Beyond Panglossian theory: strategic capital investing in a complex adaptive world

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Abstract

Traditional capital budgeting theory (as an extension of financial economics) is characterized as Panglossian because of its suggestion that rational market outcomes produce the best of all possible worlds. During the last two decades, practice-oriented theorists have increasingly been moving from algorithmic capital budgeting techniques to a focus on capital investment strategy. Also, during the last twelve years, economics researchers at the Santa Fe Institute (SFI) have scrapped the dubious assumptions of neoclassical economics and have turned to complex adaptive systems theory for a more realistic portrayal of the economy. This paper explores various SFI studies and their implications for capital investment theory and capital investment strategy. Brian Arthur’s theory of increasing returns undermines the notion that capital budgeting techniques can be counted on to generate economic efficiency. His theory further suggests that the high tech, knowledge-based sectors of the economy inherently produce outcomes that are too unpredictable for the meaningful application of traditional capital budgeting techniques. Studies by David Lane and his colleagues suggest that the identity of agents, the attributes of artifacts and the possibilities for action tend to be emergent phenomena that are generated by the interactions of agents. These considerations suggest a form of strategic action that focuses on process. Finally, it is argued that the artificial life and other SFI types of computer simulation models are potentially useful tools for the study of strategic capital investment decisions.

According to Jones and Smith (1982, p. 104), one of the first published works dealing with the use of present value calculations to assess non-financial investments was in 1887 by an American civil engineer concerned with the economics of railway construction. They also note that Irving Fisher’s *The rate of interest* (originally published in 1907, but revised and published as *The theory of interest* in 1930) was the first work in the American economic literature to discuss net present value as a criteria for appraisal of alternative investments. They further note that the first significant accounting publication dealing with capital budgeting theory (CBT) was Bierman and Smidt’s textbook, *The capital budgeting decision* (1960/1980).

The landmark publications noted above focused on the practical applications of CBT. But market economists (including those who call themselves academic accountants) have never been satisfied with merely practical applications; they have always sought theoretical explanations purportedly demonstrating that rational individuals and firms acting to optimize their self interests in a free market economy will produce the best of all possible worlds. In this sense, the market economist is...
analogous to Dr. Pangloss in Voltaire’s novel *Candide* (1759/1959).\(^1\) Thus, during the 1960s, with the development of the capital assets pricing model (CAPM), the efficient markets hypothesis (EMH), and modern portfolio theory (MPT), the theory of capital budgeting was rapidly integrated into the Panglossian story of economic efficiency. According to this story, individuals save and invest in accordance with their preference for current versus future consumption and make investment decisions that maximize return in accordance with their own psychological aversion to risk; and firms produce goods and services at the lowest possible cost while maximizing profits (i.e. the return to investors). With respect to new capital investments, a firm will accept new investments that have an expected rate of return in excess of the firm’s cost of capital. Thus, in equilibrium the firm’s marginal rate of return would be equal to the cost of capital. This story about the capital investing decision was widely heralded as “scientific”. The UK, in the 1960s, even publicized it as a way of boosting the macro performance of the economy by linking macro-level investment spending with “efficient” decentralized micro-level decisions of individual firms (Miller, 1991).

This story of capital budgeting and efficiency shares an affinity with Voltaire’s story of Candide. Recall how the young Candide encountered one misfortune after another in his series of bizarre adventures, and how Dr. Pangloss reassured Candide after each disastrous event that, in spite of appearances, this still must be the best of all possible worlds. Why was Pangloss so insistent upon this conclusion? Because it followed logically from his initial assumptions — never mind that these assumptions were wishful thinking absurdities. In like fashion, the financial economists who promote the story of Panglossian capital budgeting tend to rely upon the unrealistic assumption of global rationality, omnipresent equilibria, massive cognitive and computational capabilities, and unambiguous and readily available information.

As would be expected, the Panglossian story of economic efficiency has often been viewed by non-believers with an attitude of incredulity. Unfortunately, however, the non-believers were all too often intimidated by the “scientific” bluff and bluster of the economists, especially when couched in terms of highly abstract mathematical notations. The story has, accordingly, gone largely unchallenged in scientific and mathematical terms until quite recently, when a group of interdisciplinary economists and scientists at the Santa Fe Institute (SFI) — a private research institute devoted to the study of complex adaptive systems — began to formulate an alternative story about economic reality. Their alternative story and its implications for capital markets research in accounting has been discussed in Mouck (1998, pp. 206–210). The present paper explores the implications of SFI economic theory for traditional capital budgeting theory and highlights some of its implications for capital investment in new technologies.

Researchers in the SFI economics program scrapped the neoclassical model of equilibrium based on Newtonian mechanics and focused instead on an evolutionary model featuring continual change, instability and adaptation. Stanford economist Brian Arthur, who has been the driving force behind the SFI’s economics research, has elaborated a theory of increasing returns which radically contradicts the neoclassical emphasis on decreasing returns, upward sloping supply curves and market equilibrium analysis.\(^2\) The magnitude of the challenge associated with increasing returns is clearly manifested in the following quote:

Increasing returns are the tendency for that which is ahead to get further ahead, for that which loses advantage to lose further advantage. They are mechanisms of positive feedback that operate — within markets, businesses, and industries — to reinforce that which gains success or aggravate that which suffers loss. Increasing returns generate not equilibrium but instability: If a product or a company or

\(^1\) My use of the term “Panglossian” to describe the economic theory of capital budgeting was inspired by Tony Tinker’s 1988 article, “Panglossian accounting theories: the science of apologizing in style”.

\(^2\) As noted by the Nobel prize winning economist Kenneth Arrow (1994), Arthur’s work on increasing returns set the stage for a burgeoning literature on the subject.
a technology — one of many competing in a market — gets ahead by chance or clever strategy, increasing returns can magnify this advantage, and the product or company or technology can go on to lock in the market (Arthur, 1996, p. 100)

With respect to Panglossian capital budgeting applied to investing in new technologies, Arthur’s theory of increasing returns challenges the notion that the most efficient new technology will prevail in a free market. With respect to the practical applications of capital budgeting, Arthur’s theory implies that future cash flows associated with high tech investments may not be susceptible to meaningful estimation.

Other SFI economists (Lane, Malerba, Maxfield & Orsenigo, 1995) have mounted a powerful challenge to the Panglossian theory of rational choice, arguing that economic action, in the most interesting situations, emerges from processes of interaction between agents, rather than from choosing among a pre-existing set of structured alternatives. Their argument is contrary to traditional (Panglossian) capital budgeting theory, and it leads to a radically different perspective on strategic issues surrounding the development of new technologies (Lane & Maxfield, 1997).

The hallmark of SFI research, however, is the use of extraordinarily creative computer models to simulate the complexity of real world conditions. Many of these models (ranging from simulations of traffic jams to artificial life) are discussed in John Casti’s recent (1997) book entitled Would-be worlds: How simulation is changing the frontiers of science. One of the models discussed by Casti is an artificial stock market created by Brian Arthur and his colleagues. This computer-based artificial stock market is producing results that are surprisingly consistent with real world stock markets but quite inconsistent with the capital markets theory of financial economists. The results of this model contradict the basic theoretical notions associated with cost of capital in the Panglossian theory of capital budgeting, but the SFI approach to computer-based simulation models does shed some interesting light on new directions that could be taken by capital investment theorists.

All of these challenges to Panglossian capital budgeting theory are explored in this paper, as well as the implications for real world capital investing issues, especially those surrounding the development of new, knowledge-intensive, technologies. First, an overview is provided of traditional capital investing theory, together with a brief sketch of some of the more salient alternative perspectives that essentially move from capital budgeting theory to a theory of capital investment strategy. The next section outlines the main components of Arthur’s theory of increasing returns and the implications for economic efficiency with respect to new technologies. This is followed by a section which provides an overview of the arguments of Lane et al. (1995) with respect to rational choice theory, and an exploration of the implications for strategic issues surrounding the development of new, knowledge-intensive technologies. Finally, I turn to an account of the SFI’s stock market simulations, how they serve to undermine portfolio theory and the Panglossian cost of capital concept, and how the SFI simulation approach could play a productive role with respect to capital investment strategy.

1. From Panglossian capital budgeting to strategic capital investing

To my knowledge, the earliest accounting paper detailing the links between portfolio theory and capital budgeting was Ball and Brown’s “Portfolio theory and accounting” (1969). In this article, they weave the threads of the now familiar Panglossian story in which “the firm accepts the utility functions of investors, and by translating these into the investment decision it maximizes their utilities” (Ball & Brown, p. 309). The firm “accepts the utility functions of investors” by requiring that the expected value of the return on any new investment project be at least equal to the cost of capital. The cost of capital, according to the story, is the expected rate of return on the firm’s existing assets; i.e. the expected rate of return which the investor accepted by investing in the firm — keeping in mind, of course, that the investor’s investment decision reflects the investor’s preferences with
respect to current versus future consumption. As with other economics-based Panglossian stories, this one relies upon the assumption of equilibrium in the capital markets. As Ball and Brown point out, “Assumed equilibrium is necessary even to consider the cost of capital as a normative variable since a state of disequilibrium in the capital market does not permit us to equate maximizing owners’ utilities with maximizing the value of the firm” (p 309).

In the real world, of course, the purity described by Panglossian theorists has never been achieved. But the model advocated by these theorists became widely accepted by business schools, and it was formally adopted by large segments of the business world. During the last two decades, however, the inadequacies of the capital budgeting model have been increasingly brought to light, and theorists have increasingly been moving toward the view that capital investing decisions are more properly considered as an inherent part of an adaptive, contextually-informed strategy than as the outcome of contextually isolated algorithmic present value calculations. This trend was evident by the early 1980s. Logue (1981), for instance, argues that traditional capital budgeting theory is inadequate for “strategic investments”, which he describes as “investments that take the firm in new directions or that yield financial benefits to the firm undertaking them that are external to the investment itself” (p. 88). An options model, he suggests, would be more appropriate for evaluating such investments. Coda and Dematte (1981) argue that the formulation of an overall business strategy constitutes the framework within which specific projects should be evaluated. If more that one potential investment project fits within the strategic game plan, then traditional capital budgeting theory could be employed to determine specifically which project is to be accepted (p. 105). And Derkinderen and Crum (1981) note the emerging complexity of the business environment at the beginning of the 1980s and suggest that, “Models with adequate predictive power under relatively stable and well-understood conditions will be less able to provide adequate guidance in the more turbulent period of the 1980s” (p. 8). By the 1990s a significant literature had developed around each of these suggestions.

Buckley (1996, Chapter 3) provides an overview of the literature related to capital investment options, a literature that was inspired largely by the Black and Scholes (1973) option pricing model. As he points out, some types of capital investment projects may entail options to postpone the decision until a later date. Other types of investment projects may entail an initial investment plus options to scale up or expand at a subsequent date. Such options can be quite valuable, yet these values are not considered in the traditional capital budgeting model. Buckley argues that treating investment projects as options may be especially relevant to projects involving research and development, projects involving natural resource extraction, and projects involving expansion into new marketing territories. In sum, the upshot of the investments options literature, “is that the old-style capital appraisal techniques are more than adequate in terms of dealing with cash cow investments but leave something to be desired where there is operational flexibility or contingent opportunities for growth” (Buckley, 1996, p. 53).

Other directions in the strategic cost management literature have been critical of the tendency to evaluate investment projects too narrowly by focusing only on the “value-added” (by the specific firm); that is, by starting with the firm’s payments to suppliers and stopping at the expected sales to customers. This narrow focus neglects the strategic insights that could be gained by examining the entire “value chain” of which the firm’s value added is only one link. By developing the entire value chain, including not only the firm’s immediate suppliers and customers, but also including the supplier’s suppliers and the customer’s customers, from raw materials to ultimate consumer, the firm may gain insights into its own bargaining power vis a vis suppliers and customers that could alter the assumptions used in the capital budgeting analysis. Shank and Govindarajan (1992), for example, discuss a case situation in which a value chain analysis yielded a significantly different perspective on the investment options than traditional capital budgeting analysis. They argue that specific projects should be considered only within the context of strategic options that have been identified by a full-fledged value chain
This echoes Coda and Dematte’s (1981) claim that “the decision system of a company has a box-within-box structure, where the single investments are the smallest boxes and are hierarchically dependent on the business strategy choice. This latter structure gives the framework against which the single investment proposals are weighed and selected” (pp. 104–105).

Value chain analysis has received much of its impetus due to the influence of Porter’s (1980, 1985) books on competitive strategy which draw attention to strategies for cost leadership and differentiation leadership. Shank and Govindarajan (1992) note that “…value chain analysis is essential to determine exactly where in the firm’s segment of the chain — from design to distribution — customer value can be enhanced or costs lowered” (p. 180). In this sense, value chain analysis has a certain degree of affinity with Japanese target costing. Whereas the former is concerned with costs and values throughout the entire chain from raw materials to final consumer, the latter (target costing) focuses on costs and values of new products from research and development to completion of production.

Whereas US firms pursuing a cost leadership strategy have typically focused on the costs of production, Japanese target costing is a strategy that focuses on cost reduction opportunities at the earliest conceptual stages of a new product, even prior to production plans. As described by Kato (1993), “Target costing is an activity which is aimed at reducing the life-cycle costs of new products, while ensuring quality, reliability, and other consumer requirements, by examining all possible ideas for cost reduction at the product planning, research and development, and the prototyping phases of production” (p. 36). As compared with the traditional capital budgeting approach to evaluating the acceptability of a new project, a relatively passive approach that consists largely of gathering information about available options and choosing among them, Japanese target costing is a highly active approach. Even in terms of expected selling price, the target costing strategy requires an active versus a passive approach. It attempts to identify the functional elements of a product that are valuable to consumers; elements such as “style, comfort, operability, reliability, quality, attractiveness...” (Kato, p. 38), and to assign a value to each of these functions. The cumulative values associated with the functional elements of a product would constitute the expected selling price. With respect to costs, the procedures referred to as “value engineering” (VE) are relied upon to identify possible cost reductions. Kato notes that VE requires an extensive support system, including “cost tables, cost reduction databases and cost reduction database management systems” (p. 43). These procedures underlie the calculation of the “target cost” which, in formula terms, is the difference between “expected sales price” and “target profit” (Kato, p. 38).

None of these perspectives — target costing, value chain analysis and capital investments treated as options — necessarily negates the potential usefulness of DCF-type capital budgeting techniques. They suggest variations for viewing the strategic context and constructing assumptions, but they maintain a focus on specific projects — new products, expansion to new territories, new production equipment, etc. — that does not rule out the applicability of NPV analysis. By the early 1990s, however, a new conception of strategy was emerging; a conception that Stalk, Evans and Shulman (1992) refer to as “capabilities-based competition” (p. 57). The notion of capabilities-based competition is clearly a product of the “more turbulent period of the 1980s” predicted by Derkinderen and Crum (1981, p. 8), and it has triggered a radically different approach to capital investment decisions; an approach that is more clearly attuned to the complex adaptive world described by the Santa Fe Institute economists. Baldwin and Clark (1992) have provided a detailed description of this new perspective. They describe “capabilities” as:

…identifiable combinations of human skills, organizational procedures, physical assets, and information systems. Such complex combinations of resources are achieved because companies allocate resources (both human and financial) to their development in the expectation of future reward. In this respect, capabilities are like any other investment (Baldwin & Clark, p. 69).
The specific benefits associated with investing in capabilities arise from external integration, internal integration, flexibility, the capacity to experiment, and the capacity to cannibalize, all of which generate an ability to exploit emerging opportunities, to move creatively into new niches, and even to create new niches. “External integration is the ability to link knowledge of customers with the details of engineering design in creating and improving products” (Baldwin & Clark, 1992, p. 70). Internal integration refers to the ability to communicate, plan, formulate strategy, and coordinate production activities across functional and organizational units within the firm. Flexibility refers to the capability to switch from one product mix to another, from one level of operating capacity to another, or even from one market to another. Experimentation is intimately associated with organizational learning, and the capacity to experiment is largely a function of investment in communication and information systems that facilitate the generation and dissemination of knowledge associated with diagnosis and testing. And finally the process of cannibalization — which refers to the development and promotion of goods or services that compete with or replace some of the firm’s more profitable products — is seen as a potentially valuable strategy for preventing entry by other firms. As Baldwin and Clark point out, the capacity to cannibalize “requires a significant investment in procedures, information systems, and human skills, as well as physical assets” (p. 73).

Traditional capital budgeting may be appropriate for an economic environment in which competition is for specific product lines or specific markets. But as Stalk et al. (1992) point out, today’s complex economic environment is more aptly characterized as a “war of movement” in which “competitors move quickly in and out of products, markets, and sometimes even entire businesses — a process more akin to an interactive video game than to chess” (p. 62). In such an environment they argue that, “The building blocks of corporate strategy are not products and markets but business processes” (p. 62). And this is precisely where the work of SFI economist Brian Arthur can expand and deepen our understanding of issues involved in capital investment decisions. His work on the phenomena of increasing returns supports a radically different understanding of business and economic processes than the diminishing returns and equilibrium processes underlying Panglossian capital budgeting theory. His theory of increasing returns supports neither the efficiency claims nor the NPV techniques of Panglossian theory.

2. Increasing returns and economic (in)efficiency

Arthur (1994, p. 1) points out that conventional economic theory relies upon negative feedback mechanisms (negative returns) to generate the equilibrium, harmony and stability that its proponents (Panglossians) associate with unimpeded market forces. He further notes that, “[a]ccording to conventional theory, the equilibrium marks the ‘best’ outcome possible under the circumstances: the most efficient use and allocation of resources” (p. 1). The notion of positive returns has been resisted by Panglossian economists because it threatens to undermine their neat optimistic picture of laissez-faire economic theory.

Diminishing returns imply a single equilibrium point for the economy, but positive feedback — increasing returns — makes for many possible equilibrium points. There is no guarantee that the particular economic outcome selected from among the many alternatives will be the ‘best’ one. Furthermore, once random economic events select a particular path, the choice may become locked-in regardless of the advantages of the alternatives. (Arthur, 1994, p. 1).

Arthur’s work on increasing returns in the economy is firmly grounded in a branch of probability theory that focuses on “nonlinear Polya processes”. These are stochastic processes characterized by positive feedback, path dependency and sensitivity to initial conditions. Arthur, Ermoliev

3 Polya is the name of the mathematician who formulated and worked out the detailed mathematical proofs for such processes (Arthur, 1994, p.36).
and Kaniovski (1994, pp. 36–37) describe a very rudimentary Polya process in terms of an urn which initially contains red and white balls in equal proportions. If a ball is drawn at random, say a white ball, then replaced, and a new ball of the color just drawn is added to the urn, then the proportion of white balls increases to greater than 50% and the probability of drawing a white ball on the next round becomes greater than 50% — a classic situation of increasing returns. If this process is repeated many times, the proportion of white balls will eventually settle down to a stable amount somewhere between zero and 100%. At the outset, it is impossible to predict what the long-run proportions will be, they depend on the precise path taken during the early stages when an additional ball of one color or the other makes a significant difference in proportions. As the number of balls increases, the addition of another white ball tends to change the existing proportions by such a small amount that the probability of drawing another white ball tends to remain constant. If a stable persistent proportion of white balls is characterized as a “structure”, then one can say that a unique structure has emerged from a system “with independent increments subject to random fluctuations” (Arthur et al., 1994 p. 34).

Arthur et al. (1994) discuss the generalization of Polya processes beyond the simple urn example of the previous paragraph. Their generalization applies to processes involving more than two types of things (i.e. firms in an industry, competing technologies, or industries locating in various regions), and it extends to situations “where the probability of an addition to type \( j \) is an arbitrary function of the proportions of all types” (p. 38). They also work out theorems that apply to classes of Polya processes, indicating which types of Polya processes will be characterized by extreme attractor points (stable outcomes), which will be characterized by both attractor points and repelling points (unstable outcomes), and which will have multiple possible long-term outcomes. The significance of this generalization for Arthur’s economic work is that it allows him to specify the conditions under which a “selected” outcome will be stable and persistent. The various articles collected in Arthur (1994) include applications of these ideas to industry locations, competing technologies, and human learning and decision-making in situations with incomplete information. The application to competing technologies is directly relevant to capital budgeting theory, since the most prominent capital investing decisions in the current high-tech economy involve, directly or indirectly, competing technologies.

With respect to new technological developments, Arthur (1988) suggests that “we can think of these methods or technologies as ‘competing’ for a ‘market’ of adopters” (p. 590). And he presents an analysis of the ways in which “[increased attractiveness caused by adoption...] [i.e.] ‘increasing returns to adoption’” (Arthur, 1988, p. 590) can, under certain circumstances, culminate in technological “lock-in” with no guarantee that the prevailing technology is the best of those available. Notable sources of increasing returns to adoption include the following:

1. **Learning by using**... Often the more a technology is adopted, the more it is used and the more is learned about it, therefore the more it is developed and improved...

2. **Network externalities**... Often a technology offers advantages to ‘going along’ with other adopters of it — to belonging to a network of users...

3. **Scale economies in production**. Often, where a technology is embodied in a product... the cost of the product falls as increased numbers of units of it are produced...

4. **Informational increasing returns**. Often a technology that is more adopted enjoys the advantage of being better known and better understood...

5. **Technological interrelatedness**... Often, as a technology becomes more adopted, a number of other sub-technologies and products become part of its infrastructure. (Arthur, 1988, p. 591).

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One of Arthur’s main points is that, with respect to the “efficient harmony” that Panglossian economists presume to be guaranteed by the unfettered play of market forces, there is in fact no guarantee that the most economically efficient technology will prevail. His analysis suggests that the benefits from adopting one of two competing technological alternatives will be an emerging function of the sequence of adoptions, i.e. it will be path-dependent. Suppose, for instance, that a firm has initially determined that technology A (say a new computer software system) will be more cost effective than technology B (a competing software system). It is altogether likely that this same firm would change its assessment if adoptions of technology B began to outrun the adoptions of technology A to the extent that the “returns to adoption” (network externalities, scale economies in production, technological interrelatedness, etc.) associated with B began to dwarf those associated with A.

The “dynamics of adoption”, accordingly, are of primary importance in Arthur’s theory of competing technologies, and he illustrates the implications in several models of varying sophistication and generalizability. A review of all his models is neither possible nor desirable within the scope of the present paper, but a brief overview of his basic model should prove helpful. The basic model involves two competing new technologies, (A and B) and two types of adopters (R and S). R-types are assumed to have a “natural” preference for technology A and S-types have a “natural” preference for technology B. However, with increasing cumulative adoptions of one technology versus the other the “returns to adoption” (discussed above) begin to outweigh natural preferences. Thus, if one of the technologies (say technology A) accumulates sufficient adoptions, then both types of adopters will begin to choose that technology and the competition will be over. Technology A, in this case, will have achieved “lock-in”.

In Arthur’s basic model the adopters, R-types and S-types, are assumed to arrive at the “adoption window” in a random order so that anytime prior to lock-in the probability that the next adopter will choose A (or B) is 50%, the probability of heads versus tails in a coin toss. If the pattern of cumulative adoptions is charted, the result will be a “random walk with absorbing barriers” (Arthur, 1988, p. 594) as illustrated in Fig. 1. The hypothetical graph in Fig. 1 shows the difference in adoptions of A versus B on the vertical axis with time on the horizontal axis. The dashed lines represent the “absorbing barriers”, the differences beyond which one of the two technologies achieves lock-in. Between the barriers R-types will choose A and S-types will choose B, but as indicated, once the cumulative adoptions push the difference beyond either barrier both types of adopters will choose the same technology resulting in technological lock-in. “The important fact about a random walk with absorbing barriers is that absorption occurs eventually with certainty” (Arthur, 1988, p. 594). Thus, in the long-run, according to this model, “the economy must lock in to monopoly of one of the two technologies, A or B, but which technology is not predictable in advance” (Arthur, 1988, p. 594).

“Real world” competition, of course, is rarely as passive as suggested in this basic model. As Arthur points out, the possibility of “winner-take-all” in a technological competition creates powerful incentives for strategic competition. The incentive for strategic competition, however, is not unique to winner-take-all situations — and Arthur (1988) does include a model which results in a shared market. In any case, it is the fact of increasing returns to adoption that motivates aggressive competition among technologies. This is why Arthur claims that “competition between technologies usually becomes competition between bandwagons, and adoption markets display both a corresponding instability and a high degree of unpredictability” (1988, p. 590).

Arthur calls attention to several actual case histories involving competing technologies. One of the most straightforward case histories is the early VCR market.

The VCR market started out with two competing formats selling at about the same price: VHS and Beta. Each format could realize increasing returns as its market share increased: large numbers of VHS recorders would encourage video outlets to stock more prerecorded tapes in VHS format, thereby
enhancing the value of owning a VHS recorder and leading more people to buy one. (The same would, of course, be true for Beta-format players.) In this way, a small gain in market share would improve the competitive position of one system and help it further increase its lead (Arthur, 1994, p. 2).

The VCR market is a clear-cut example of increasing returns. It also illustrates a Polya process that results in lock-in to one of the alternatives. Such a market is initially unstable. Both systems were introduced at about the same time and so began with roughly equal market shares; those shares fluctuated early on because of external circumstance, ‘luck’, and corporate maneuvering. Increasing returns on early gains eventually tilted the competition toward VHS: it accumulated enough of an advantage to take virtually the entire VCR market. Yet it would have been impossible at the outset of the competition to say which system would win, which of the two possible equilibria would be selected. Furthermore, if the claim that Beta was technically superior is true, then the market’s choice did not represent the best economic outcome... (Arthur, 1994, p. 2).

Other competing technology examples cited by Arthur (1994) include: the QWERTY keyboard versus other possible keyboards; gasoline versus steam and electric power for automobiles; allium arsenide versus doped silicon in the semiconductor industry; computer software; nuclear versus other technologies for the generation of electricity; and light-water versus gas-cooled technologies for nuclear reactors (1994, pp. 15, 16, 25).

It must be noted that Arthur does not deny a role for negative returns and the analytical techniques of conventional economics. He fully accepts their applicability with respect to “the parts of the economy that are resource-based (agriculture, bulk goods production, mining)” (1994, p. 3). The increasingly dominant sectors of the contemporary economy, however, are associated with the production of high-value, knowledge-based goods and services such as “computers, pharmaceuticals, missiles, aircraft, automobiles, software, telecommunications equipment, or fiber optics” (Arthur, 1994, p. 3). These sectors are, according to Arthur, “largely subject to increasing returns” (1994, p. 3.).
These sectors dealing in high-value, knowledge-based goods and services are also the sectors for which, according to Lane et al. (1995), the neoclassical economists’ conception of economic action breaks down, as the importance of rational choice is superseded by the importance of networks of interaction between various agents and artifacts. In these sectors increasing returns plays a unique role in the competition for adopters since, in the words of Lane and Maxfield (1997, p. 185), new configurations in agent/artifact space breed further configurations...”, generating what they refer to as “complex foresight horizons” (a notion discussed in detail in the next section) and radically altering the nature of strategic competition.

3. Beyond “rational choice”

A fundamental presumption of neoclassical economics generally — a presumption that is incorporated into traditional capital budgeting theory — is that all economic action is the result of structured choices made by rational, optimizing agents. Lane et al. (1995) summarize this rational choice (RC) presumption as follows:

RC1 Universality: Every significant economic action is the result of a choice.

RC2 Context representation: To choose what course of action to take, the agent must construe the context in which the action is to take place in terms of a choice situation. A choice situation consists of a specification of a set of available acts and, associated with each available act, a set of consequences that describe what might happen should the agent choose that act.

RC3 Rationality: The agent must select an act on the basis of a calculation of the value of the consequences associated with it. The algorithm guiding the calculation must be such that the agent obtains some pre-specified measure of value from the chosen act. The value may be specified in absolute terms, or relative to what can be attained from the other available acts.

It should be noted that this description of RC is broad enough to encompass the notion of bounded rationality as well as the strict rationality of neoclassical economics models. This description of RC is also consistent with the old-fashioned business school optimization approach to strategy in which “A strategy specified a precommitment to a particular course of action... [and] choosing a strategy meant optimizing among a set of specified alternative courses of action, on the basis of an evaluation of the value and the probability of their possible consequences” (Lane & Maxfield, 1997, pp. 169–170). This view of strategy presumes that agents can foresee the alternative courses of action and their consequences, if not with certainty, then at least with enough clarity to assign probabilities. A capital investment strategy, from this perspective, would essentially amount to a precommitment to traditional capital budgeting theory. Suppose, however, that the consequences of alternative courses of action include contingencies that are unknown but will unfold with some degree of clarity in the future. In such situations, an options-type capital investing strategy, or value chain analysis, may be appropriate as a modification of traditional capital budgeting theory. But suppose that the investment situation involves too many other agents and too many possible consequences for rational evaluation. To use the words of Lane and Maxfield, your foresight horizons “have become complicated” (p. 170), and traditional capital budgeting and its strategic variations are no longer applicable.

If you cannot even see a priori all the important consequences of a contemplated course of action, never mind carrying out expected gain calculations, you must constantly and actively monitor your world and react quickly and effectively to unexpected opportunities and difficulties as you encounter them. As a result, an essential ingredient of strategy in the face of complicated foresight horizons becomes the organization of processes of exploration and adaptation. (Lane & Maxfield, 1997, p. 170).

For situations with such complicated foresight horizons, the capabilities-based capital budgeting
strategy discussed above would seem appropriate since it highlights the processes of exploration and adaptation.

Suppose, however, that foresight horizons are not merely complicated, but are literally complex in the full richness of that term as it is used in complex adaptive systems theory. According to Lane and Maxfield (1997), this is the decision-making situation for large segments of the contemporary economy, especially those segments that deal in high-value, knowledge-based goods and services. It is clearly a situation in which the rational choice perspective outlined above is not applicable. Neither, therefore, is traditional capital budgeting theory applicable. But the claim of Lane and Maxfield is more radical yet. They argue that situations involving complex foresight horizons require a new conceptualization of strategy. Before examining their arguments regarding strategy, however, it may be useful to explore briefly what they mean by “complex foresight horizons”.

The situations of concern to Lane and Maxfield involve networks of relationships between agents and artifacts. They use the term “agent/artifact space” to characterize such networks, and they use the term “structure” to refer to a specific set of agent/artifact relationships. Agent/artifact relationships in general are a function of the attributions that various agents assign to each other and to artifacts; “[a]ttributions about what an artifact ‘is’ and what agents ‘do’...” (Lane & Maxfield, 1997, p. 182). Such attributions play a crucial role in economic actions.

The meaning that agents give to themselves, their products, their competitors, their customers, and all the relevant others in their world, determine their space of possible actions — and, to a large extent, how they act. In particular, the meaning that agents construct for themselves constitute their identity: what they do, how they do it, with whom and to whom (Lane & Maxfield, 1997 p. 182).

“Complex foresight horizons”, according to Lane and Maxfield, result from processes by which an agent’s actions generate changes in the network of agent/artifact relationships which, in turn, generate changes in the agent’s identity.

Contrary to the rational choice model of neoclassical economics, their perspective focuses on the interactions of agents. It is the interactions of agents that generate changes in attributions, changes in structure of agent/artifact networks, changes in the structure of the agent’s world, and changes in the agent’s identity. Following Lane et al. (1995), they use the term “Generative Relationships” (GRs) to refer to the relationships among agents that have the potential to generate such changes. “The attributions, competences and entities that are constructed from GR interactions cannot be predicted from a knowledge of the characteristics of the participating agents alone, without knowledge of the structure and history of the interactions that constitute the GR” (Lane et al., p. 15). The world constructed by interactions forms the context within which an agent acts, but at the same time an agents actions may trigger a change in that world. Thus, not only does the agent experience ambiguity with respect to the consequences of an action, the agent experiences ambiguity with respect to his or her own identity and the structure of the world within which s/he acts. The structure of the agent’s world, i.e. the networks of agent/artifact relationships, is thus appropriately characterized as an emergent phenomena, a characterization that is central to Lane and Maxfield’s notion of complex foresight horizons... “Emergent structure and cognitive ambiguity generate complex foresight horizons...” (Lane & Maxfield, 1997 p. 174).

Lane and Maxfield (1997) support their views about agent/artifact networks and GRs by recounting how a small computer company operating in California’s silicon valley in the early 1970s elected to enter the PBX market and within a few years became one of the three firms dominating the industry, with a market share that was exceeded only by ATT. The small computer company

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5 In the language of complex systems theory, “emergent phenomena” refers to phenomena that exhibit features that are not to be found in any of their constituent parts. Emergent phenomena result from the interaction or organization of the parts. Consciousness is thus an emergent phenomena in that the neurons that collectively produce consciousness are, individually, totally devoid of consciousness.
was ROLM, and the opening they perceived was a direct result of a 1968 decision by the US Federal Communication Commission (in the Carterphone case). Prior to this FCC decision, local telephone companies enjoyed monopoly status with respect to PBX systems, the systems that manage the routing of incoming calls to an organizations internal telephone system. The FCCs 1968 decision ended the monopoly of local phone companies. New firms immediately began entering the PBX business. “In particular, a whole new kind of business was created: the interconnect distributors who configured, installed, and maintained business communication systems” (Lane & Maxfield, p. 176). But until ROLM entered the business the basic technology employed in PBX systems did not change significantly. “Most PBXs still used electromechanical switching technology and had only a few ‘convenience’ features like call-forwarding” (Lane & Maxfield, p. 175).

In 1973, ROLM determined that it was both technically possible and economically feasible to produce and sell PBX systems that employed digital switching and computer-based control. “Digital switching would provide the means to integrate voice and data into a single system, while computer control would make possible such additional functions as least-cost routing of long-distance calls, automatic dialing, and call-detail recording — and would permit an organization to move telephone numbers from office to office just by typing commands at a keyboard, rather than by ripping out and rewiring cable” (Lane & Maxfield, 1997, p. 176). The success of their idea is indicated by the fact that, in 1973 ROLM had annual revenues of $4 million, but 5 years after the installation of their first PBX they had annual revenues of over $200 million.

At first glance, it might appear that the explanation of ROLMs success was essentially due to their technological breakthrough. But Lane and Maxfield (1997) challenge that explanation: “We think the right explanation is social, not technological…” (p. 176). They point out that, although the Carterphone decision broke the monopoly of local phone companies, it did nothing to alter the established patterns of interaction among relevant agents. So, even 5 years after the 1968 FCC decision, when the telecommunications manager (TM) of a large company needed to order a new PBX system, s/he typically simply contacted the local phone company for information about the available options and followed the phone companys recommendation. Lane and Maxfield point out that, “…TMs tended to be telephone company employees, with little incentive to be creative — or training or experience in how to be creative managers, even if the will were there” (p. 177). Nor did the 1968 decision do anything to alter the attributions assigned to PBX systems. The suppliers of PBXs, the higher level management of firms, and the TMs all tended to share the same notion about a PBX: “…in particular, that a PBX is just a switchboard connected to telephone sets at one end and an outside line at the other; and that managing a PBX means making sure that there is a serviceable telephone on each desk where one is needed” (Lane & Maxfield, p. 177).

What ROLM did, in addition to their technological innovation, was to change the pattern of interactions; a move which fortuitously facilitated the development of generative relationships, new product attributions, and new identities.

When ROLM contracted with an interconnect distributor, it required the distributor’s sales people to attend a ROLM training program, staffed by instructors recruited from IBM and Xerox. Second, ROLM sought to establish direct relationships with the TMs of large firms such as General Motors, Allied Stores, and IBM. It did this by creating a group of “national accounts” representatives, ROLM employees whose mandate was to provide “liaison and support” to major customers. But the representatives’ first task was to start talking to

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6 Lane and Maxfield (1997) had access to detailed information about ROLM and the sequence of events they relate. They note that, “Our version of the story relies on various ROLM marketing and strategy documents currently in possession of one of us (RM), a cofounder of ROLM who led its PBX division, and material collected in a Stanford Graduate School of Business case prepared by Professor Adrian Ryans” (p. 175, n. 12).
their targeted TMs, to let them know what the ROLM technology would be able to do for them, to find out what their problems were, and to figure out how ROLM could help solve them. (Lane & Maxfield, 1997, pp. 178–179).

The resulting interactions culminated in a series of new shared understandings of what ROLM’s PBX technology could do (new attributions that went far beyond what the ROLM engineers and representatives originally were aware of) and what kinds of revenue-enhancing/cost-saving measures could be proposed by TMs to their higher management (measures that went far beyond what the TMs were originally aware of). In short, the interactions initiated by ROLM culminated not just in a technologically improved PBX, they culminated in a series of new products; the PBX became a new artifact, playing a completely different role in agent/artifact networks. “In time, the very idea that users had about a PBX was changed — from a telephone system, to an intelligent interface between a company and outsiders, to a tool that could be adapted to solve a wide range of ‘line-of-business’ voice-based applications, providing productivity improvements in many aspects of customers’ operations” (Lane & Maxfield, p. 180). Among other things the ROLM technology was reprogrammed to become an automatic call distribution (ACD) system which could be used for “order processing, customer service, account information, and so on” (Lane & Maxfield, p. 180). The ROLM PBX could also be modified to provide “what came to be called Centralized Attendant Service” (Lane & Maxfield, p. 180), a service which allowed an organization to use a centralized bank of operators to process calls to any number of outlets or stores at different locations.

Not only did ROLM benefit from these new attributions to its PBX technology, in their own firms many of the TMs who initiated the purchase and implementation of the new technology acquired a new status with new roles, new responsibilities and a new structure of rewards. “From a relatively low-level ‘custodian’ of a company’s telephonic system, the TM began to be perceived as a major factor in the ability of a company to enhance its productivity and to respond to customers. In many companies, the position became equal in importance to the information systems manager, often with a vice-presidency attached” (Lane & Maxfield, 1997 p. 180). Furthermore, Lane and Maxfield (p. 180) note that many of the TMs developed an intense loyalty to ROLM, sometimes exceeding their loyalty to their own employers, a fact which further enhanced the success of ROLM. As described by Lane and Maxfield, many of the TMs were members of the International Communications Association which held an annual convention. “At these conventions, ROLM backers in the association gave formal presentations describing productivity-enhancing applications of the ROLM system — and afterwards, over drinks in the bar, talked about the personal rewards and recognition they had won for championing ROLM inside their companies. As a result, other TMs actively sought out ROLM and its distributors” (Lane & Maxfield, p. 181). Within 5 years of installing their first PBX system, ROLM controlled 23% of the US PBX market (Lane & Maxfield, p. 182).

So, what are the implications of all this for strategy? From Lane and Maxfield’s (1997) framework of foresight horizons, three relatively distinct stages of strategic focus can be delineated. First, when foresight horizons are relatively clear, strategy can be described as an attempt to control outcomes. This view of strategy was widely relevant when, in the words of Stalk et al. (1992), the economy was “characterized by durable products, stable customer needs, well-defined national and regional markets, and clearly defined competitors...” (p. 62). This is the perspective in which traditional capital budgeting theory is more or less applicable. But when new products proliferate, customer wants and needs change rapidly, and markets and competitors can no longer be clearly defined, then in the words of Lane and Maxfield, “foresight horizons have become complicated”, outcomes are no longer predictable, let alone controllable, and traditional capital budgeting theory is no longer applicable. With complicated foresight horizons, the emphasis of strategy shifts from outcomes to processes, and the emphasis of capital budgeting,
according to Stalk et al. (1992), should shift to a capabilities perspective, which focuses on the processes of exploration and adaptation. But when foresight horizons are not merely complicated, but are complex, in the sense indicated above, Lane and Maxfield argue that strategy should focus on a different set of processes, the processes of interaction.

Noting that “strategy” is usually situated “within a suite of concepts” that includes vision, mission, goals, and tactics, Lane and Maxfield (1997, p. 189) customize these concepts to fit their language. They suggest that a firm’s vision and mission culminate in “directedness in agent/artifact space”. That is, vision and mission specify the kinds of artifacts the firm intends to create, identifies the agents to whom the firm wishes to sell those artifacts, and establishes the direction of change in agent/artifact space that the firm wishes to initiate. They expand the usual notion of goals (in terms of desired outcomes) to include desired “reconfigurations of agent/artifact space”. They use the term “tactics” in the conventional sense having to do with the process of executing the actions they decide upon. They then locate “strategy” as follows:

Strategy lies between directedness and execution. It lays down “lines of action” that the firm intends to initiate and that are supposed to bring desired outcomes. Since outcomes depend on the interactions with and between many other agents (inside and outside the firm’s boundaries), strategy really represents an attempt to control a process of interactions, with the firm’s own intended “lines of action” as control parameters (Lane & Maxfield, pp. 189–190).

The attempts to control the process of interactions suggests “a set of practices, which are partly exploratory, partly interpretive, and partly operational” (Lane & Maxfield, 1997 p. 191). Lane and Maxfield particularly emphasize two kinds of practices that they characterize as “populating the world” and “fostering generative relationships”. The first of these has to do with the fact that the rapidly changing structure of agent/artifact relationships tends to render original assumptions about agents and artifacts obsolete. “Hence, the strategic need for practices that help agents ‘populate’ their world: that is, to identify, criticize, and reconstruct their attributions about who and what are there” (Lane & Maxfield, p. 191). These are essentially discursive practices of ongoing interpretation and reinterpretation of agent/artifact attributions and relationships. Lane and Maxfield (pp. 191–193) offer several observations regarding the detailed characteristics of such practices, but they summarize succinctly as follows: “…it ought to be top management’s strategic responsibility to make sure that interpretive conversations go on at all relevant levels of the company — and that sufficient cross-talk between these conversations happens so that attributions of the identities of the same agents and artifacts made by people or groups with different experiences and perspectives can serve as the basis for mutual criticism and inspiration to generate new and more useful attributions” (p. 193).

They suggest, however, that ongoing interpretation of emerging structure is, by itself, too passive. The firm can attempt to control the processes of interaction more aggressively if it engages in practices designed to selectively encourage certain types of relationships. These are the practices that they characterize as “fostering generative relationships”. And the relationships that should be encouraged are those with the greatest potential for generating new attributions and new structures of agent/artifact relationships. Presumably, if the firm is in on the ground floor with respect to attributional shifts, and is actively engaging in interpretive practices, then it will be at a strategic advantage in responding to those changes. Agents should, accordingly, be encouraged to actively “monitor relationships for generativeness” (Lane & Maxfield, 1997, p. 197). And such monitoring is likely to be more effective if agents can identify and recognize indicators of generative potential. Lane and Maxfield thus discuss the following as some of the “essential preconditions of generativeness” (pp. 194–195):

- **Aligned directedness** The participants in the relationship need to orient their activities in a common direction in agent/artifact space...
Heterogeneity ... generativeness requires that the participating agents differ from one another in key respects. They may have different competencies, attributions or access to particular agents or artifacts. . . .

Mutual directedness Agents need more than common interests and different perspectives to form a generative relationship. They also must seek each other out and develop a recurring pattern of interactions out of which a relationship can emerge. . . .

Permissions Discursive relationships are based on permissions for the participants to talk to one another about particular themes in particular illocutionary modes (requests, orders, declarations, etc.). These permissions are granted explicitly or implicitly by superordinate agents and social institutions. Unless potential participants in a relationship have appropriately matched permissions, or can arrogate these permissions to themselves, the generative potential of the relationship is blocked.

Action opportunities . . . Engaging in joint action focuses talk on the issues and entities of greatest interest — those around which the action is organized. And action itself reveals the identities of those engaged in it. In addition, new competencies emerge out of joint action, and these competencies can change agents’ functionality and, hence, identity — even leading to the formation of a new agent arising from the relationship itself (Lane & Maxfield, pp. 194–195).

If an agent is aware of these preconditions, then steps can be taken to strengthen the ones that exist and/or to promote one that is missing. With respect to the ROLM case, for instance, the development of user groups promoted heterogeneity and aligned directedness, the promotion of account representative/TM relationships fostered mutual directedness and action opportunities. And with respect to permissions, it is fair to say that much of ROLM’s success was due to the fact that the firm actively facilitated the exchange of problems, ideas, information, requests, etc. between account representatives and TMs, and between account representatives and ROLM’s engineers. A more hierarchically compartmentalized company would have missed some of the key opportunities that ROLM was able to take advantage of as a result of providing permission for discursive exchanges between different groups within the firm as well as between the firm’s representatives and agents from other firms. In summary, as Lane and Maxfield (1997) demonstrate with the ROLM case, “[t]o realize generative potential, relationship participants must have the right permissions, time, and space to talk; they must do work together; and that work must facilitate their coming to shared understandings about each others’ competencies and attributions of identity; and their relationship must be embedded in a network of other relationships that can amplify whatever possibilities emerge from their joint activities” (p. 196).

All of this has clearly moved miles (in conceptual strategic space) from the rational choice model of Panglossian capital budgeting theory. But it brings us much closer to the computer simulation models that are fundamental to the Santa Fe Institute’s research program. Just as agent based interactions were at the heart of Lane and Maxfield’s (1997) ROLM story, interactions between artificial agents are at the heart of the SFI’s most heralded computer simulation models, models that are generally characterized as artificial life models. “Artificial life (alife) is the bottom up study of basic phenomena commonly associated with living organisms, such as self-replication, evolution, adaptation, self-organization, parasitism, competition, and cooperation” (Tesfatsion, 1997, p. 534). In his provocatively titled article, “How Economists can get Alife”, Tesfatsion refers to the numerous ways in which artificial life simulations are enhancing our understanding of complex issues in evolutionary economics. Could alife simulation models also shed light on some of the complex issues in capital investing theory?

4. Should capital investment theorists get “alife”?

The usefulness of computer-based simulation with respect to capital investment decisions has been argued by some theorists for at least 35 years.
Following the pioneering work of Hertz (1979, 1968), most of these approaches have relied upon normal probability statistical methods to simulate rates of return for projects when various factors (that are subjectively believed to influence returns) are randomly selected and combined. Repeated simulations with different combinations of relevant factors yields, according to Hertz (1968), a “risk-based profile” for the project at issue. Such simulation models are variously referred to as “Hertz-type risk simulation” or simply as “sophisticated risk analysis” (Ho & Pike, 1991, 1998).

Using the language of Lane and Maxfield, these types of computer-based simulation models may be useful in situations with complicated foresight horizons, but they fail to fill the bill with respect to the increasing returns sectors of the economy in which the macro structure of economic and financial reality tend to be emergent phenomena that result from the interactions of agents who are acting in accordance with their respective subjective beliefs which, in turn, are largely emergent phenomena. The SFI view of economic agents’ subjective beliefs and their role in economic activity has been described by Arthur (1995, p. 20) as follows:

Economic agents make their choices based upon their current beliefs or hypotheses… about future prices, or future interest rates, or competitors’ future moves, or the future character of their world. And these choices, when aggregated, in turn shape the prices, interest rates, market strategies, or world these agents face. The beliefs or hypotheses that agents form in the real economy are largely individual and subjective. They are often private. And they are constantly tested in a world that forms from their and others’ subjective beliefs. Thus at a sub-level, we can think of the economy ultimately as a vast collection of beliefs or hypotheses, constantly being formulated, acted upon, changed and discarded; all interacting and competing and evolving and co-evolving; forming an ocean of ever-changing, predictive models-of-the-world. This view is useful, I believe, because it forces us to think about how beliefs create economic behavior — and how economic outcomes create beliefs. And it leads to different insights. Beyond the simplest problems in economics, this ecological view of the economy becomes inevitable; and it leads to a world of complexity.

Arthur and his SFI colleagues have used the genetic algorithms and Classifier Systems developed by John Holland (1975, 1986) to create an artificial stock market that reflects the interplay of subjective expectations. The results of their stock market simulations pose fundamental challenges to Panglossian capital budgeting theory.

Investors in the SFI’s artificial stock market are artificially intelligent agents who continually create “market hypotheses” (“expectational schemas”) about future dividend and price movements. Some of the schemas relate to fundamental accounting and economic expectations and some relate to “technician-oriented” expectations about price patterns. Arthur (1995) points out that the simulation is typically run with 100 agents, each of which is endowed with a portfolio of 60 expectational schemas. “Thus there are at any time 6,000 expectational models” (Arthur, 1995, p. 24). These schemas, however, are not fixed and immutable; genetic algorithms have been used to allow mutation, thus facilitating the formation of new schemas. As agents try out various schemas, they throw out the ones that perform poorly and stick with the ones that pay off.

The simulation runs of this market produce an artificial time series that can be studied visually (in terms of price patterns) or statistically. The model has produced results that are in accordance with conventional (Panglossian) portfolio theory, but only when the simulation is started with parameter settings that reflect conventional theory: “If we start our traders off with identical, fundamental-value expectations (by setting the parameters of all their expectational models to reproduce prices that validate these expectations), we find that deviating, nonfundamentalist expectations cannot get a footing” (Arthur, 1995, p. 24). However, when the resulting time series generated under these special circumstances is compared with actual stock market
price movements, the artificial market looks extremely bland and unrealistic: “The market in a sense in this regime is essentially ‘dead’” (Arthur, 1995, p. 25).

On the other hand, when a simulation run begins with heterogeneous expectational schemas, the market “comes to life” (Arthur, 1995, p. 25). Trends emerge when expectational schemas by chance produce price movements that become self-reinforcing, often producing price bubbles that move prices significantly away from fundamental values. The market also occasionally produces crashes when trends reverse. When expectations begin to converge, the market may enter a period of stability. But this stability never lasts because some of the expectational models begin to exploit the pattern of stability. “Then there will be swift changes of gestalt, swift readjustments in expectations that change the market itself and cause avalanches of further change” (Arthur, 1995, p. 25). Thus, the resulting time series often exhibits periods of relative price stability followed by prolonged periods of high volatility.

In sum, the SFI’s artificial stock market bears a remarkable resemblance to the stock market as described by John Maynard Keynes: “…it is, so to speak, a game of Snap, of Old Maid, of Musical Chairs — a pastime in which he is victor who says Snap neither too soon nor too late, who passes the Old Maid to his neighbor before the game is over, who secures a chair for himself when the music stops” (1936, pp. 155–156). It is a game infused with “animal spirits” (Keynes, pp. 161–162). It is a game in which “we devote our intelligences to anticipating what average opinion expects the average opinion to be” (Keynes, p. 156).

The SFI’s artificial stock market is a prime example of an alife model that is relevant to the critique of traditional capital investment decision theory. But given the discussions, in previous sections, of the strategic aspects of capital investment decisions, a more important question is whether such models can be used to shed light on issues related to capital investment strategy. I suggest that the answer to this question is “yes”.

Consider a model reported by Dalle (1998) that simulates the diffusion of a new technology. In this model, the potential adopters of a new technology are heterogeneous firms. Each firm has an adoption decision rule that is a function of adoption costs (including the costs of switching from the old technology) versus the potential profit and risks associated with the new technology. The adoption decision rules differ from firm to firm as a result of differences in products, markets, size, organization, knowledge base, learning processes, etc. But despite these differences, each firm is part of a “local interaction structure”, explained by Dalle (p. 245) as follows:

When one of the ‘neighbors’ of a firm adopts the technology, this contributes to reducing the adoption costs and risks for this firm, or indeed increases the costs and risks associated with the decision not to adopt. There are many reasons for this..., notably related to problems of technological compatibility and accessibility to knowledge and specific information acquired by others, which therefore reduce adoption costs and risks. Technological adoptions are therefore locally cumulative: the adoption decision of each agent... take[s] into account the decisions of a certain number of other agents, i.e. his ‘relevant neighbors’... with whom he is interacting. We can therefore attribute to each of these agents a neighborhood, that is to say a group of agents with whom he is interacting; if we then assume that these neighborhoods are interconnected..., we obtain what we propose to call a connected local interaction structure.

The simulations reported by Dalle (1998) are based on interaction structures in which each agent has four immediate neighbors. Statistical behavior functions are specified with respect to the probability that a given firm will adopt the new technology if zero, one, two, three, or four of its neighbors, respectively, have already adopted the technology. On the assumption that network externalities (Arthur’s positive returns to adoption discussed earlier) will reduce the costs and risks associated with the new technology as it is adopted by more and more of a firms neighbors, a higher probability of adoption is specified if one
neighbor has adopted than if no neighbors have adopted. A still higher probability is specified if two neighbors have adopted than if only one neighbor has adopted, and so forth. The simulation protocol employed by Dalle involves simulating trajectories obtained by drawing randomly, at each time step, one agent from the population whose adoption probability as a function of his neighborhood is given by $F$ [a statistical probability function]” (p. 247).

The results indicate that heterogeneity (of adopting firms) and local interactions are sufficient to account for the logistic, “S-shaped”, diffusion path of a new technology. A typical diffusion path generated by Dalle’s (1998) computer simulation is shown in Fig. 2. Dalle’s simulations also indicate that the time it takes a new technology to “flood the market” of potential adopters is highly sensitive to the likelihood of early adoption. The diffusion path in Fig. 2 was generated by assigning 0.05 and 0.10, respectively, as the probability of a firm adopting if none of its neighbors had adopted and the probability of adoption if one of its neighbors had already adopted the new technology. The sensitivity of the diffusion path, with respect to early adoptions, was studied by altering these probabilities of early adoption. The variation in the resulting diffusion paths is shown in Fig. 3. The steeper diffusions paths (the ones that represent a faster flooding of the market) were associated with higher probabilities of early adoption; the flatter diffusion paths were associated with lower probabilities of early adoption.

An even more interesting finding, however, is that “The taking into account of local interactions... provides an explanation for the formation of technological niches and enclaves” (Dalle, 1998, p. 251). There are various factors, such as size, the availability of technical support, etc., which tend to reduce the adoption costs of a firm relative to its neighbors, thus increasing its likelihood of early adoption. But the fact that adoption costs include the costs of switching from the currently used technology, suggests that some “neighborhoods”, in which the firms are using the same, more established technology with its own local externalities, may as a group be more likely (or less likely, as the case may be) to adopt a new technology than other neighborhoods which may be using a different established technology. Such local interaction factors account for the appearance of “technological niches”.

The first niches to appear initially grow slowly, or even fail to survive, because the technology which is gradually being abandoned is itself still subject to strong local externalities which incite its users to continue to exploit it: the switching costs are still statistically high, and all the more so if the firm is dealing with others who exploit the same technology. This growth then becomes much more rapid: due to the growth of one or more of the niches, the remaining potential adopters have statistically an ever increasing number of neighbors who have already adopted it, which renders their own adoption more and more likely. Finally the diffusion gradually becomes complete as the number of adopters still not having adopted slowly decreases: it actually tends to zero as the probability that an adopter of the new technology returns to the former becomes extremely weak when the quasi-totality of his neighbors have also adopted the new technology. (Dalle, 1998, pp. 251–252)

As Dalle (1998) points out, this simulation model offers some significant insights that are relevant to capital investment strategy. If new technologies spread from niche to niche, and if the speed of the diffusion process is significantly influenced by early adoption behavior, then it would behoove the producers of new technologies to identify the potential niches with the highest likelihood of early adoption and develop their promotional strategy accordingly: “it is therefore to these potential clients that a firm must initially pay the more attention, not only because it wants to sell, but also, so it seems, because the future success of its technology will often depend greatly on its success in these niches, as the future adopters will actually be greatly influenced by these first ones” (Dalle, p. 253). It should be noted, however, that the strategic implications are not limited to producers of new technologies. The potential benefits and risks
associated with the adoption of new technologies likewise depend upon the path dependent character of the diffusion process. Thus, the capital investment strategies of potential adopters of a new technology will be more effective to the extent that they are informed by the knowledge of what kinds of niches already exist for the technology, what new niches may emerge, and how one’s “neighbors” are likely to be impacted by one’s own adoption decision.

Other simulation models that may be relevant to capital investment strategy and/or capital investment
theory include the information contagion model (ICM) reported by Lane (1997) and the trade network game (TNG) reported by Tesfatsion (1997). The ICM allows for computer simulation of agent’s sequential selections of either product A or product B, based on their knowledge of the performance characteristics of A and B, respectively. The agents’ knowledge of relevant performance characteristics comes from two sources, publicly available (but incomplete) information and information gained from privately polling a sample of previous adopters of A or B. The cumulative information about A and B is strongly path dependent depending largely upon relatively small differences in the pattern of early adoptions and/or the chance differences in early polling results. Lane (p. 105) makes an apt comparison with the process of deciding what movie to see.

Suppose you are thinking about seeing a movie. Which one should you see? Even if you keep up with the reviews in the newspapers and magazines you read, you will probably also try to find out which movies your friends are seeing — and what they thought of the ones they saw. So which movie you decide to see will depend on what you learn from other people, people who already went through the same choice process in which you are currently engaged. And after you watch your chosen movie, other people will ask you what film you saw and what you thought of it, so your experience will help inform their choices and hence their experiences as well.

Now suppose you are a regular reader of Variety, and you follow the fortunes of the summer releases from the major studios. One of the films takes off like a rocket, but then loses momentum. Nonetheless, it continues to draw and ends up making a nice profit. Another starts more slowly but builds up an audience at an ever-increasing rate and works its way to a respectable position on the all-time earners’ list. Most of the others fizzle away, failing to recover their production and distribution costs.

The ICM simulations reported by Lane (1997) indicate that, as with movies, the macro-structure (in terms of market share) of competing product markets can be an emergent product of individual agents decisions at the micro-level. Furthermore, just as an inferior movie may eclipse, in attendance and revenues, a superior movie, the ICM simulations reported by Lane indicate that “…giving agents access to more information does not necessarily lead to a better outcome at the aggregate level: increasing the number of informants for each agent can decrease the proportion of agents that end up adopting the better product” (Lane, p. 106). Such results contradict Panglossian economic theory, but they should prove very interesting and thought provoking for a firm that is formulating a strategy for the promotion of a new product, or for a firm evaluating a decision to invest in a new technology.

Tesfatsion’s (1997) TNG (trade network game) simulations suggest yet other potential applications to capital investment strategy. The TNG builds upon previous game theory models that link choice and refusal (CR) of game partners with iterated prisoner dilemma (IPD) models. The players, or agents, in the TNG are “autonomous endogenously interacting software agents” which Tesfatsion characterizes as tradebots (p. 537). The tradebots can store information internally, including information about previous encounters with other tradebots; they can “display anticipatory behavior (expectation formation); and they can communicate with each other at event-triggered times...” (Tesfatsion, p. 537). Differing trade strategies and differing trade networks evolve as the tradebots interact with each other in a game. Numerous games are, of course possible depending upon the initial specifications as to strategies, expected payoffs, etc. The potential significance of such simulation games with respect to capital investment strategy — at least in the high-tech, knowledge based segments involving companies such as ROLM (discussed above) — is due to the insights that may be gained about cooperation and networking partnerships.

Choice [with respect to trade partners] allows players to increase their chances of
encountering other cooperative players, refusal gives players a way to protect themselves from defections without having to defect themselves, and ostracism of defectors occurs endogenously as an increasing number of players individually refuse the defectors’ game offers. On the other hand, choice and refusal also permit opportunistic players to home in quickly on exploitable players and form parasitic relationships. (Tesfatsion, p. 537)

Issues of trust, cooperation, defection and parasitism loom large in a firm’s decisions about strategic alliances with other firms. And such alliances are crucial with respect to the development and promotion of many high-tech goods and services. As Arthur suggests, “technological ecologies are now the basic units for strategy in the knowledge-based world, [and] players compete not by locking in a product on their own but by building webs — loose alliances of companies organized around a mini-ecology — that amplify positive feedbacks to the base technology” (1996, p. 106). As he also points out, “a careful choice of partners” as well as “psychological positioning” are crucial to the strategic management of such alliances. The insights generated by Tesfatsion’s TNG, with respect to trust, cooperation, etc., are clearly relevant to the choice of partners and psychological positioning in the formation of high-tech, inter-firm alliances.

My discussion of aliife computer simulations, however, is not so much intended as an advocacy of any particular model or models, but as an indication of the contributions that such models, in general, can make to our understanding of capital investment strategy and capital investment theory. Although they do not yield the precise definitive conclusions that characterize the Panglossian capital budgeting model, their dynamic, non-linear, path dependent characteristics make them ideal tools for a more realistic (and more useful) understanding of the processes underlying high-tech, increasing returns sectors of the economy. Thus, the answer to the question posed at the beginning of this section is: Yes, capital investment theorists should get aliife.

5. Conclusions

The Panglossian theory of capital budgeting is an interwoven set of theories, not just about rational maximizing decisions on the part of the firm, but about investor preferences, stock price behavior, and efficient resource allocation. It is part and parcel of the bigger theory of market economics; a theory that is built upon a set of notoriously dubious assumptions. It is a story that has always appeared suspect to discriminating observers, but it has been perpetuated by mainstream financial economists, in part, due to the lack of an alternative theory of market behavior. During the last 10 to 12 years, however, economic researchers affiliated with the Santa Fe Institute have begun to flesh out an alternative, more realistic, perspective that views the economy as a complex adaptive system.

In light of the SFI’s economics research, the notion that a canned formulaic approach to capital investing decisions will systematically contribute to profit maximization for the firm, efficient production of goods and services by firms, optimal return for investors, and utility maximization for consumers is less credible than ever. In the economic world postulated by SFI researchers, the beliefs and preferences of investors/consumers are constantly changing in response to the evolutionary flow of events and in response to each other, frustrating the Panglossian attempt of financial economists to capture any meaningful measure for utility maximization and ultimately for economic efficiency. In an economic world dominated by high tech, knowledge-based goods and services, new technologies compete for adopters in an environment characterized by positive feedback and increasing returns. Positive feedback, together with sensitivity to relatively small chance events, makes it an environment characterized by instability and unpredictability. The phenomenon of increasing returns creates the potential for technological lock-in. The result is a high-stakes “winner-take-most” (if not “winner-take-all”) environment that requires an adaptive strategic stance for capital investment decisions.

This does not mean, however, that there is no constructive role whatever for the DCF and NPV
techniques associated with traditional capital budgeting theory. There are still situations in which an agent can foresee the alternative courses of action and their consequences with relative clarity. The most obvious situation would be the evaluation of a contract under which a firm would agree to provide certain goods or services for a specified period of time in exchange for a contractually specified series of payments. Under the UK’s Private Finance Initiative, for example, massive amounts of goods and services are procured by entering into long-term contracts with private firms. It would certainly be prudent for any firm bidding on such contracts to calculate the discounted value of cash flows stipulated by the potential contract. In more complicated situations in which the consequences of alternative courses of action include contingencies that are unknown but will unfold in the future, DCF and NPV techniques may be useful within an options-type capital investing strategy, or a value chain analysis.

Increasingly, however, the more interesting and more important capital investing decisions are related to the high-tech, knowledge-based, increasing returns sectors of the economy, and in these sectors the characteristics of agent/artifact networks, as well as the related opportunities for economic action, are likely to be emergent phenomena that are generated by the interactions of agents. Such situations cannot be appropriately characterized in terms of rational choice; indeed, they call for a form of strategic action that is focused on processes. In the words of SFI researchers, Lane and Maxfield (1997 pp. 189–190), the appropriate form of strategy in these situations “represents an attempt to control a process of interactions”. The traditional capital budgeting model is virtually useless for situations such as these — situations in which the alternative courses of action are emergent phenomena. These are the cases in which the artificial life and other SFI types of computer simulation models are likely to prove increasingly useful for understanding the processes and interactions that dominate the high-tech, increasing returns sectors of the economy. In sum, for strategic capital investments in high-tech goods and services the algorithmic tools associated with Panglossian capital budgeting theory increasingly appear to be obsolete, while artificial life and other sophisticated computer simulation models increasingly appear to useful tools for the study of strategic capital investment decisions.

References


