Leveraging IT Capabilities into Bioinformatics in India

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Abstract: Strategic management research on the development of new capabilities has largely overlooked the process whereby initial capabilities are transformed by the firm to create new capabilities. Applying an evolutionary biology model, this paper investigates the leveraging of information technology (IT) capabilities into bioinformatics by India-based Tata Consultancy Services (TCS). However, leveraging capabilities in a vacuum is a model set for failure, as the early days of TCS demonstrated, because the environment of the new application area provides important inputs, often in the form of complementary resources. In the case of TCS, their choice to open-source their software and offer consulting services enabled clients to develop proprietary intellectual property (IP), even more crucial to bioinformatics and life sciences than in traditional IT services.

Keywords: Evolution, Selection, Technological capabilities, Information Technology, Bioinformatics

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Introduction

Strategy literature either directly or indirectly explores the ability of a firm to achieve disproportional rents. Most academics agree that a firm's superior performance is correlated with the possession of a capability, defined as the firm's knowledge that accounts for the firm's ability to perform and extend its output actions (Dosi, Nelson and Winter; 2000). A number of theoretical perspectives offer insights into how firms develop capabilities: the resource-based view (Wernerfelt; 1984, Barney; 1991), evolutionary economics (Nelson and Winter; 1982), the dynamic capabilities perspective (Teece, Pisano and Shuen; 1997), the organizational learning and the knowledge-based view of the firm (Kogut and Zander; 1995, Grant; 1996). These theories also offer insight into how a firm can develop new capabilities from an initial set of capabilities, i.e. that existing capabilities define the menu of future choice. In other words, a specific set of capabilities can serve as a platform into other markets and related product areas or services (Kogut and Zander; 1995). However, the process by which initial capabilities are transformed to create new capabilities has not received the same level of attention.

In this paper, the transformation of capabilities is explored based upon a biological model of evolution, Lewontin's 2-state space model (Lewontin; 1984). This model is further elaborated to incorporate organizational growth by utilizing the concept of exaptation (Gould and Vbra; 1982). Defined by Gould, exaptation is the evolution of a trait possessing one function that later comes to serve an entirely different function. The concept has been brought into the capabilities literature to refer to capabilities or technologies being "co-opted" (Dew, 2006). In this paper, the concept of exaptation is applied to examples of technological growth, which can be termed exaptive technological capabilities. The concept of exaptive technological capabilities expands and enhances Christensen's (1996) model of disruptive technologies by enabling technological capabilities to evolve across multiple bases of competition. Exaptive models are taken from evolutionary biology literature in order to help strategists better understand how knowledge bases can be utilized to build the various capabilities of the firm.

Furthermore, successful capability growth is not only an incremental, linear or a non-linear adaptive process, but in fact may also be a nonlinear exaptive process. Adaptive processes have a prescribed feedback-response loop whereas exaptive processes have a feedback-response loop that can generate unexpected or unintended outcomes. The next step in understanding the exaptive process is to investigate technological growth through exaptive techniques, as evidenced in the bioinformatics industry. Bioinformatics provides both a theoretical and empirical construct to examine exaptive technological capabilities: bioinformatics grew out of the convergence of the information technology (IT) and biotechnology (BT) industries, however, neither industry alone could have spawned the bioinformatics industry.

This paper, structured in five parts, uses the rise of the bioinformatics industry to investigate how initial capabilities are transformed by the firm to create new capabilities. The first section provides a brief summary of existing literature, introducing the theories for technological growth and technological change. The second and third sections apply a specific model of evolutionary biology, Lewontin's 2-state model, to organizational growth to build on the concept of exaptive technological change. This evolutionary biology model examines the set of internal and external selection factors that drive the selection, acquisition and development of knowledge in order to build firm competencies. Lewontin's model requires some adjustment, however, to fully appreciate the relationship between knowledge, which is a core capability, and competencies, which are the external manifestation of the firm's knowledge and capabilities.

The fourth section presents the case of Tata Consulting Services (TCS). The example of TCS, an India-based IT services company, demonstrates the transformation of internal capabilities and confluence of environmental factors that enabled one of India's most venerable IT companies to become a pioneer in the field of bioinformatics. The fifth section concludes with a brief discussion of the learnings and implications from TCS's bold venture into bioinformatics, which albeit successful over time, in its early days could reasonably have been viewed as a failure.

Brief Review of Literature

Theories of evolutionary economics, dynamic capabilities, organizational learning, and knowledge-based literatures offer very useful insights into capability development, as capabilities often rest upon unique sources of knowledge (Kale and Singh; 2002). Dynamic capabilities (Teece, Pisano, and Shuen; 1997) and evolutionary economics (Nelson and Winter; 1982) focus on how firms build, replicate, and adapt capabilities in rapidly changing industries. Firms have to alter their existing routines and learn new routines in order to successfully adapt and survive. Nelson and Winter (1982) define routines as repeatedly invoked patterns creating continuity. Capabilities change through new combinations and reconfiguration of existing routines with newly developed routines as well as through the creation of new patterns among existing subroutines (Nelson and Winter; 1982). Furthermore, firms develop capabilities as they act and engage in experiential actions and learning thus creating sequences and patterns of adaptation.

Dynamic capabilities literature states that organizational capability is based on a system of organizational routines that create firm-specific and difficult-to-imitate advantages. A firm's organizational capability consists of a static capability to consistently outperform rivals at any given point in time and a dynamic capability that enables the firm to improve its performance and capabilities faster than rivals (Penrose; 1959, Nelson and Winter; 1982, Teece, Pisano, and Shuen; 1997). The dynamic capability approach emphasizes the key role of strategic management in appropriately adapting, integrating, and re-configuring internal and external organizational skills, resources, and functional competencies toward changing the environment (Teece, Pisano, and Shuen; 1997).

As described by Grant (1996), the knowledge-based view holds that individual and organizational knowledge acts as a basis for creating firm-level capabilities that become a source of competitive advantage. This knowledge is typically built by learning that involves making associations between a firm's past actions or decisions, the effectiveness of those actions (through success in achieving desired payoffs), and future actions or decisions (Kogut and Zander; 1992). Capabilities develop as a result of recombining and/or integrating knowledge within the firm. Thus, capabilities are developed through a process that involves the interpretation of past individual and organizational experience as a basis for present and future actions.

In contrast, organizational learning literature (e.g. Zollo; 1998, Kale and Singh; 2002) posits that firm capabilities are developed on the basis of incremental learning and fine-tuning of relevant day-to-day activities in the firm. Incremental learning can be replaced or supplemented by organizing principles by which individual and group knowledge is structured and coordinated to develop internal firm capabilities (Kale and Singh; 2002). These organizing principles have also been referred to as the firm's "combinative capabilities" (Zander & Kogut; 1995) or "architectural competence" (Henderson and Cockburn; 1994). Architectural competence requires the development of new ways of recombining existing routines (and knowledge) within the firm. Essentially, they comprise organizational processes that are used to integrate and coordinate knowledge and activities across various individuals and sub-units within the firm.

Cohen and Levinthal (1990) have argued that the firm's level of prior related knowledge is important in the firm's ability to recognize the value of new, external information, assimilate it, and apply it to commercial ends, called "absorptive capacity." The ability to acquire knowledge is not only linked to firms' absorptive capacity but also to the existing flow of knowledge surrounding firms. However, as architectural competence, combinative capabilities, or organizing principles, the selection that shapes the previous stores of knowledge into new capabilities is perhaps not clearly delineated. In order to capture this aspect of capability creation, we need to borrow material from evolutionary biology.

The Introduction of Selection: Shaping Knowledge Bases into Capability

This process of building capabilities is modeled by borrowing the 2-state space model from evolutionary biology (Lewontin; 1984). Lewontin's model captures the interaction relationship between genotypes and phenotypes. Genotypes are the coded, inheritable, and stored information used as a blueprint or set of instructions for building and maintaining an organism. Phenotypes are the outward, physical manifestation of observable characteristics. In his model (Figure 1), both genotypes and phenotypes serve as state variables, where population genetic theory maps a set of genotypes to a set of phenotypes, provides a transformation in the phenotype space (e.g. phenotype = genotype + development in a given environment), then maps these new phenotypes back to genotypes, where a final transformation occurs to produce the genotypic array in the next generation (e.g. mutations). There exist two parallel systems of evolutionary dynamics, one operating in the space of genotypes and bypassing the phenotypic space, and another operating entirely in the phenotypic domain. It is important to note that fitness of an organism is a function of the phenotype, not the genotype. State variables must be added to provide sufficient dimensionality, as transition between generations depends on passing of genetic information (genotypes) and not in terms of phenotypes alone.

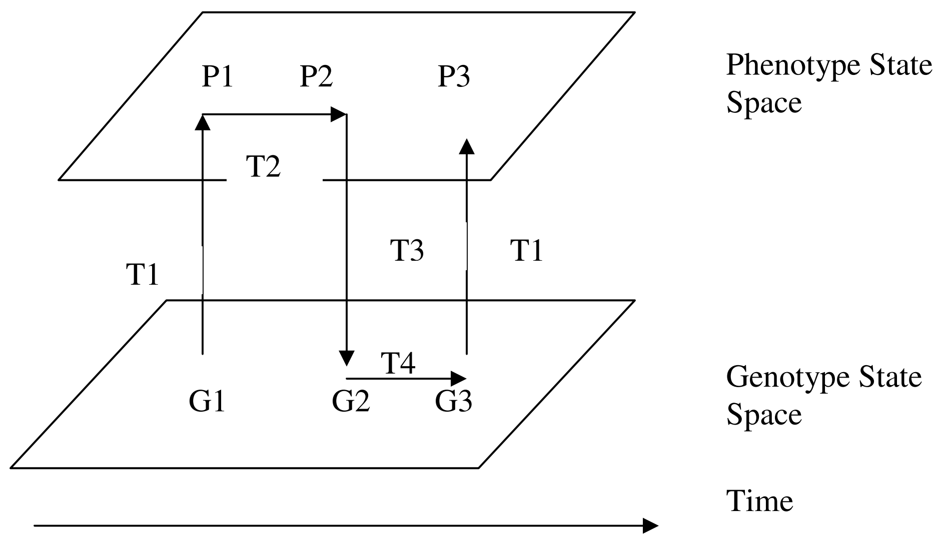

Figure 1: Schematic representation of the paths of transformation of genotype from one generation to the next. G1, G2, G3 are genotypic descriptions at various points in time within successive generations. P1, P2, P3 are phenotypic descriptions. T1, T2, T3, T4 are laws of transformation.

This 2-state model can be utilized to illustrate the dynamics of internal selection forces and external selection forces on the molding of knowledge to demonstrate firm competences. There exist multiple and varied definitions for the notions of knowledge, capability, and competence. We will define knowledge as a set of skills, capabilities, and information about causal relationships among business-related phenomena. Knowledge underlies capability, where capability is a firm's ability to deploy and integrate resources to produce desired results. In other words, capabilities are intangible assets that determine how various firm assets are coordinated and managed in order to create, produce and/or bring a product to market. Knowledge is absolutely necessary to solve business tasks successfully just as a genotype is absolutely necessary to build an organism for survival. We define competence as an effective ability to successfully carry out a totally identified problem-solving activity. Competence is not a probability of success in the execution of one's job; it is a real and demonstrated capability in completing a task. Competence is that domain where the firm is deliberately able to coordinate and apply its assets in a manner that results in sustainable competitive advantage. Competence can be visibly observed as performance, unlike a firm’s knowledge-based resources, i.e. capabilities.

Lewontin's 2-state model cannot be applied without some modifications. This modified model captures the relationship between knowledge and competence performance (i.e. problem solving performance). Knowledge is acquired, stored, and transferred, and used as a blueprint or set of instructions for building and maintaining an organization's activities. Competence is the outward, physical manifestation of knowledge held by the firm. In this modified version (Figure 2), both knowledge and performance are state variables, where a knowledge base maps to a domain of resolved business problems/tasks/actions, provides a transformation in the performance space (e.g. actual result = knowledge + selection by the environment), then maps these new performance domain back to the knowledge base, where a final transformation occurs to produce the knowledge state of the firm before the next action is performed. Similar to Lewontin's model, there exist two parallel systems of evolutionary dynamics, one operating in the space of knowledge and bypassing the performance space, and another operating entirely in the performance domain. It is important to note that the fitness of a firm is a function of performance, not the knowledge base, yet transition depends on passing of knowledge in order to deliver future performance. It is also important to note that each state space represents the realm of possibilities for firms that perform similar business tasks, i.e. relativized to a stereotypical family of firms, strategic group, or industry.

However, unlike Lewontin's model, knowledge states can be recombined to create new knowledge states, and some knowledge states are subsets of other larger states. Knowledge bases, in this sense, are partially ordered. As mentioned before, both knowledge and performance are tied to business tasks and market issues, i.e. to fulfill contract agreements, to meet product specifications, to address supplier/buyer requirements, etc. Knowledge can be further disaggregated into a lower level of individual knowledge. We assume knowledge can be developed, designed, gathered, from individuals collectively into organizational knowledge. We also assume that there is access to complementary assets. Lastly, we assume that the initial state of knowledge K1 is given, and do not delve into how internal selection has shaped resources, skills, capabilities. We do not dismiss the importance of how internal selection pressures shape the firm, but in order to develop our model, we assume selection pressures exist and work to shape the firm into the knowledge base descriptions at various points in time.

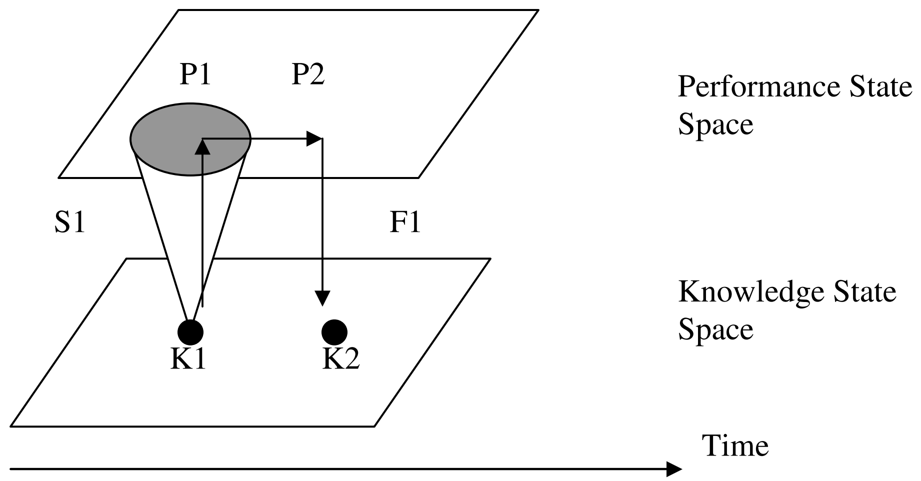

Figure 2: Schematic representation of the paths of transformation of knowledge from one action to the next. K1 and K2 are knowledge base descriptions at various points in time within successive actions. P1 and P2 are performance domain descriptions. S1 is the solution to a given business problem. F1 is the feedback from the market.

With a given knowledge state, an action is made to achieve a certain performance. When this performance is expressed to the external market, it elicits a consequence. Such a consequence can be a reaction by the market, by competing firms, by other industries, by the local/regional/national government, or by the customers. Consequences can be monetary on non-monetary. Examples include increased or decreased economics, positive or negative press, increased attractiveness as a strategic partner, etc.

This consequence may be subject to external selection in the performance domain. This type of selection occurs because there exists competition from firms in the same market. Existing firms hope to grow in size and new entrants increase the number of firms in the environment. This increase is constrained by the scarcity of resources (capital, labor, knowledge), and the combination creates a struggle for survival that over time leads to changes in the firm's performance. All of these dynamics interact in determining whether a firm actually achieves its objectives as seen by the external environment. The achievement of performance is provided to the firm via feedback.

From this feedback, a firm will modify its knowledge bases through recombination and acquisition of complementary assets, for example in cross-application (Banerjee and Miller, 2007). This process of shaping knowledge bases by selection builds capabilities that are held internally, though the explicit knowledge may be diffused. However, this type of 2-state model describes a static type of adaptive behavior, but rarely is such a model seen as comprehensive.

Instead we explore a more dynamic type of interaction that has been overlooked in existing literature about capability development that incorporates co-optive growth of the firm's capabilities.

From Exaptation to Exaptive Technological Capabilities

Penrose (1959) developed a theory of the growth of the firm that saw the firm as a pool of resources organized in an administrative framework. To explain the growth of the firm, Penrose elaborated a process view of production and competition that drew a distinction between resources and productive services. In Penrosian growth, every firm is unique and the uniqueness derives from a distinction between resources and the services of those resources: "…it is never resources themselves that are the 'inputs' in the production process, but only the services that the resources can render" (p. 25). The services of resources derive from the unique experience, teamwork, and purposes of each enterprise. Yet, the services yielded by resources are a function of the way in which they are used – exactly the same resource when used for different purposes or in different ways and in combination with different types or amounts of other resources provides a different service or set of services (p. 25).

Thus, productive services are potentially dynamic: "…the process by which experience is gained is properly treated as a process of creating new productive services available to the firm" (p. 48). And the generation of new productive services is a knowledge-creating process: "the very process of operation and of expansion are intimately associated with the process by which knowledge is increased" (p. 56). Penrose sets the basis for firm growth: "In general there will always be services capable of being used in the same or in different lines of production which are not so used because the firm could not plan extensively enough to use them". Moreover, there is a fundamental imbalance inherent in the execution of firm processes: "…the execution of any plan for expansion will tend to cause a firm to acquire resources which cannot be fully used…and such unused services will remain available to the firm after the expansion is completed". Unused resources offer the opportunity to add to revenues without increasing costs. However, the act of deploying unused resources will set in motion the process whereby new knowledge is created and, with it, unused resources which, in turn, creates a new round of pressures to seek yet new activities.

Barney (1986) adds the concept of strategic factor markets, where the resources necessary to implement a strategy (i.e. firm growth) are acquired. In order for a buyer to extract superior performance from any factor, the buyer must have superior knowledge about the potential uses of the factor, or serendipitously acquire the factor despite underestimating its value. Barney concludes that firms that select a strategy without looking inwardly to exploit resources they already control, can only expect to obtain normal returns from their strategy efforts.

In exploring how a firm can create value from already existing resources, both Penrose and Barney look to diversification of the firm's core business into other businesses to utilize excess. However, research has found that focus and relatedness matter. Berger and Ofek (1995) find that firms that diversify are valued at a discount of around 13-15% compared to single-business counterparts. In order to resolve this apparent contradiction, we look to evolutionary biology for a growth theory that integrates focus and relatedness in a novel way: exaptation.

Steven J. Gould coined the term exaptation in 1982 in order to differentiate between the evolutionary mechanisms of historical genesis and current utility (Gould and Vbra; 1982). Earlier biologists tended to view historical process and current product as one among evolutionary mechanisms, which confounded the relation between form and fitness. Thus, Gould introduced exaptation as a missing term in the taxonomy of evolutionary morphology. Gould additionally distinguished exaptation from adaptation. *Adaptations* are features shaped by selection for their current use, whereas, *exaptations* are features previously shaped by selection for a particular function, which have been co-opted for their current use or features. Exaptations are features not specifically selected for (originally non-adaptive) that have been similarly co-opted for a currently adaptive purpose. The concept of exaptation was introduced into the strategic management literature to differentiate the co-option of capabilities or technologies that have non-adaptive origins, that is, they evolve for one reason and then later are co-opted for a new role (Dew, 2006).

The difference between adaptation and exaptation is clearly observable in evolutionary biology. For instance, an example of adaptation is found when a giraffe, whose neck is extended to reach food that is untouched by other animals, keeps growing and extending to get at higher and higher sources of food. On the other hand, an example of exaptation is the use of bird's wings. Wings were originally adapted for thermal regulation but then exapted into tools for flying. Another example of exaptation involves turtle's back flippers, originally adapted for swimming, that exapted into the covering of eggs after reproduction.

The relevance of exaptation to the study of growth is demonstrated by Gould (1991), who links our expanded brainpower with exaptation: "The human brain, is par excellence, the chief exemplar of exaptation" (p. 55), and "exaptations of the brain must greatly exceed adaptation by orders of magnitude" (p. 57). John Skoyles furthers this example through the concept of neural plasticity (Skyoles, 1999). Neural plasticity is related to the property of neural circuitry to potentially acquire (given appropriate training) nearly any function. For example, the connections between the eye and the optic nerves might suggest that neural circuits have been wired by evolution for sight. Not necessarily: in the blind these nerves process hearing and Braille reading. Conversely, neural circuits in the somatosensory cortex (that give one the five senses) might be expected to lack the ability to process vision, but can do this when retinal inputs are surgically directed to them. Neural plasticity has been co-opted for another important function: enabling brains evolved for life in simple hunter-gatherer bands to live in agricultural and complex societies. Of the many exaptations this required, perhaps the most obvious is the acquisition of biologically novel skills linked to technology and notational systems such as reading, writing and mathematics.

Just as the features of the brain described by Gould and Skoyles, knowledge can be exapted in the following phases: (i) co-opted from a previously evolved trait that was naturally selected for one function that (ii) shifted to another that (iii) offers distinct advantages. In conclusion, selection shapes knowledge into capabilities or exapted knowledge -- giving us a firm, like the brain, specialized at acquiring non-innate skills.

What are some examples in the business world? Examples of adaptive behavior can be expressed as either radical or as incremental innovation (Henderson and Cockburn; 1994). These innovations possess the same research, development and customer drive; they are built on existing capabilities and technologies. Adaptive behavior creates value networks that mirror product architecture. Another example is that of sustaining innovations, or the concept of enhancing product attributes along a single basis of competition (Christensen and Bower; 1996). An example: disk drives over time have achieved higher functionality (speed and capacity), better reliability (failure rates) and greater convenience (portability), while driving down the per unit cost of storage.

Examples of exaptation in innovation involve the use of initial knowledge bases for new product lines, often seen in disruptive technologies. Disruptive technologies are those where the initial technology has a particular use but is then extended to create a new dominant basis of competition. In the disk drive industry, 14-inch disk drives for mainframe computers were replaced by 8-inch drives which were initially marketed to the minicomputer market, but rapidly gained popularity among mainframes (size, rather than capacity, became the basis of competition). In this example, the disk drive is an exaptive and disruptive technology; 14-inch disk drive firms could not adapt: they were responsive to their customers, spent on product development, but ultimately could not exapt knowledge to new market competences and performance requirements.

Different markets have can different usage and performance patterns of the same knowledge base requirements. Since such knowledge requirements are similar, they can be created from similar knowledge base interaction to meet different demands. The dimensions of performance can change. Exaptation can therefore be seen as growth in one structure that is fundamentally different from existing structure. That said, firms can be limited from exhibiting exaptive behavior if they cannot justify the initial costs of changing the structures that allow knowledge bases to be exapted into new uses. However, exaptation is more than an intra-industry phenomenon and therefore merits further examination using the 2-state evolutionary biology model.

Exaptation is particularly important in technological innovation, in the form of *exaptive technological capabilities*. Exaptive technological capabilities are those capabilities built by applying existing knowledge and resources into a new application domain. The new application domain provides a new selection environment (Cattani, 2006; Levinthal, 1998) with new cusomter needs and requirements. There are two main criteria for exaptive technological capabilities: 1) they have non-adaptive origins and 2) increase fitness not by improving the particular function but through complementary means (Dew, 2006). In other words, the technological capability evolved for one reason and was later co-opted for a new role for which it was not historically created for, i.e. has no historical genesis. Also, the technological capability meets the needs of the new role not by increasing performance, for example on the same technological trajectory (Dosi, 1982), but by adding complementary resources.

Data and Methods

Given that the process of transforming technological capabilities has not been studied extensively[1], an inductive, longitudinal, field-based case study (Glaser and Strauss 1967; Eisenhardt 1989) is used. In particular, this approach enabled examination of feedback processes driving change over time. I studied the bioinformatics industry and in particular, one company, Tata Consultancy Services (TCS), from its initial venture into bioinformatics in 2001. Bioinformatics, the science of developing computer databases and algorithms to facilitate and expedite computational biological (genomic and proteomic) research, has rapidly emerged as a significant revenue opportunity for the Indian software industry in this decade. TCS was selected because of their strong existing capabilities in information technology (IT) services and their explicit goal of leveraging these IT capabilities into bioinformatics.

Research Setting

Tata Consultancy Services (TCS) is an India-based IT consulting services firm. TCS is one division of the multi-national India-based conglomerate, Tata Group. TCS was founded initially under Information Systems & Communications for Information Systems and eventually became an independent and publicly traded entity.

The data collection spanned over five years, from late 2001 to early 2007. Research was carried out in three stages. During the first stage, secondary sources and company documents were used to develop a chronology of the bioinformatics industry's development in India and TCS's entry into the sector. Next, we conducted semi-structured interviews with managers in the Indian bioinformatics industry to discuss our initial timeline and understanding of TCS's role in the industry. Finally, we conducted a round of interviews with managers from TCS to confirm initial findings and analyze internal documents and memos. The process was highly iterative and multiple sources allowed for triangulation of themes and conclusions (Miles and Huberman 1984).

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1 Similar investigations have been made by Cattani (2006) and Danneels (2007). Cattani (2006) investigates the outcome of leveraging technological knowledge and Danneels (2007) investigates the process of leveraging technology competence, i.e. a fungible technology.

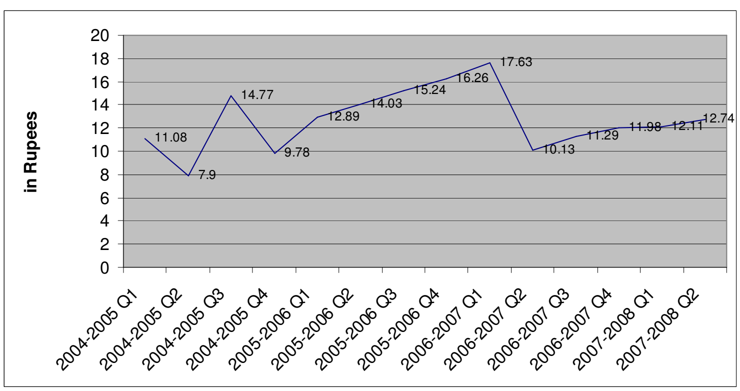
Bioinformatics in India: The Case of Tata Consultancy Services

TCS is a publicly traded arm, as of June 2004, of Tata Group. Founded in the 1860s by Jamsetji Tata, as of August 2006 Tata Group comprised 93 companies and accounted for approximately 2.8% of India's GDP. TCS was founded in 1968 as an internal group providing management consulting and IT services to Tata's business units and holding companies. Table 1 shows historical financial and employee data during the timeframe of this study. Figure 3 shows earnings per share of TCS stock since IPO.

Table 1: Historical financial and employee data for TCS

Historical Financial &Employees		Revenue(mil $)	Employees
	Mar-06	2528.5	62832
	Mar-05	2221.7	40992
	Mar-04	1614	62832
	Mar-03	1041	24000
	Mar-02	880	19000
	Mar-01	689	16000

Figure 3: Earnings Per Share



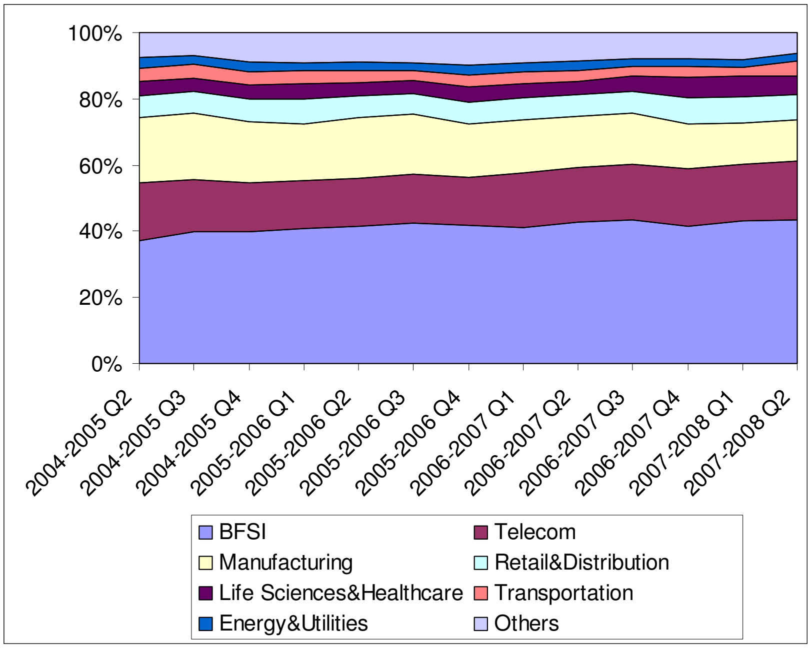
TCS is far from alone in the Indian IT services market, with fierce competition from multinational rivals Infosys Technologies and Wipro Technologies. Indeed, in the fiscal year ended March 31, 2004, TCS's revenues grew 29%, compared with 49% for Wipro and 41% for Infosys. However, as one employee described, "What is the difference between Wipro [and TCS]?… R&D is our differentiator. [We are] the only IT company with an R&D program. Because of our scale, we can invest in it and either make profit or not. This is how new business lines generate revenue, through R&D and thought leaders. If we are not investing in future new advances of technology, someday we will be eclipsed, commoditized."

In 1981, twenty-six years ago, TCS opened its first research and development laboratory, the Tata Research Development and Design Centre (TRDDC) in Pune, India. Today, TCS has nineteen laboratories across the world and holds six U.S. patents (Table 2). These laboratories were the early genesis of TCS's life sciences programs. Figure 4 shows the percentage share of revenues by application.

Table 2: TCS USPTO patents

	PAT. NO.		Title
1	7,130,753	T	Methods for aligning measured data taken from specific rail track sections of a railroad with the correct geographic location of the sections
2	7,072,810	T	Method and apparatus for pattern based generation of graphical user interfaces (GUI)
3	6,986,120	T	System and apparatus for programming system views in an object oriented environment
4	6,968,344	T	Method and apparatus for object-oriented access to a relational database management system (RDBMS) based on any arbitrary predicate
5	6,804,621	T	Methods for aligning measured data taken from specific rail track sections of a railroad with the correct geographic location of the sections
6	6,689,227	T	Eco-friendly starch quenchants

Figure 4: Percentage share of Revenues by Application



TCS Innovation Laboratories gives TCS customers 'on-demand' access to IT innovation and creativity with a team comprised of domain experts, business process analysts and technology and R&D specialists working within a collaborative hub. In addition, customers have continuous access to specialized laboratories and "Co-Innovation Network" (COIN) partner expertise. This help customers ensure that innovations implemented and tested in the laboratory will deliver real value before enterprise-wide deployment.

In 2000, TCS inaugurated an Innovation Laboratory in Hyderabad, India and appointed as its head, Dr. M. Vidyasagar (See Appendix for biography). The TCS Innovation Lab in Hyderabad, also called the Advanced Technology Center (ATC), focuses on computational methods in life sciences, meta-genomics, systems biology, e-security, smart card-based applications, digital media protection, nano-biotechnology, and quantitative finance. The lab works on technologies like computational algorithms for biology, natural language processing, advanced encryption methods, digital watermarking, identity management, web enablement for Indian languages, etc.

As one TCS employee described Dr. Vidyasagar, "He is a world-renowned expert in control theory - applying control theory to different areas of AI, biology, medicine, mathematics, machine theory. He was head of CARE Artificial Intelligence and Research, a defense-space program and was hired as Executive Vice President of TCS. 'Build your dream, come to

Hyderabad. Tell us how to use your algorithms and statistical computations' and it has resulted in 5 new business lines with targets of $5 billion in revenues. Life sciences is one of the areas… we can create wealth with new revenues."

ATC is a state-of-the-art facility with over 2000 people. The bioinformatics group is approximately 100 people – in life sciences, e-security, language processing, and quantitative finance, i.e. using control theory approaches. There are 35-40 Ph.D.s in life sciences and fewer than 100 Ph.D.s in computer science. TCS sponsors a five-year undergraduate and masters education program that graduates hires in computer science. "[Graduates] are hired right away and then developed…The kind of people hired in life sciences [are] strong in core sciences – math, computer science, biology, but not interdisciplinary – essentially [as] we cook them in the lab, put them onto teams. We have two to three physicists and one Bio–IT guy from Johns Hopkins."

ATC has generated some of the important bioinformatics products and developments in India, including Bio-Suite™, Bio-Appliance™, and structure-based drug discovery. TCS has transformed ATC into a powerful *in silico* drug discovery platform that delivers bioinformatics research services to multi-national pharmaceutical and biotechnology companies seeking high throughput, low cost drug-target screening. From serving a small set of beachhead customers in 2001, TCS has rapidly expanded its research services base to include most of the major global pharmaceutical companies. Despite their rapid growth, research services provided by TCS and others in India represent a de minimis fraction of the $55 billion spent in 2007 by the industry on global drug development. However, as the number of new drugs being developed and approved by regulatory agencies continues to decline globally despite the industry's hefty spending, the role of TCS in bioinformatics research should only continue to grow.

Their recent successes in bioinformatics belie the early challenges that TCS faced in 2001 of building an unprecedented and completely unproven business in a geographic market (India) that itself was a virtual unknown in global drug development. In 2001, despite the emergence of several Indian pharmaceutical companies over the last decade, India was still known as a market for – and maker of – generic and bulk drugs, nutraceuticals, herbal and natural products, and homeopathic medicine. Road signs in India proudly proclaimed the therapeutic benefits of honey, bay leaf extracts, and tulsi leaves (found on any roadside) in combating various forms of cancer. Moreover, India's drug discovery and development programs were intrinsically disadvantaged: India lacked the major toxicology centers that are prevalent in the U,S., U.K. and Israel for early-stage drug development, there were broad restrictions on animal testing, as well as weak intellectual property laws (a critical barrier to fast-follower generic drugs, especially given the 10- to 15-year timeline to develop a single drug). Against this backdrop, the likelihood that India would receive international credit or acclaim as a source of cutting edge biotechnology or bioinformatics research services, appeared very remote.

The correction in the global stock market bubble from 2000-02 proved to be a blessing in disguise for Indian bioinformatics. The global stock market pullback from "irrational exuberance" (as Federal Reserve Chairman Alan Greenspan called it) also marked a burst in the "genomics bubble" as the hype and lofty valuations of cutting-edge genomics companies disappeared virtually overnight. With this decline, yet faced with growing pipeline productivity pressures, several global pharmaceutical companies (most notably Novartis, Pfizer, Aventis and GlaxoSmithKline) turned to India for its low cost and highly skilled scientific and computational work force. In 2003, for example, Pfizer and Novartis each opened $100 million genomics and proteomics research facilities in India, and forged relationships with TCS and local IT services companies for bioinformatics research. Only a few years into existence, TCS' bioinformatics services business had found the committed corporate and financial sponsors needed to build and sustain a global competitive advantage in bioinformatics.

Today, life science industry reports suggest that bioinformatics is the "next growth engine" for India. Many small- and medium-sized bioinformatics companies have merged into leading companies to leverage the rapid growth and consolidation of bioinformatics research services in India. As the CEO of an Indian venture-bacekd bioinformatics company noted, "Bioinformatics requires too much specialization for small companies to create a sustainable revenue model – each company wants its own proprietary solution." The dual drive for scale and specialization favors consolidators such as TCS. As an ATC scientist described, "The world of biochemistry is where physics was 50 years ago. We have moved from *in vivo* to *in vitro* to, now, *in silico.* TCS believes *in silico* is the future for biology – it has come and will change everything. TCS delivers on this promise. We believe in bio-mathematical methods, and we can do it."

The leap that TCS and others made from IT to bioinformatics was not an obvious strategic decision. Although India had already established itself earlier this decade as a potent source of computational and scientific talent and capabilities, it was not immediately apparent that India had the investment flexibility to fund capital-intensive genomics initiatives or major bioinformatics centers. Recognizing this, TCS made a strategic decision to offer bioinformatics services to major pharmaceutical companies rather than build stand-alone bioinformatics research discovery efforts. The access to global pharmaceutical funds, limited start-up capital requirements, knowledge gained from working on major drug programs, as well as validation that such partnerships entailed, helped TCS mitigate their risk and launch a compelling bioinformatics software and services offering. TCS believed they could meet customers' needs because of their strong heritage and industry-leading capabilities in computational sciences, traditional biology and chemistry (wet-lab capabilities), as well as customer service mindset.

By 2004, TCS had achieved global stature and was selected by the industry for its "Best-in-Class 2004" Bioinformatics Software Package. The software package, in conjuction with their research services offering, was helped by TCS' strategic decision to build an open-source software platform upon which pharmaceutical customers could innovate and develop their own intellectual property. Empowering customers with the ability to develop their own applications and IP in effect bolstered TCS's innovation efforts as TCS retained rights to commercialize select novel applications. As one TCS executive said, "We want an option on the IP – perhaps create a new molecule – tinker with something where we can share in the risk-reward partnership… collaborate on the R&D and share the revenue. That is the upside opportunity for TCS."

TCS launched several partnerships in 2004 with pharmaceutical customers and academic institutions. The growing recognition of bioinformatics in academia sparked an influx of biologists into the sector. According to an R&D executive at TCS, "My impression is that biologists historically are not quantitative. The people who liked science and did not like math went into biology. Now, we are in a revolution – people good in biology or math take that to go into bioinformatics. There is a generational shift and engineers are commoditized. Pure IT people have mixed views about biologists moving into computational biology. It is easier for a biologist to learn math and programming, than for an IT person to learn biology and science. This puts the 'new world' biologists at a significant advantage in the competitive market for bioinformatics jobs." TCS is leveraging this trend to build its knowledge and competencies through rigorous hiring and training of the best biology and IT technicians in India.

In order to drive innovation and growth in bioinformatics, TCS management has separated the bioinformatics business and performance expectations from other business units as well, in line with strategies for cultivating disruptive innovations. "Our timelines are different," said a TCS executive, "TCS is extremely profitable and [TCS President] Dr. Ramdorai has a vision for R&D over a long timeline. He takes a long-term view so we don't need to have profits next quarter. Growth takes time – it is not going to happen overnight." Moreover, TCS's service teams are organized to work in a highly team-oriented and performance-driven culture. In any innovation center, there can be 100 open cubicles with employees working together on 3-4 different projects or areas. Team members also get along despite the diaspora of Indian languages (over 60 primary dialects are still spoken in India today) because English is the primary spoken language. In organizing and establishing the culture of the bioinformatics group, TCS drew heavily from its experience in growing a high performance IT services organization.

Conclusion

The strategic choice that Tata Consulting Services made to leverage their IT services into bioinformatics exemplifies how firms build exaptive technological capabilities. Capitalizing on exaptive technological change, however, required more than simply leveraging computational and mathematics capabilities into a new application area. Several exogenous and environmental variables, including changes in TCS' selection environment, had to fall into place in order for TCS to realize success. At the macro industry level, TCS benefited from the changing global landscape of drug discovery (compounded by the decline of the "genomics bubble" and challenges in global stock markets in 2000-02) that made India more attractive for drug discovery research services due to intrinsic skill and low cost advantages. At the organizational level, TCS structured itself around bioinformatics innovation centers – leveraging the success of this model in technology services – filled with experts drawn from multiple technical and business disciplines, that resulted in more potent innovation and sharing of ideas. Finally, at the individual level, TCS capitalized on the growing sophistication of Indian biologists in computer science and transformed their knowledge and capabilities into bioinformatics. This set of complementary resources and environmental factors enabled TCS to drive sustained capability development and build competencies in bioinformatics, and to rapidly become a new power in the global bioinformatics industry.

The case of TCS provides insight into the process of building exaptive technological capabilities and driving exaptive technological change. The Lewinton 2-state model provides an enhanced perspective and understanding of the complex interaction between firm-held knowledge bases and external pressures on performance that are instrumental in transforming firm capabilities over time, i.e., capabilities invented to serve one purpose can eventually find their use in other, often unanticipated on unintended, purposes. Capitalizing on exaptive technological development opportunities provides another powerful tool in the armamentarium of technology companies looking to build sustainable competitive advantage.

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Appendix:

Brief Biography of Dr. M. Vidyasagar

Dr. Mathukumalli Vidyasagar was born in Guntur, Andhra Pradesh on 29 September 1947. He received the B.S., M.S., and Ph.D. degrees, all in Electrical Engineering, from the University of Wisconsin, in 1965, 1967, and 1969, respectively. Between 1969 and 1989, he worked as a Professor of Electrical Engineering at various universities in the USA and Canada. His last overseas job was with the University of Waterloo, Canada between 1980-89.

In 1989 he returned to India as the Director of the newly-created Centre for Artificial Intelligence and Robotics (CAIR), under the auspices of the Defence Research and Development Organisation (DRDO), Ministry of Defence, Government of India. In that capacity he built up CAIR into a leading research laboratory consisting of about 40 scientists working on various cutting-edge areas such as aircraft control, robotics, neural networks, and image processing.

In 2000 he joined Tata Consultancy Services (TCS), India's largest IT firm, as an Executive Vice President in charge of Advanced Technology. In this capacity he created the Advanced Technology Centre (ATC), which currently consists of about 60 engineers and scientists working on e-security, advanced encryption methods, and bioinformatics.

In addition to his academic positions, he has held visiting positions at several universities including MIT, California (Berkeley), Califomia (Los Angeles), CNRS Toulouse, France; Indian Institute of Science; University of Minnesota and Tokyo Institute of Technology.

He is the author or coauthor of nine books and more than one hundred and thirty papers in archival journals. He has received several honours in recognition of his research activities including the Distinguished Service Citation from his alma mater, the University of Wisconsin at Madison. He is a Fellow of IEEE as well as the Indian Academy of Sciences; the Indian National Science Academy, the Indian National Academy of Engineering and the Third World Academy of Sciences.