obsessed with customer service. Stinchcombe forces us to ask: would Connelley have been as successful, as Avisionary,@ in choosing a strategy in another environment?

Porter's analysis was fundamentally agnostic on this point, but a simplistic interpretation of his work seemed to imply that structural analysis could be used prospectively: that doing strategy was about Achoosing good industries@ or Arebuilding industry structure.@ The literature filled up with Afive force analyses@, and it was tempting to use them prescriptively: build these kinds of barriers to entry, structure rivalry along these lines, and your firm and perhaps your industry would become more profitable. Notice that at its roots, this stream of work returns to the founding assumption of the field: good strategy is about leadership, about foresight. Managers that are smart enough to understand the implications of structural analysis and to make the commitments that it requires are likely to outperform those that do not (Ghemawat, 1991; Shapiro and Varian, 1998). Certainly it is the case that most teaching in strategy (at least implicitly) assumes this to be true. We act as if we believe that if we teach our students to analyze industry structure, they will be better positioned to allocate resources into the Aright@ industries, or to influence industry structure in favorable directions. But we should recognize that while a variety of field

[2] HBS #: 9-378-024

studies certainly suggest that this is the case, there is, at least to our knowledge, no compelling quantitative evidence supporting this view: no broad-based statistical study showing that firms in which senior management actively used analytical tools to understand industry structure outperformed those that did not.

It was against this background that the Aresource based view@ of the firm emerged (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993). At one level, the resource based view (hereafter ARBV@) is simply a reinterpretation of the environmental perspective. Where the latter describes analytically why a differentiated position within an industry coupled with high entry barriers can lead to profitability, the former redirects attention towards the underlying heterogeneity making such a position sustainable. For example, while early environmental analyses seemed to suggest that competitive advantage arose from purely technological factors (such as economies of scale) or from unique assets (such as a brand name reputation), the RBV emphasized the idea that these technological or market positions reflect internal organizational capabilities, such as the ability to develop new products rapidly, to understand customer needs profoundly, or take advantage of new technologies cheaply. Proponents of the RBV suggested that strategic investments directed towards these *internal* activities might be of equal (or even greater) importance in generating supranormal returns.

More importantly, however, the RBV deepened the discussion of causality by focusing attention on two key insights about to the sources of competitive advantage. First, in many cases, an industry=s Astructural@ features are the result of the organizational capabilities of it's constituent firms: a powerful brand name, for example, may reflect years of successful new product introduction and superb (and unique) marketing skills. Second, there are good reasons for thinking that the market for organizational capabilities may be imperfect in exactly the kinds of ways likely to lead to the existence of supranormal returns. In part because of these two insights (which are implicit but not always manifest in environmental analyses), the RBV is often positioned as an Aalternative@ to the environmental perspective. In our view, such a positioning reflects a significant misconception, since the RBV and the environmental perspective are complementary in many important respects. Each proposes a model of why firms may sustain superior performance, but the two models are not mutually exclusive, at least in terms of their empirical predictions: while the environmental view focuses attention on external industry structure, the RBV directs us towards the fact that internal capabilities and investments provide the instruments and tools to shape this external environment.[3]

[3] For example, from an environmental perspective, the pharmaceutical industry has historically been a profitable because buyers and suppliers are weak, entry is costly and difficult, and substitutes and rivalry are quite muted. At least in part, this structure reflects external forces, such as the fact that the industry=s

products can be securely protected through patents, and so is not the result of a specific organizational competence on the part of a particular firm. But the industry-s attractiveness also reflects the unique competencies developed by the larger pharmaceutical firms, including, among other factors, their years of investment in sophisticated research capabilities, their knowledge of regulatory systems around the world, and their extensive distribution and physician networks.

Moreover, both literatures offer a similar theory about the process of strategic choice. In the case of environmental analysis, while economics is used to explain what kinds of strategic positions are likely to be most profitable, the theory is essentially agnostic as to how firms come to assume them. Firms can be lucky, they can be fast, or they can be far sighted: as long as they deal with the Afive forces@ they will be profitable, and the power of the tools lies in explaining exactly what these forces are and what kinds of mechanisms will help a firm deal with them. At least at some level, many (perhaps most) empirical treatments within the RBV tradition follow a similar logic, with the caveat that rather than emphasizing the fact that one firm rather than another Achose@ a particular market position or production technology, the analyses focus on the fact that one firm Achose@ to develop a certain set of internal capabilities or unique organizational assets (see for example, Henderson and Clark, 1990; Clark and Fujimoto, 1991; Eisenhardt and Tabrizi, 1995).

At a more subtle level, however, the RBV literature begins to address causality and the ultimate origins of competitive advantage more deeply. It has implicit within it a significantly different view of the dynamics of strategic advantage, and, in particular, of exactly what managers can and cannot do. While the canonical reference for the RBV literature is usually taken to be Penrose (1959), the RBV perspective on the strategy *process* seems to be influenced more by Stinchcombe (1965), on the one hand, and Nelson and Winter (1982), on the other. Specifically, RBV scholars often seem to suggest that organizations are fundamentally different from each other for reasons that may have very little to do with any kind of Astrategic logic,@ and that they can only change through limited, local search. To the extent that competencies are built on organizational routines that are only tacitly understood C indeed if tacit understanding and complexity are a prerequisite for any competence to be a source of competitive advantage C then there may exist a fundamental tension between the fact that competencies lie at the heart of competitive advantage and the use of this insight to guide strategy choice (Leonard-Barton, 1991). From this perspective, the simple observation that competencies may lead to advantage is only half the battle: the other half is understanding where competencies come from.

The theoretical RBV literature thus makes explicit a view of Astrategy@ that has long been latent C the sense that strategy is not all, or not only, about the cognitive ability of the senior management and their ability to make the Aright@ decisions, but also about their ability to work creatively with the raw material presented by their firm and their environment (Quinn, 1978, Mintzberg, 1987); to respond appropriately when their firm's organizational structure finds Agood@ strategies (Burgelman, 1994); and to create decision structures and procedures that allow a firm to respond to its environment adaptively (Bower, 1974; Levinthal, 1997). In short, in focusing on the dynamics of competence and resource creation, the RBV is

centrally concerned with the degree to which successful firms are indeed Alucky@C since it suggests that many of the competencies underlying advantage are the result of investments made under a heavy cloud of uncertainty and that they are subject to local but not globally adaptive evolution.

This approach promises a bridge between the insights of those who stress Aluck@ or Ainitial heterogeneity@ in shaping firm performance and the central insight of the strategy field: that what managers do matters. But we believe that these implications have not been fully worked out. Most importantly, the RBV has not generated the kinds of empirical studies of adoption that are crucial both to fleshing out a full response to Stinchcombe=s critique and to building a richer understanding of the origins of competitive advantage. While there are studies suggesting that the possession of unique organizational competencies is correlated with superior performance (Henderson and Cockburn, 1994; Powell, Koput and Smith-Doerr, 1996), and others suggesting that competitive advantage may be heavily influenced by conditions at a firm=s founding (Klepper, et al., this volume, Eisenhardt, 1988; Eisenhardt and Schoonhoven, 1990), so far as we are aware, there are few careful studies of the hypothesis that successful strategy is the successful management of the evolution of organizational skills and its changing environment.[4] Indeed, some of the most elegant and widely cited studies of the diffusion of organizational innovation do not control for firm founding conditions (see, for example, Davis, 1991). At its worst, just as overenthusiastic readings of Porter led to the prescription Achoose a good industry,@ overenthusiastic readings of the RBV have had the flavor of Abuild the right resources/competencies.@ Even Barney's original piece has something of this tone, as for example when he suggests that:

> *ATo be a first mover by implementing a strategy before any competing firms, a particular firm must have insights about the opportunities associated with implementing a strategy that are not possessed by other firms in the industry, or by potentially entering firms...@*
>
> (Barney, 1991, p 104)

Such an analysis clearly places the source of competitive advantage in the insight of the firm=s managers, and leaves unanswered the critical empirical question: <u>how does one know</u>? Is the success of

[4] There is of course a powerful literature demonstrating that changes in top management team compensation is correlated with major strategic reorientations (See, for example, Fletcher and Huff, 1990, and work by Tushman and his collaborators, including Murmann and Tushman, 1997). While this literature is suggestive, in general it leaves the question of causality unaddressed.

Sony in introducing the Playstation the result of a strategic competence possessed by Sony=s senior managers? Or is it the result of a complex history, an evolutionary process by which Sony was Alucky@ enough to be in the right place at the right time? In short, what are the concrete and distinct implications of Stinchcombe=s and Nelson and Winter=s insights for our understanding of strategy?

III. Empirical Methodology

In the remainder of this paper, we begin to address the implications of these questions for empirical research in strategy, at least in a preliminary way. Distinguishing between alternative theoretical perspectives in evaluating the origins of competitive advantage is a massive and difficult task. The empirical work in the remainder of this paper should thus be interpreted as outlining one type of empirical approach which might yield fruitful analysis of the origins of competitive advantage rather than as a definitive test of one particular theory in the specific context that we examine.

Our empirical analysis is designed to tease apart the issues that we identified above. We identified two core hypotheses: on the one hand, the view that competitive advantage is largely determined by factors put in place at the organization=s founding, and, on the other, the view that competitive advantage results from a firm=s Astrategic@ response to changes in this environment or to new information about profit opportunities. We believe that one way in which one might plausibly begin to separate these two effects is to identify an organizational practice that is closely associated with competitive advantage, and then to explore the determinants of the diffusion of this practice across a population of firms.[5]

To do this, we build on a long tradition of modeling the process of diffusion of new technologies. Our analysis consists of the estimation and interpretation of a Adiffusion equation@ $y_{j,t} = f(I_{j,0}, Z_{j,t}, t; \Omega)$, where $y_{j,t}$, our dependent variable, is a measure of the extent to which firm j has adopted the practice as of time t, and the explanatory variables are chosen to illuminate the competing hypotheses. $I_{j,0}$ is a measure of the initial, or founding conditions of firm *j*, while $Z_{j,t}$ is a vector of variables which reflect the opportunities and environmental conditions affecting firm *j* at time *t*, and thus highlight the existence of potential sources of differences across firms. For example, $Z_{j,t}$ might include measures of the nature of firm decision-making, of absorptive capacity or other strategies associated with seeking external sources of knowledge, of market position, or of the talent or focus of managers in the firm. Time, *t*, plays a critical role as an explanatory variable here, since it allows us to capture the *rate* of diffusion of the practice, and

[5] Note that our focus on diffusion contrasts with the traditional emphasis on explaining *performance* as a function of initial conditions, environmental factors, or strategic choices.

so allows us to test whether firms in alternative environments tend to have faster or slower rates of adoption of the practice in question. Ω is the vector of parameters to be estimated.[6]

Within this general framework, choices about functional form or about which of these explanatory variables to include correspond to different perspectives on the sources of competitive advantage. Three possibilities are of particular interest. First, perhaps the simplest model one can imagine would be to regress y_t on a favored set of Z_t-s, from which one might conclude that the level of adoption of the practice was satisfactorily Aexplained@ by the Z's, providing support for a Astrategic response@ perspective. Alternatively a second approach would be to regress y_t on I_o by itself, perhaps to test the conclusion that Ait-s all initial conditions.@ Finally, our focus on diffusion allows us to evaluate a third (somewhat more subtle) implication of the Aenvironmental@ perspective, namely that firms who find themselves to have chosen strategies or organizational practices which are particularly *unfavorable* will be likely to have a higher rate of adoption than firms who are near the Afrontier@ of profitability. In other words, even if the level of y_t is positively associated with I_o (there is Apersistence@ in the impact of initial conditions), a strategy-oriented perspective suggests that y_t will be *negatively* associated with $I_o \times t$. That is, firms which begin at the Alowest@ level will have the highest rate of increase. This strategic response, if it occurs, will manifest itself in the data in the form of *convergence* over time among (surviving) organizations in terms of the organizational practices which they exhibit C the laggards will Acatch up@ with firms who were Alucky@ enough to have chosen favorable practices at their founding (or at the beginning of the observed sample period).

To assess the relative salience of Ainitial conditions@ and environmental heterogeneity in driving e patterns of adoption of a performance-enhancing practice, we require an empirical model of the dynamics of diffusion which allows for both effects to work factor simultaneously. We therefore specify a model which includes a firm-s initial conditions, I_o, a firm-s environment and opportunity set at a given point in time, Z_t , and interactions between each of these elements and time, t.

$$y_t = \alpha + \beta t + \gamma I_o + \delta I_o \cdot t + \varphi Z_t + \rho Z_t \cdot t \qquad (1)$$

[6] In the remainder of this discussion we suppress the firm-specific subscript j on all the variables.

The parameters of this model nest a number of key hypotheses about the determinants of y_t which can be formulated as restrictions on the parameters.[7] For example, a naive reading of population ecology would suggest that, beyond a firm=s initial conditions, there should be no systematic pattern to diffusion relating to the firm=s changing environmental circumstance: some firms will be able to execute the practice as a function of their founding conditions and others will not. Thus for a given set of firms, current levels of adoption should be a function only of initial conditions, implying that $\varphi = \rho = \delta = 0$.

Conversely, the simple environmental or Astrategic@ hypothesis implies that y_t should also be driven by Z_t : firms may change their behavior in response to changes in the environment with levels of adoption not wholly determined by a firm=s starting position. This would imply $\varphi \neq 0$ and/or $\rho \neq 0$. For example, we believe that one could interpret a finding that y_t was correlated with the current market position of the firm as suggesting it is indeed reacting to exogenous shocks in its environment, independent of its founding conditions. Similarly a finding that y_t was correlated with the experience of the firm=s CEO would suggest that the firm is changing its strategy as it develops new capabilities.

Finally, the Aconvergence@ hypothesis suggests that, in addition to a firm=s initial conditions, and its responsiveness to objective measures of its environment, firms who face unfavorable initial conditions may be those who are most likely to have the highest rate of adoption, that is, $\delta < 0$. This would imply that initial conditions are important in shaping strategy, though hardly in the way that Stinchcombe hypothesized.

Before turning to the data, two further modeling issues must be addressed. The first is that of functional form: if we interpret y_t as Afraction adopted@ then it would be appropriate to follow the diffusion literature in recognizing that the diffusion of most practices or technologies follows an S-shaped (or sigmoid) pattern through time. There are a variety of functional forms which allow for this type of nonlinear time path, but the simplest transformation involves taking the log-odds ratio ($\log(y_t /(1- y_t)$) of the dependent variable measuring the extent of adoption (Griliches, 1957). On the other hand, if y_t is a

[7] Note that this is very much a Areduced form@ model of adoption. It is not our goal (at least in this paper) to develop or estimate a fully specified structural model of optimizing adoption behavior. Indeed, given the diverse set of plausible hypotheses about the drivers of adoption behavior, it is not clear that estimating such a model is currently feasible without preliminary empirical work which substantially narrows down the potential range of theories to be accommodated. Consequently, we confine ourselves here to identifying the principal covariates of adoption, recognizing that adoption is a dynamic process. Distinguishing the relative empirical salience of competing hypotheses may provide an initial guide to specifying a more fully articulated structural model.

more general indicator of the use of a practice, then theory offers us little guidance as to functional form.[8]

[8] Our empirical results are surprisingly robust to variation in the functional form imposed on the adoption-intensity variable. Our robustness checks (not presented here, but available on request) included using the level of adoption intensity as well as the natural logarithm.

A second issue relates to the measurement of initial conditions, I_o. Two possibilities present themselves: either to take on the formidable task of identifying and explicitly measuring all the relevant aspects of heterogeneity in firm capabilities, or, more straightforwardly, to capture their empirical content with y_0 C the pre-sample value of y_t. This second option is attractive not just because it is easy to implement, but also because it allows us to be agnostic about the precise nature of the initial characteristics of firms which drive their subsequent evolution.[9] Actual estimation of these models therefore requires data only on $\boldsymbol{y}$ and $\boldsymbol{Z}$. We now turn to our specific application of this framework, the diffusion of science-driven drug discovery in the worldwide pharmaceutical industry.

IV. Data and Variable Construction

Competitive Advantage from Science-driven Drug Discovery

We focus here on the adoption of Ascience-driven drug discovery@ as a primary strategy in the management of pharmaceutical research. As we have laid out in a number of papers, prior to the late 1970s pharmaceutical research was conducted largely through a process of so called Arandom@ search (See, for example, Henderson, Orsenigo and Pisano, 1999, and papers referenced therein).[10] From the late 1970s on, firms began to responded to the acceleration in the growth of publicly available biological knowledge by adopting a new mode of so called Ascience-driven@ drug discovery. This move appears to have been tightly associated with the creation of competitive advantage: those firms adopting the new techniques appear to have been significantly more productive (Gambardella, 1995; Henderson and Cockburn, 1994) in an industry in which the introduction of blockbuster drugs is a source of tremendous value (Grabowski and Vernon, 1990).[11]

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[9] Conditioning on the starting value of the dependent variable (or some function of it) is a well-understood procedure in the econometrics literature on dynamic panel data models, see for example Arellano and Bond (1991). This also allows us to understand the implications of our results in the framework the heterogeneity/state-dependence distinction used by econometricians. See Heckman (1991).

[10] Notice that this terminology can be deceptive. The major pharmaceutical firms began investing in fundamental science after the first world war, and by the 1950s many of them employed significant numbers of well trained scientists (Parascandola, 1985). ARandom@ drug discovery was Arandom@ in that while research was often guided or informed by fundamental science, the precise mechanism of action of many drugs was not understood, and new compounds were screened against animal models rather than against particular disease pathways (Henderson, 1994; Henderson, Orsenigo and Pisano, 1999).

[11] The question of just why Ascience-driven drug discovery@ should be a major source of competitive advantage is a fascinating one. The interested reader is referred to our related work (Henderson, Orsenigo and Pisano, 1999; Cockburn and Henderson, 1998; Cockburn, Henderson and Stern 1999a, 1999b; Stern

Despite the power of this strategy, its diffusion across the industry was surprisingly slow. As late as 1991, some firms continued to view scientific publication and participation in the broader community of public science C a key requirement for the full adoption of science-driven drug discovery C as a diversion from the more Aimportant@ business of finding drugs. As the research manager at one of these companies put it:

> *AWhy should I let my people publish? It's just a waste of time that could be spent in the search for new drugs.@*
>
> Quoted in Henderson (1994)

Here we argue that exploring the factors that drove these differences in the rate of adoption across firms not only concretely illustrates the difficulty of distinguishing between explanations, but also serves as a springboard for thinking through the relationship between theories of adoption and theories of the source of strategic advantage. The remainder of this section describes the sources of the data from which we construct our empirical tests, our alternative measures of the practice itself, y_t, and measures associated each firm=s environment at a given point in time, Z_t.

Data Sources and Sample Construction

1999). There are, of course, other sources of competitive advantage in the pharmaceutical industry, including the possession of strong regulatory capabilities, an extensive distribution network or well developed marketing capabilities.

We draw on two primary data sets. The first contains detailed qualitative data and quantitative data for ten major pharmaceutical firms for the period 1965-1990. These data formed the basis for our previous work and are described in detail there (Henderson and Cockburn, 1994, 1996). The second data set consists of a sample of 16 large research-oriented pharmaceutical firms for the period 1980-1997.[12] Overall the average firm in both samples is somewhat larger than the average publicly traded pharmaceutical firm. While they do not constitute a random sample in a statistical sense, they are reasonably representative of the larger pharmaceutical firms who invest substantially in original research and comprise a substantial portion of the industry (the firms in the sample account for approximately 50% of US pharmaceutical sales in 1993). While we were able to obtain detailed, internal data for the first sample, the second relies on comprehensive data collected from secondary sources, including information on the composition and background of senior management, firms' geographical location and patenting activity, scientific papers, and product sales compiled at the therapeutic class level (e.g., cardiovascular therapies, anti-infectives, or cancer). Data about senior management was collected from annual reports while geographical data was derived from the publication record of each firm. Our source for patent data is Derwent Inc=s *World Patent Index*; scientific publications are drawn from ISI=s *Science Citation Index* and *Web of Science*. Sales data are from various publications of IMS America, a market research firm.

[12] The firms are: Abbott, Bristol-Myers Squibb, Burroughs-Wellcome, Ciba-Geigy, Glaxo, Fujisawa, Hoechst, Hoffman La-Roche, Lilly, Merck, Pfizer, Sandoz, Searle/Monsanto, SmithKline Beecham, Takeda, and Upjohn. Nine of these firms are also included in the earlier sample: the remainder were selected to include the industry's leading R&D performers and to obtain worldwide geographical representation.

Measuring the Adoption of AScience-driven Drug Discovery@ (y_t)

A quantitative analysis of the adoption of science-driven drug discovery requires the construction of a reliable measure of the extent to which firms are engaged in the practice.

Our initial measure of this practice, PROPUB, identifies the degree to which researchers were given incentives to establish standing in the scientific public rank hierarchy. In prior work (Cockburn and Henderson, 1998; Cockburn, Henderson and Stern, 1999b), we have argued that the extent to which a firm has adopted this practice is an indicator of how thoroughly they have embraced the techniques of science-driven drug discovery.[13] This measure was derived from detailed qualitative interviews conducted within ten major pharmaceutical firms. While it has the great virtue of being a direct measure of the organizational practice in which we are interested, it unfortunately suffers from two important limitations. First, it was derived from qualitative interviews conducted by a single researcher, which may raise questions as to its reliability and replicability. Second, PROPUB is not currently available beyond 1990 or for the 11 firms in the sample that were not included in our earlier data collection efforts.

We therefore also evaluate the diffusion of science-based drug discovery using three quantitative measures derived from public sources. These variables all draw on bibliographic information collected for every paper published in the journals indexed in the Institute for Scientific Information's *Science Citation Index* between 1980 and 1994 for which at least one author's address was at one of our sample of firms. The most straightforward, PAPERS, is a simple publication count: the number of papers published in any given year for which at least one author was affiliated with our sample firms. As prior research has established, pharmaceutical companies publish heavily, with annual counts of papers comparable to the output of similarly sized universities and research institutes (Koenig, 1983; Hicks, 1995). Publication counts are clearly an important indicator of research activity, and have been previously interpreted as capturing the level of investment in Abasic science@ (Gambardella 1995). Of course, since the volume of publication activity may simply reflect the scale of the firm's research effort, when we use any of these measures as a dependent variable we control for size by including total US pharmaceutical sales in the regression.[14]

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[13] In the ideal case we would like to be able to use a measure based on the actual nature of the science conducted within each firm over time: in the absence of longitudinal reliable survey data about research methodology this is impossible to construct from secondary sources. Instead we use here a number of measures derived from the publication behavior and incentives provided by research-oriented pharmaceutical firms.

[14] Total spending on research would clearly be preferable, but for the complete sample we have only data on total R&D expenditures. This measure is very noisy in that it includes development expenditures in

addition to discovery expenditures, and we know from our prior work that the ratio of discovery to development spending is not constant across firms. It is a particularly noisy measure when the firm is diversified beyond the pharmaceutical industry.

While PAPERS has several attractive properties in terms of capturing the degree to which firms have adopted the science-based drug discovery techniques, PAPERS is also fundamentally an output measure, and may therefore also measure factors such as the success of the firm's research program: the discovery of interesting compounds also generates interesting papers. Using the same data, we therefore constructed AUTHORS: a variable which identifies the number of science-oriented researchers at each firm. AUTHORS is a count of the number of distinct individuals publishing at the firm in any given year. We hypothesize that at those firms in which the scientists face high powered incentives to raise their standing in the public eye the marginal incentives to publish will be higher and the Amarginal@ scientist will make more of an effort to get their name on the papers to which they have contributed.[15]

Although counting authors may give us a better measure of the adoption of the new practice than a raw publication count, it remains an output measure. Our preferred measure of the degree to which the firm has adopted pro-publication incentives is PUBFRAC: the fraction of individuals whose names appear on a patent who also appear as an author on papers published within two years of the patent application. By explicitly tying publishing and patenting together, this measure incorporates the degree to which a firm is encouraging those researchers who are directly involved in the firm=s drug discovery process to participate in scientific publication. In addition, since this is measured as a share rather than an absolute number of papers or authors, in principle it captures the *propensity* to publish, independent of the scale of

[15] Another possibility would be to count Astars@: the number individuals in a firm who publish prolifically. Zucker, Darby, and Brewer (1998) have suggested that this Ahigher standard@ is critical for understanding successful performance in, at least, biotechnology firms. In preliminary work we have found that this variable performs much like AUTHORS.

the firm, either in terms of sales or number of employed scientists.[16]

[16] Constructing PUBFRAC was far from straightforward. For each firm in the sample, we first identified all papers (a) which were published between 1980 and 1994 in journals indexed by the *Science Citation Index* and (b) in which the name of the firm, or one of its subsidiaries appears in at least one of the authors' addresses. We had then to attempt to match the names of many thousands of individuals across two different data sets and consistently apply rules for ambiguous cases. Much of this matching was accomplished straightforwardly in software, but a number of difficulties did induce some measurement error into the process. These included typographical errors in the source data, and differences across papers by the same author in the use of initials, surnames and given names; extensive hand-coding was necessary to complete the task. A consistent matching procedure was applied to all firms, and so we are reasonably confident that bias in the measurement of PUBFRAC is limited to differences across firms in the severity of these problems.

Table (1) provides summary statistics and the correlation coefficients for these four variables. In addition to the relatively high levels of the objective measures such as PAPERS and AUTHORS, it is worth noting that all four of the measures are quite closely correlated. The time path of these variables indicates the gradual diffusion of the practice across the industry over time. Table (2) shows the evolution of both the mean values and the coefficient of variation (standard deviation/mean) for each of our four measures of science-driven drug discovery. Not only does the mean level of each measure rise, but the coefficient of variation steadily falls, suggesting that there was considerable Aconvergence@ towards a common level of intensity of use of the practice at the same time that its average level increased. Note that this diffusion is not driven primarily by the exit of firms from the sample.[17] In itself, this immediately raises questions about the extreme form of Stinchcombe=s hypothesis: the firms in the sample appear to be actively adopting the practice of science-driven drug discovery over the period covered by our data, an observation which suggests that there is more going on than a simple initial random distribution of capabilities followed by an exogenous environmental shock. Indeed, it is consistent with a Astrategic@ view in which managers gradually recognize the opportunities presented by the new techniques and move to adopt them. These simple statistics highlight the empirical salience of the convergence hypothesis: that initial conditions engender persistence over the medium term, but that laggard firms aggressively move to adopt these techniques, erasing the importance of the past in the long-term.

Measuring Initial Conditions, I_o.

As discussed above, rather than attempt to characterize initial conditions directly, we use y_0, or the firm=s initial level of adoption of the practice of science-driven drug discovery as the summary statistic for its initial condition. This is calculated from average level of y in the two years preceding the sample period.

Defining Z: measures of firm heterogeneity

We draw on the literature and on our qualitative data to construct six distinct measures of heterogeneity in the environment and opportunity sets of each firm. Some of these focus on general characteristics of the firm: others focus on the role of cardiovascular therapies C a leading application for

[17] Of our original sample of 10 firms, 2 exited through merger. Of our later sample of 19, only two have (at the time of writing) exited through merger.

science-driven drug discovery C in the firm=s research and sales portfolio and on the firm=s share of the market for cardiovascular therapies. This list of variables includes both factors that might Arationally@ drive differences in the diffusion of science-driven drug discovery C including the firm=s closeness to public science and its technological experience and market position C and factors that might shape the attention of senior managers, including whether the firm=s CEO has a scientific background and the composition of its sales portfolio. Our discussion here focuses largely on the qualitative and theoretical evidence that motivates each variable: full details of the ways in which each was operationalized are included in the appendix. Table (3) presents descriptive statistics for these variables.

(a). Scientist-CEO

Qualitative interviews with senior industry participants often explained variations across firms in the rate at which they moved to science-driven drug discovery in terms that resonate deeply with a Astrategic@ picture of adoption[18]. Our informants suggested that differences in Aleadership@ or Avision@ across firms had a very significant effect on the decision to adopt the new mode of research. One senior researcher remembered:

> A*We spent most of the seventies going to T groups. It was fun, but we didn't get much science done... The managers of the firm were largely focused on using the cash generated by the pharmaceuticals group to look for diversification opportunities...*@

Managers in firms that failed to adopt the new techniques looked back on their failure as an embarrassment:

> A*By now you will have worked out that we didn=t really do any real research in the eighties. We talked about it, but X didn=t understand what it required. We kept doing what we had always done...*@

[18] In order to assist us in framing our hypotheses, between September 1998 and April 1999 we conducted interviews at seven pharmaceutical firms. All but one were based in the United States. The interviews were loosely structured discussions that explored first, whether it was plausible that the adoption of science-driven drug discovery had significant effects on research productivity and second, why it might have been the case that despite their plausible impact on productivity, many firms were slow to adopt them.

The decision to invest in the science-driven approach was often identified with the hiring of key individuals:

> *AOh, that's when we hired Y. He built a completely new research facility and started to hire aggressively. He had a fundamental belief that if we did leading edge science we would find breakthrough drugs...@*

Capturing this insight empirically is a challenging task. One option is to explore the correlation between changes in research strategy and changes in senior management personnel. Unfortunately we have not yet been able to collect this information in rich enough detail for our full sample. Here we use a binary variable (Scientist-CEO) measuring whether or not the firm=s CEO has a scientific background as a first attempt at capturing the idea. We hypothesize that firms with scientifically trained CEOs will be more likely, all else equal, to adopt the techniques of science-driven drug discovery. While the classical environmental approach implicitly suggested that top managers who can deeply understand the value associated with novel strategies is important, the RBV literature has placed much greater emphasis on these kinds of factors.

(b). Cardiovasculars as a share of total firm sales

Our qualitative evidence suggests that the speed with which the new techniques were adopted was a function of the balance of power within the firm. Those firms whose sales portfolios were dominated by therapeutic classes in which the new techniques were likely to be particularly important C particularly by sales of cardiovascular drugs C appear to have become convinced that the new techniques were likely to be important much faster than managers in those firms in which sales were much more heavily concentrated in therapeutic areas for which the new techniques were much less useful. Thus we hypothesize that firms whose sales are dominated by cardiovascular therapies will adopt the new techniques faster than their rivals.

Notice that because of the very long lead times characteristic of the pharmaceutical industry, share of the sales portfolio is <u>not</u> highly correlated with share of the patent portfolio. Thus we interpret any effect of the share of sales portfolio on the diffusion of science-driven drug discovery as a reflection of the focus of attention of senior management attention, rather than as a response to any difference in the firm=s research base[19]. It may also, of course, reflect the presence of marketing and sales assets.

[19] Share of the sales portfolio might also shape the choice of research technique if firms have specialized marketing or distribution assets. These assets certainly exist C Eli Lilly, for example, has historically had a very strong position in the distribution and marketing of treatments for diabetes. However we believe that in the majority of cases they are relatively fungible.

(c). Distance from public science

Our qualitative evidence suggests that differences in geographic location may also have had systematic effects on the decision to adopt the new research techniques since the benefits of adopting the new approach may well have been significantly higher (and the costs significantly lower) for those firms whose research laboratories were located in reasonably close proximity to large communities of publicly funded researchers. Close proximity not only made it easier to attract the best quality researchers, but probably also made it much easier to maintain close connections to the public sector once these researchers had joined the firm (Jaffe, 1986; Zucker, Darby, and Brewer, 1998). Indeed, both the classical environmental perspective and the RBV have emphasized the role of geographic location in shaping the ability of firms to more aggressively adopt practices associated with superior performance. We have developed a measure, DISTANCE, of the geographical position of a firm's research activities using the publications data from ISI.

(d). Knowledge capital: Cardiovascular patents as a percentage of total firm patents

One of the key claims of the RBV is that a firm=s particular experience with specific technologies or technological trajectories provide it with a firm-specific capital stock which it can both exploit as well as providing a mechanism to draw upon outside knowledge. In the current context, the techniques of science-driven drug discovery were not immediately applicable to all areas of drug research. In the late 1970s and early 1980s, for example, many scientists believed that the new techniques would be much more useful in the search for cardiovascular therapies than they would be in the search for new anti-infective drugs. Scientific understanding of cardiovascular disease was much further advanced, and it was thought that this understanding would provide a particularly rich basis for drug discovery. Firms with more experience in cardiovascular therapies might therefore have expected to benefit disproportionately from adoption of the new techniques. Thus, in the RBV tradition, we hypothesize that adoption will be positively correlated with experience in cardiovascular disease.

(e). Market Position: Share of the cardiovascular market

Following the classical environmental perspective, we also expect a firm=s position in the product market to have an effect on its decision to adopt the new techniques. A large literature in economics links the degree to which a firm possesses monopoly power in the product market to its decision to adopt an innovation (Gilbert and Newbury, 1982; Reinganum, 1981; Fudenberg and Tirole, 1985; Henderson,

1993; Karshenas and Stoneman, 1993). Unfortunately this literature yields no very clear predictions C under some circumstances monopolists appear to have incentives to adopt innovations *before* entrants; under others they have an incentive to wait. Moreover, it has not directly addressed the question of the drivers of adoption of a research technique, as opposed to the adoption of a new product. Nonetheless, we believe that in this context the most plausible interpretation of this literature is that firms with monopoly power in the relevant product market will have higher incentives to adopt the new techniques, since they are more likely to benefit from them. Thus, consistent with an externally-oriented environmental perspective, we evaluate whether firms that have a high share of the cardiovascular market will adopt the new techniques faster than others.

(f). Firm sales

Finally, total US sales is included to control for the fact that there may be economies of scale in the adoption of the new techniques. Zucker and Darby (1997) found evidence for economies of scale in the adoption of the techniques of biotechnology, and to the degree that Ascience-driven@ drug discovery also takes advantage of scientific resources that can be maintained centrally and exploited throughout the organization one would expect economies of scale to be important in this case as well. Indeed, one of the key tenets of most strategy perspectives (either the classical environmental perspective or RBV) is that *scale matters*, if only in terms of having sufficient liquidity or slack resources to aggressively adopt performance-enhancing organizational practices.

Other potential sources of heterogeneity.

This list of variables could be expanded almost indefinitely. We do not explore, for example, the degree to which either a firm=s position in its network or wider institutional context determine adoption. Determining the network position of a major pharmaceutical firm turns out to be an exceptionally difficult undertaking[20] and while we are sure that the wider institutional context plays a role in shaping the adoption

[20] To begin with, there is the question of which network to focus on. In the context of a single industry study, it does not make sense to focus on the degree to which there is interlock across board of directors, for example, since within a single industry directors are forbidden from serving on multiple boards to avoid potential conflicts of interest. We explored the degree to which we could use patterns of joint publication to construct a plausible network, but discovered that constructing such a network requires the collection (and coding) of data about hundreds of thousands of papers and would result in an intractably large network containing thousands of nodes. We are currently exploring whether we can usefully construct such a network by tracing the movement of senior executives across the industry.

of science-driven drug discovery, distinguishing between the effects of institutional isomorphism or management fashion and the simple effects of time and convergence turns out to be very difficult. We also do not address the extent to which governance structures and incentive systems at the most senior levels of the firm affect adoption decisions. While this is an intriguing hypothesis, preliminary analysis highlighted both the difficulty of constructing consistent measures of governance problems across national boundaries and the fact that they appeared to be only very weakly correlated, if at all, with the firm=s choice of research technique.

V. Results

In this section we discuss the results from two sets of regression models. The first set focuses on the Ainitial conditions@ and convergence model. The second set brings in the measures of environmental heterogeneity.

Our analysis begins by considering a simple model of the adoption of science-driven drug discovery which focuses exclusively on the dynamic impact of Ainitial conditions@:

$$y_t = \alpha + \beta t + \gamma y_o + \delta\, y_o \cdot t + \varepsilon_t$$

This equation is estimated using each of our alternate measures of the extent of diffusion of science-driven drug discovery (with the appropriate functional forms for each measure). Table (4) presents the results, which we find quite striking. In the first place, they show that at any point in time the degree to which a firm has adopted the techniques of science-driven drug discovery is to a very great extent a function of the firm=s position at the beginning of the period. The estimated coefficient on the initial value of the dependent variable is large and very significant in all of the regressions. Second, the highly significant *negative* coefficient estimated for the interaction of y_0 with time provides evidence in favor of the convergence hypothesis. The firms that were Afurthest away@ from best-practice (with lower initial levels of the dependent variable) moved *fastest* to adopt. However, while convergence seems to be an important aspect of these data, the coefficient estimates imply a relatively slow diffusion process: ten years or more for the laggard firms to catch up with the leaders.

These results are important. They illustrate concretely a model of competitive advantage that is implicit in much of our teaching and research but that is rarely demonstrated. Understanding the origins of competitive advantage requires a focus on two distinct processes: *creation*, the means whereby first adopters develop and exploit new techniques or strategies, and *imitation*, whereby laggard firms respond to their unfavorable positions and move to imitate market leaders.

Note that at one level, these results are consistent with a Stinchcombian view of the sources of

competitive advantage. Early movers, who happen to be endowed with the Aright@ set of organizational practices, reap the returns from being in the right place at the right time. Laggards manage to change, but changing does not create advantage, it merely re-levels the playing field. At another level, though, convergence provides evidence for a more Astrategic@ perspective on the dynamics of competitive advantage. Competitive advantage is as much about responding to unfavorable positioning as it is about exploiting those opportunities which present themselves. As such, aggressive imitation by those who are initially positioned most unfavorably is consistent with a process whereby thoughtful managers actively interpret their environment and use their discretion to implement a *strategic* response.

Table 5 builds on this analysis and develops evidence relating to the full diffusion model following equation (1). Each column includes either (a) only variables associated with initial conditions (5-1), (b) only variables associated with time-varying environmental heterogeneity ((5-2) through (5-4)), or (c) both types of variables (5-5). For each regression, the dependent variable is PUBFRAC.[21] The environmental variables are lagged by one period to allow time for firms to adjust their level of PUBFRAC, and each regression includes both a time trend and the log of total firm sales as control variables.

After replicating the Ainitial conditions plus convergence@ result in (5-1) for easy reference, we present our initial analysis of the impact of environmental heterogeneity by dividing the explanatory variables into two groups corresponding to Abehavioral@ and Aeconomic@ hypotheses about the drivers of adoption. The two Abehavioral@ variables are Scientist-CEO and the within-firm share of cardiovascular drugs, which are included by themselves in (5-2). The Aeconomic@ variables are those measuring the firm's distance from science, its knowledge capital, and its competitive positioning, which are included by themselves in (5-3). (5-4) includes both the behavioral and economic variables together but still does not include initial conditions. These results are quite weak. Among the eleven explanatory variables (including firm sales), the only (marginally) significant coefficients are associated with firm sales and the interaction between the firm=s market position in cardiovasculars and TIME; the small positive parameter suggests faster Acatch-up@ for firms with a larger share of the cardiovascular market.

However, we believe that each of the first four regressions in Table 5 are likely mis-specified. For example, by excluding the impact of initial conditions in (5-2) through (5-4), we introduce a great deal of

[21] We have experimented extensively both with PUBFRAC as well as our other measures of the intensity of science-driven drug discovery (PUBFRAC, PAPERS, and AUTHORS). Overall, the key results as they relate to distinguishing between alternative sources of competitive advantage are robust.

noise into the regression, likely limiting our ability to distinguishing the Atrue@ impact of the environmental drivers. Model (5-5) therefore includes both the initial conditions and environmental heterogeneity variables, with a dramatic impact on the explanatory power of the regression and on the coefficient estimates. For example, the regressions suggest that, after controlling for initial conditions and convergence (the coefficients for which remain large and significant as in earlier regressions), those firms whose sales were concentrated in cardiovascular therapies were associated with higher levels of PUBFRAC (though their *rate* of adoption was slower) and firms more distant from scientific centers are associated with lower levels of PUBFRAC. Those firms that had a larger share of the cardiovascular market were also faster to adopt the new techniques (though the impact on the level is negative (in contrast to our initial hypotheses)). Finally, the measures of Scientist-CEO and knowledge capital (share of firms patents associated with cardiovascular therapies) remain insignificant, perhaps due to the noisy nature of each of these proxy measures and their imperfect correlation with the underlying concepts they are associated with. More generally, (5-5) suggests that the inclusion of variables to incorporate the impact of initial conditions and convergence allows for a more precise and systematic evaluation of the impact of environmental heterogeneity on the diffusion process, as well as providing an important confirmation for our earlier results about the impact of initial conditions and convergence.

The alternative specifications offered in Table 5 also provides some evidence about the relative importance of initial conditions versus environmental heterogeneity, at least in terms of goodness-of-fit. Of course evaluating the differences in R^2 from each regression is of only limited value since it cannot provide evidence for how a change in one of the explanatory variables changes the expected value of the dependent variable. However, this comparison does suggest two things in the current context. First, the regressions which focus on the firm=s initial conditions explain a significantly higher share of the overall variance than the regressions which evaluate environmental heterogeneity by itself. Second, and perhaps more importantly, initial conditions and environmental heterogeneity are complementary in their explanatory power B there is over a 33% in adjusted R^2 in the combined model (5-5) compared with either (5-1) or (5-4).

VI. Conclusions and Implications for Further Research

These results are intriguing. At face value, Table (5) appears to offer support for Stinchcombe=s critique, in that initial conditions play a very important role in explaining the diffusion of science-driven

drug discovery.[22] However, by developing a dynamic model of adoption which allows for both convergence and change associated with local environmental cues, our results suggest that conscious strategic adjustment is also quite important for understanding the dynamics of competitive advantage: convergence is a key factor in explaining the overall pattern of adoption, many of the Astrategic@ variables are significant after controlling for initial conditions, and the explanatory power of the diffusion model substantially improves when all of the effects are included simultaneously.

In other words, our results imply that C at least in this context C Stinchcombe=s hypothesis is powerful but not all encompassing. One of the most striking features of our data is *convergence*: firms that were initially Abehind@ at the beginning of the period move more rapidly to Acatch up@ to their more advanced competitors. While associated with the same Ainitial conditions@ that Stinchcombe emphasizes, the process of convergence and imitation is nonetheless interestingly different from a simple model of competition in which competitive advantage reflects the failure or exit of those firms that are not initially well positioned. Our results also suggest that, after controlling for initial conditions, variables traditionally associated with Astrategic intent@ are important determinants of the level and rate of adoption. While Stinchcombe=s hypothesis is well worth taking seriously (and we would encourage future researchers to be careful to control for it), it seems to us that there is sufficient evidence here to suggest that firms can and do change in purposeful ways in response to exogenous shocks. For example, convergence suggests that managers who are initially associated with poorly positioned firms may be the most proactive in altering their practices and strategies. In other words, there seems to be a clear role for understanding the processes of strategic adjustment which occur in response to the internal and external environmental cues. In this sense, our framework and results provide evidence consistent *both* with Stinchcombe=s hypothesis that competitive advantage is importantly driven by exogenous initial variation and with the more Arational@ or Astrategic@ perspective that views firms as responding with foresight to changes in their environment.

[22] One possibility, of course, is that y_o is capturing not the characteristics of the firm=s founding, but a complex (unobserved) history of strategic adjustment. As a very preliminary cut at whether this is plausibly the case, we compared the usefulness of our measures of heterogeneity as measured at the beginning of the period, Z_o, as explanatory variables for y. The regression performed quite poorly, with an even lower proportion of the variance in the dependent variable explained than in the regressions that included contemporaneous measures of heterogeneity.

Of course, as we have emphasized several times, our empirical results are quite preliminary, and perhaps raise as many questions as they answer. Indeed the statistical analysis is largely descriptive, and we have tried to highlight throughout the paper some of the difficult and interesting statistical questions that are raised by the attempt to distinguish among the central hypotheses. Our paper also highlights the need for richer longitudinal data. One could plausibly argue, for example, that the significance of initial conditions in our results is simply a consequence of Aleft truncation:@ that if we knew more about the history of the firms in our sample C about the origins of each firm=s Ainitial conditions@ C that we might be able to uncover additional evidence for the importance of managerial vision and action in shaping competitive advantage. For example, we know from a number of early histories of the industry that pharmaceutical firms differed enormously in the extent to which they invested in basic or scientific research in the 1940s and 1950s. Some firms, such as Parke-Davis, Lilly and Merck, made early and extensive commitments to pure research, while other firms delayed making these investments for many years (Parascandola, 1985). Perhaps extending our empirical study of this industry further back in time would allow us to conclude that the adoption of science-driven drug discovery stemmed from farsighted decisions made decades before the practice became widespread.

This suggestion brings us back to the discussion with which the paper began. During the 1980s, firms that used science-driven drug discovery techniques outperformed those that did not. As such, one might be tempted to conclude that adopting this practice was a Agood@ strategy that led, through the creation of unique capabilities, to significant competitive advantage in the sense of superior ability to generate new drug products. We have, ourselves, recommended to pharmaceutical firms that they adopt these techniques and the managers of many firms have by and large agreed with us. But one of the key conclusions to be drawn from our analysis here is that positively responding to such a recommendation is only half the battle. Incorporating best practice is necessary, but imitation based on the experience of rivals can usually only level the playing field, and in this case, at least, imitation took many years. While key aspects of the adoption process C in particular firms' rate of convergence to best practice C reflected purposive Astrategic@ responses to a changing environment, these responses were greatly constrained by factors that were in place long before many of these firms even began to think seriously about the issue. The RBV has emphasized the importance of long-lived Asticky@ assets, and the powerful influence of historical circumstances seen here indicates that these can be very long-lived and very sticky indeed.

The advent of science-driven drug discovery had a dramatic impact on the innovation process in the pharmaceutical industry. The basis of competitive advantage was changed in important ways, and firms in the industry responded to this shock by making appropriate changes to their internal structure, and

by investing in the necessary capabilities and resources. But some firms entered this period of transition much better equipped than others to exploiting the potential of the new techniques. Were they lucky or were they smart? The difficulty of answering this question empirically points to a deeper research agenda. We believe that a fuller appreciation of the origins of competitive advantage is to be found in a better analytical and empirical understanding of the types of managerial processes which allow some firms to be ahead, and stay ahead, of the game. Ex post, it is clear that some firms actively identify, interpret, and act upon early signals from their internal and external environment, and so position themselves to effectively exploit these opportunities well in advance of others' demonstration of the payoffs from the strategies which emerge later on as Abest practice.@ These firms are *creating* new sources of competitive advantage. Understanding how they organize ex ante to do this is, in our view, a central question for strategy research.

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Data Appendix: Construction of our Measures of Z.

Scientist-CEO

Scientist-CEO is a binary variable set to 1 if the firm=s CEO has a scientific background. We constructed this variable by systematically checking the Annual Report of each company in our sample for the title or background of the CEO. Those CEO=s who were listed as having either a PhD or an MD were coded as scientists.

Distance from science

For any single paper, ISI lists the addresses of each author. From these data we constructed a count of the paper authorships by city for each firm for each year. We designated every city that constituted more than 2% of all the firm's authorships over the entire period a "research node" for the company, and obtained its longitude and latitude. We then weighted each node by the fraction of authorships it hosted relative to all authorships attributed to the company that year. These data gave us a good sense of the changing geographical location of the firm's research over time.

In order the degree to which the firm was "close" to publicly funded science we need to constructed a weighted measure of the location of publicly funded research. This is difficult to do without full data on public spending by geographical location across the world, and data for Europe and Japan are relatively difficult to obtain. As a first approximation we constructed a data set consisting of the addresses of all those authors who coauthored papers with NIH researchers over our period. We designated each city listed in these data that constituted over 2% of total NIH coauthorships an NIH node, and obtained its latitude and longitude. We weighted these nodes using two schemes: as the fraction of NIH coauthorships that they obtained in a given year and as a rank from 1-10 on the basis of the scientific reputation of each node.

A firm's "closeness to science" was then calculated as: $\sum_{ij}\ w_i * w_j * 1/d_{ij}$ where d_{ji} is the distance from each firm $node_i$ to NIH $node_j$, w_i is the weight assigned to the company node and w_j to each node.

Firm Sales

Firm sales is measured as total pharmaceutical sales in the US, as reported to IMS. We excluded sales of OTC or Aover the counter@ medications that can be obtained without a prescription. Note that the US is only about 50% of the world pharmaceutical market, and that many of the firms in our sample have substantial global sales. US sales are thus a rather noisy measure of total sales.

Knowledge Capital: Share of patents in cardiovascular therapies

We used Derwent patent data to construct a measure of the firm's experience or "knowledge capital" in cardiovasculars. For all of the firms in our data set, Derwent generously donated to us complete data about each patent family granted to each firm over our period. Each patent family includes complete information about the patents granted to the firm across the entire world and a complete set of Derwent "manual codes"[23]. For each patent that had been granted in two out of three major world markets (Japan,

[23] The US patent office classifies pharmaceutical patents largely on the basis of chemical structure: a classification that contains very little information about therapeutic intent. The Derwent manual codes are

the US and Europe) we used the "manual codes" to assign patents to particular therapeutic areas. We then calculated a "knowledge stock" in the standard manner assuming a 20% deprecation rate.

Market Position: share of the cardiovascular market

We measure share of sales using detailed data at the product level obtained from IMS America. Note that the pharmaceutical market is a global one. The US market represents roughly 50% of the world market, and nearly every firm in our sample has extensive global operations. Unfortunately our share measures will be distorted by the fact that the distribution of sales across therapeutic classes is not uniform across the world.

Managerial Attention: cardiovascular therapies as a share of the sales portfolio

We measure cardiovascular sales as a share of total firms sales using IMS America data. Note that it is subject to the same source of error as our measure of market position, above.

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assigned by specialists in the field who classify each patent on the basis of its therapeutic implications.

Table (1): Descriptive statistics for alternative dependent variables.

(A) Summary statistics

	N	Mean	Std. Dev
PROPUB	83	3.6	1.3
AUTHORS	153	854	550
PAPERS	153	299	189
PUBFRAC	153	0.65	0.14

(B) Correlation coefficients

	PROPUB	PUBFRAC	AUTHORS
PUBFRAC	0.11		
AUTHORS	0.56	0.42	
PAPERS	0.55	0.38	0.35

Table (2): Means & coefficients of variation over time, alternate dependent variables

	PROPUB		PAPERS		AUTHORS		PUBFRAC	
Year	Mean	C.V.	Mean	C.V.	Mean	C.V.	Mean	C.V.
1976	2.40	0.71						
1977	2.40	0.71						
1978	2.50	0.66						
1979	2.70	0.55						
1980	2.70	0.55						
1981	3.10	0.51	182.4	0.63	393.6	0.60	0.54	0.30
1982	3.30	0.43	197.2	0.65	431.7	0.61	0.58	0.24
1983	3.30	0.43	210.1	0.67	478.3	0.64	0.53	0.31
1984	3.40	0.42	199.3	0.69	489.9	0.66	0.56	0.29
1985	3.40	0.42	252.0	0.74	615.8	0.68	0.58	0.25
1986	3.50	0.41	257.9	0.67	656.3	0.62	0.66	0.18
1987	3.50	0.41	283.9	0.67	746.3	0.55	0.68	0.17
1988	3.60	0.37	279.8	0.68	800.1	0.59	0.67	0.21
1989	3.67	0.36	309.1	0.50	913.9	0.46	0.64	0.16
1990	4.00	0.23	370.6	0.46	1128.8	0.38	0.68	0.13
1991			376.8	0.47	1230.1	0.41	0.68	0.16
1992			452.5	0.46	1436.0	0.45	0.73	0.12
1993			460.1	0.49	1553.9	0.45	0.80	0.13

Table (3) Descriptive Statistics for independent variables.

Variable	Mean	Std. Dev.	Min	Max
Cardio patents share of firm patents (%)	12.47	4.40	5.18	27.98
Cardio as share of firm sales (%)	18.54	19.50	0	73.78
Share of firm in US cardio market (%)	5.27	8.71	0	44.92
Total firm sales ($m)	938.8	701.1	99.9	3653.7
Scientist-CEO	0.065	0.248	0	1
Distance from science	0.363	0.515	0.001	2.290

(150 observations)

Table (4): Initial conditions and convergence at determinants of the adoption of science driven drug discovery.

Dependent variable:	Log-odds (PROPUB)	Ln (PAPERS)	Ln (AUTHORS)	Log-odds (PUBFRAC)
N	135	150	150	150
$PROPUB_0$	1.00** (0.08)			
$PROPUB_0$ * time	-0.04** (0.01)			
$Ln(PAPERS_0)$		1.02** (0.07)		
$Ln(PAPERS_0)$ * time		-0.05** (0.01)		
$Ln(AUTHORS_0)$			1.04** (0.05)	
$Ln(AUTHORS_0)$ * time			-0.04** (0.01)	
$PUBFRAC_0$				3.57** (0.71)
$PUBFRAC_0$ * time				-0.29** (0.11)
Intercept	-3.87** (0.61)	-1.03* (0.04)	-0.85* (0.40)	-2.45** (0.60)
Time	0.18** (0.03)	0.32** (0.06)	0.35** (0.05)	0.26** (0.06)
Ln (Fmsales)	0.21* (0.10)	0.15** (0.05)	0.10** (0.03)	0.09 (0.08)
Adj R Sq.	0.75	0.82	0.91	0.38

Table (5): Initial conditions and contemporaneous heterogeneity

Dependent variable: log-odds (PUBFRAC), 150 observations throughout

	(5.1)	(5.2)	(5.3)	(5.4)	(5.5)
$PUBFRAC_0$	3.57** (0.71)				7.11** (0.92)
$PUBFRAC_0$ * time	-0.29** (0.11)				-0.79** (0.15)
Scientist-$CEO_{(t-1)}$		0.84 (0.53)		0.87 (0.54)	0.33 (0.46)
Scientist-$CEO_{(t-1)}$ * time		-0.07 (0.13)		-0.07 (0.13)	-0.01 (0.11)
Share of cardio in firm $sales_{(t-1)}$		-0.00 (0.01)		0.00 (0.01)	0.05** (0.01)
Share of cardio in firm $sales_{(t-1)}$ * time		0.00 (0.00)		0.00 (0.00)	-0.006** (0.001)
Distance from $science_{(t-1)}$			0.20 (0.26)	0.29 (0.27)	-0.60* (0.25)
Distance from $science_{(t-1)}$ * time			-0.01 (0.04)	-0.02 (0.04)	0.08 (0.04)
Share of cardio in firm $patents_{(t-1)}$			0.01 (0.03)	0.00 (0.03)	-0.03 (0.03)
Share of cardio in firm $patents_{(t-1)}$ * time			0.00 (0.01)	0.00 (0.01)	0.01 (0.01)
Share of US cardio $market_{(t-1)}$			-0.03 (0.02)	-0.03 (0.02)	-0.12** (0.02)
Share of US cardio $market_{(t-1)}$ * time			0.004* (0.002)	0.01* (0.00)	0.02** (0.00)
Intercept	-2.45** (0.60)	-1.22** (0.56)	-1.43* (0.74)	-1.52 (0.83)	-4.99** (0.83)
Time	0.26** (0.06)	0.08** (0.02)	0.04 (0.07)	0.03** (0.07)	0.44** (0.10)
Ln(total firm $sales_t$)	0.09 (0.08)	0.21* (0.09)	0.23* (0.11)	0.24* (0.12)	0.22* (0.10)

Adj R sq.	0.38	0.28	0.28	0.33	0.51