Assessing Technology Projects Using Real Options Reasoning

An options-based process offers a systematic approach to investing in highly uncertain, new technology projects.

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OVERVIEW: *Real options reasoning is a logic for funding projects that maximizes learning and access to upside opportunities while containing costs and downside risk. Although it has considerable advantages over conventional approaches, the tools for using it remain scarce. This article describes a method for assessing uncertain projects that approximates option value through scoring a series of statements. Variables are the size and sustainability of potential revenue streams, speed or delay in market adoption, development costs, commercialization and market access costs, company strengths, likely competitive responses, dependence on standards, and the degree of uncertainty. Each variable is measured by asking questions that, in turn, can be used to assess the risks confronting a proposed project and to suggest remedies, even if they demand abandoning or reconfiguring the project. A major advantage of this approach is that it integrates both technological and strategic considerations.*

Technology managers are perpetually on the horns of a dilemma. Rapidly changing competitive environments are unforgiving of those who delay. Yet, even testing the potential of some new technologies is a massively risky and expensive proposition, with no guarantee of eventual success. How are you to respond, after all, when some excited scientist declares that he has invented a monochromatic beam of light and then expects you to throw budget at it? How are you to know, ahead of time, that this thing he calls a "laser" might actually be worthwhile?

The comforting logic of the net present value rule goes out the window. At the same time, you cannot bet the company on every gee-whiz idea without a sense of its strategic importance. In this article, we describe a process of strategic technology assessment review (STAR©) that can help to simplify the decision and ensure that your team has not overlooked the most important strategic variables.

STAR is based on real options reasoning (*1–3*). A real option is analogous to a financial option contract; it is a limited-commitment investment in an asset with an uncertain payoff that conveys the right, but not the obligation, to make further investments should the payoff look attractive. If you decide not to make further investments, the option expires, but all that is lost is its price. Ironically, the ability to provide access to significant upside potential while containing downside losses makes options more valuable with greater volatility.

Real options differ from financial ones in several important respects: They cannot be valued the same way, they are typically less liquid, and the real value of an investment to one firm may differ a lot from its value to another firm. This creates a substantial challenge to evaluating a real option. Our approach is to use fuzzy, albeit carefully developed, measures to obtain an early indication of likely option value.

Genetic Code for Uncertain New Projects

Just as knowing the genetic characteristics of a pair of breeding animals cannot predict exactly the features of the fully mature offspring, mapping the genetic code of a technology proposal cannot predict its ultimate fate. But you can at least make some intelligent conjectures, informed by previous research into the factors that give a technology greater or lesser potential.

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For example, contrast the upside to a drug that dramatically ameliorates the symptoms of the common cold with that of one that cures a disease afflicting one person in 100,000. In the first case, repeat use and huge incidence of demand creates a huge potential payoff. In the second case, use is infrequent and limited, implying a less attractive payoff.

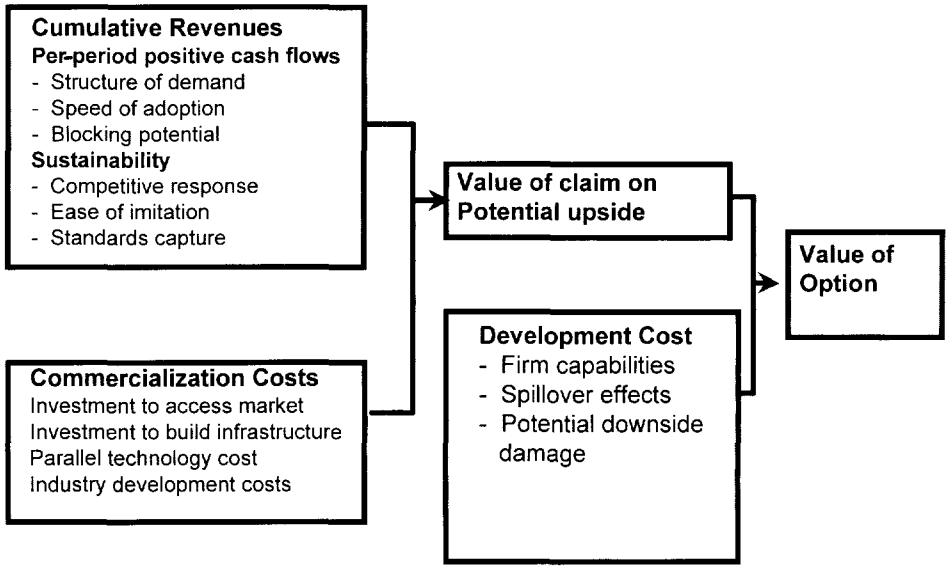
So, too, with the other factors that might predict the long-run potential of a business: adoption rate, competitive response, commercialization costs, the firm's resources, the state of standards, and the ambitiousness of the project. The diagram below shows how we see these as being interrelated in the assessment of option value. This framework emerged out of many years of consulting to high-technology firms, and considerable academic research into the primary drivers of long-run technology option value.

The logic of the diagram is that the value of a proposal is a function of the claim on the potential upside gains less the cost of creating that claim, which is the development cost. The claim on the upside is the value of cumulative revenue flows, less commercialization costs. If the value of the claim on the upside exceeds the cost to develop the investment, it makes sense to make the investment.

There is an enormous desire on the part of managers to tie these values to a specific number. If only we could quantify the value, the logic seems to go, we would get clear and unambiguous guidance as to what to do. We strongly encourage the people we work with to try to avoid this temptation, for two reasons. First, those opportunities that can be quantified with any degree of confidence are not, by definition, uncertain, and one may as well use conventional approaches. Competitors with the same calculators could easily come to the same conclusions! Second, and somewhat more subtly, the actual value of an investment in real options is idiosyncratic. It depends greatly on the configuration of competences and resources already belonging to a firm. In other words, there is no such thing as a universal option value for most strategically interesting proposals—the value of the investment is a function of the capabilities of the specific firm making the investment.

There is no such thing as a universal option value for most strategically interesting proposals.

Believing that a precise calculation of option value is not meaningful does not mean that you are back to relying on intuition. Instead, you can tap the potential genetic code by considering a series of statements that can yield insight into factors that enhance the attractiveness of a project and that will lead to problems if not attended to in advance. The statements are presented in Tables 1–15 and discussed now. Typically, we would have a group (a project team plus important functional colleagues) score their agreement/disagreement with each statement using a 7-point scale, and then use the responses to initiate discussion.



These factors influence the value of a technology option.

Sure, the statements are a little fuzzy. We believe, though, that most R&D managers would rather have an early, fuzzy, measure to work with than an accurate measure available only after the window of opportunity has closed.

Cumulative Revenue Potential

Different configurations of demand for the features of a product or service create a radically different profit potential. Following the options logic of the diagram, we assess demand by capturing estimates of three critical components of the revenue structure. The first is per-period cash flow, driven by the size of the potential revenue stream, by how rapidly adoption occurs, and by the absence of factors that might block access to the market. The second is sustainability of cash flows, driven in turn by the aggressiveness of likely competitive response, how easy the technology is to imitate, and the extent to which your company can capture the standard. Third is the extent to which network effects allow you to leverage the value you create.

The statements we use to assess future demand are listed in Table 1. We first consider whether the proposal has sufficient scope to be interesting, looking at Part A of the table. Lots of applications, lots of growing markets with customers who can pay for our products, and frequent, repeat usage, are all positive indicators. This gives us a way of establishing an order-of-magnitude estimate of how attractive the likely demand is. The statements in Part B draw attention to risks.

Potential demand aside, you don't make money until someone adopts it. This can take a lot longer than one might anticipate (*4*). People are slow to change established habits, reluctant to throw away assets, and resentful of having to make the time investments necessary to learn a new way of doing things.

Citibank, for instance, pioneered electronic banking over the telephone a decade before the Internet and on-line services came along. Citi went so far as to design a special telephone with which customers could do their banking from home. The concept was incredibly insightful, but customers were simply not ready for it.

When adoption is slow, the discount that must be applied to the funds that do flow in becomes deeper. Moreover, competitors have much more time to respond and to match, or even leapfrog, your idea. Understanding likely adoption dynamics is thus crucial. Table 2 lists the survey items we use to assess adoption dynamics.

Factors that tend to speed adoption include customer dissatisfaction with current alternative solutions, low perceived risk to the customer, and a selling proposition in which those who stand to benefit can actually make the purchasing decision. More commonly, however, we find new technologies vulnerable to Part B of Table 2, which identifies adoption problems.

Factors that delay or inhibit adoption include requirements for extensive education or training of customers, any characteristics that cause customers to have to significantly change their usage patterns, requirements for complementary products to be in place before customers perceive value in the new product, significant sunk costs in an existing solution on the part of the customer, delays due to regulation, and the perception on the customers' part that purchasing the product or service might be risky (*5*).

The last category of potential risks to positive cash flows involves blocking. Blocking occurs when a business is prevented from accessing critical resources, sales channels or customers because of the actions of other parties. The trouble with blocking is that it can either simply stop a business in its tracks or it can require enormous investments of managerial time and other resources to resolve. Table 3 lists relevant items.

Sometimes, blocking is built into the industry structure—heavily regulated industries such as nuclear power and pharmaceuticals, for instance, have to overcome massive regulatory hurdles before new businesses can generate revenues. Sometimes, blocking is related to a deliberate strategy by competitors. Microsoft, for instance, has been dragged into court, accused of anti-competitive blocking behavior. Blocking can also come from government. Foreign companies seeking to access markets in mainland China and India are often required to partner with a local firm—no partner, no access. Groups with a social agenda can also block; witness the controversy surrounding the so-called "abortion pill" in the United States.

A blocked business is not a profitable business. Thwarting or overcoming blocking factors is thus essential. Citibank's credit card processing operation, for instance, had been located in New York, a state whose usury laws capped interest that could be charged at a rate that was (in the high-interest 1970s) actually lower than the firm's cost of capital. The bank found a way out of being blocked from charging higher interest by moving the entire card division to South Dakota, whose legislature was more accommodating. The point is that you do not have to fatalistically accept a blocked condition; rather, you need to figure out what to do about it prior to launch.

Sustainability of Cash Flows

Three factors—properties of demand, speed of adoption, and the hazard of blocking—help to anticipate likely issues with the creation of cash flows. The next concern is duration, by which we mean the sustainability of the cash flow stream.

The reality of competition today is that fewer and fewer competitive advantages are sustainable (*6*). Grim though

Table 1.—Assessing Demand. (The more you agree with the statements in Part A, the more favorable the structure of demand is likely to be; the more you agree with the items in Part B, the more likely this demand is to be at risk. Score 1 if you strongly disagree, 7 if you strongly agree.)

A: Positive indicators of favorable demand structure.

- The potential long-run market demand for the solution we offer is enormous.
- The demand will grow for a long time.
- There are many critical problems we can solve by pursuing this business.
- There are many potential sub-markets we might be able to tap by pursuing this business.
- The beneficiaries of the final product/services are willing and able to pay, or can be easily funded.
- The demand will not be satisfied with only one purchase by the beneficiary—purchase will be repeated.
- The repeated usage will be frequent.
- There are many potential products and services we can offer by investing in this business.

B: Negative indicators.

- The customer's perception of value will be dependent on the backing of other parties.
- The sale of the product will depend on contribution of effort and resources of other parties, like distributors.
- The market demographics are likely to change substantially against us.
- The offering serves an emotionally sensitive market (e.g., risks to babies).
- We may be exposed to long-term legal liabilities if we pursue this business.

Table 2.—Adoption Dynamics. (The more you agree with the items in Part A, the greater your chances for rapid adoption; the more you agree with the items in Part B, the more trouble you can expect with respect to adoption. Score 1 if you strongly disagree, 7 if you strongly agree.)

A: Factors that speed adoption.

- The technology will be able to offer substantial performance advantages over current solutions.
- Our target customers are very dissatisfied with current solutions.
- Those individuals who will benefit from the technology make the purchasing decision.

B: Trouble with adoption.

- The final offering will need to undergo a significant regulatory approval process.
- The acceptance of the technology will require that users, customers or distributors change expensive imbedded systems.
- We will have to educate the target market in the use of the product.
- The target markets will have to radically change their usage patterns.
- It is not yet clear what the technical standards will be in this industry.
- The purchasing decision will be risky for target customers.
- We are unlikely to get significant sales until a critical mass of products is in use.
- There will be long delays to adoption in general.

Table 3.—Blocking. (High-scoring items represent blocking hazards. Score 1 if you strongly disagree, 7 if you strongly agree.)

- Entry barriers are high in most of the markets we would seek to access.
- Many potential products or services are socially or politically controversial (for example, the "abortion pill").
- We can anticipate organized resistance to our entry into the market.
- There are many existing or potential regulatory barriers.
- Our competitors have pre-existing relationships with critical value chain partners.
- Our competitors are more influential with regulators than we are.
- Competitors are more highly respected in the public eye than we are.
- Competitors have a better relationship with the media than we do.
- Stock analysts think more highly of competitors than they do of us.
- The competitors may use leverage over customers, distributors or suppliers to block us.
- Competitors can lock us out of crucial business networks.
- Potential industries are dominated by exclusionary business networks.

this is, coming to a deep and shared understanding of the dynamics of competitive response can often allow you to avoid or allay the immediate hazards. Even more important, it can allow you to structure investments in such a way that the period over which payback must be obtained is realistic. Some businesses that don't look attractive initially might turn out to be, while other businesses that at first blush seem wonderful turn out to have a fatal flaw because they depend on assumptions of sustainability (*7*).

To assess potential sustainability, we consider three factors. The first has to do with how rapid and aggressive the competitive response to your entry is likely to be. Next, we consider whether the business is fundamentally easy to imitate. If it is, a basic law of

strategy suggests that it will attract entrants and rapidly drive down price and differentiation. Finally, do you own, or can you access, the dominant standard?

Many well-intentioned technology managers underestimate the speed and aggressiveness of the competitive response, which can make prices collapse overnight. Computer hardware, long-distance telecommunications and even used cars are businesses whose managers are feeling the effects daily. Competitors can be surprisingly destructive—they can price irrationally, driving profits through the floor, intimidate suppliers or distributors on whom you depend, bundle their less-attractive product with other services, or create unreasonably high expectations among customers.

A key dynamic in competitive response is matching. Matching occurs when competitors, having observed your success at solving an important customer problem, proceed to address the same problem but do it using technology or other resources proprietary to themselves. They find a different path to what is essentially the same end, as far as the customer is concerned.

Matching is a particular problem for industries in which customers neither know nor care much about the inputs to the product or service, but simply evaluate the offering on the basis of what they can observe. Many service industries—from insurance to banking to commercial lending—have this quality. Often unable to judge the true quality of the product until long after the purchasing decision has been made, customers can be the targets of competitors who match what customers see, even if the offering is not equal in terms of underlying quality.

To assess the likely response of competitors to entry of the new business, we use the statements in Table 4. To the extent that your team agrees strongly with any of these, you are likely to face substantial issues involving aggressive competitive response.

Matching aside, imitation is always a threat to profitability. A business that is easy to imitate is less likely to be able to preserve price premiums or sustain market share than a business in which it is hard for competitors to simply copy. This is obvious; what is

Table 4.—Competitive Response. (The more you agree with these items the greater the likelihood of an aggressive competitive response. Score 1 if you strongly disagree, 7 if you strongly agree.

- We can expect strong competitive response in our target markets.
- We anticipate many competitors in our target markets.
- We can anticipate competitive response from firms with substantial resources.
- There are many firms with the degree of technical competence needed to respond to our introduction.
- Competitors have recently hired some of our best people in this area.
- Competent players in other industries are pursuing similar technology aggressively.
- This is an area that many competitors think is exciting and worth entering.
- The competitors we will be affecting are very competent.
- The competitors' key staff have good track records.

Table 5.—Increasing Sustainability. (The more you agree with these items the more likely you are to be able to sustain your advantage. Score 1 if you strongly disagree, 7 if you strongly agree.)

- The new business is an extension of a protected business that we already have.
- This business, even if imitated, uniquely leverages other proprietary assets we possess.
- Formal mechanisms (patents, trademarks, etc.) are available to protect our business.
- Commercialization will embody formally protected process or trade secrets.
- Avenues to enforce formal protection mechanisms are available in our most important markets.
- Our firm will take advantage of these avenues.
- Our technology will be difficult to reverse-engineer.
- We have the potential to establish exclusive collaborative arrangements.
- Our products have "cachet"—our target market will not accept imitations.

Table 6.—Standards Capture Potential. (The more you agree with these items the more likely you are to be able to take advantage of standards. Score 1 if you strongly disagree, 7 if you strongly agree.)

- Previous generations of our technology have become the standard, either formally or informally.
- We should be able to arrange agreement among the strongest competitors for common specifications.
- Other companies will find it more attractive to license our technology than to invent an alternative.
- Our company is in a position to favorably influence standards-setting organizations.
- We have a dominant position with critical customer groups for this technology.
- We can use our existing market presence to create the standard in this area.
- Lead users in this industry have remained loyal to our technology through several previous generations.

often less obvious, even to experienced managers, is that an attractive arena in which products and services are easy to imitate is also likely to trigger massive new entry from previously uninterested competitors—whether startups or established firms.

The history of the Winchester drive industry is a case in point. Optimistic sales forecasts and easy-to-acquire technology led to the entry of over 120 firms, each seeking only a small share of what was widely believed to be an attractive market (*8*). Easy-entry Internet businesses have been awash in venture capital and investment, even though most observers expected the bubble to eventually burst.

Recognizing the realities of potential imitation, however, is not a counsel of despair. In our consulting work, we have observed many ways in which companies with products that are seemingly easy to imitate can enjoy sustained advantage. One of the more interesting strategies to counter imitation is used by firms such as Rubbermaid and Sony. Instead of seeking to establish a sustainable advantage for one product, these companies simply introduce so many new products and variants on products that competitors find imitation to be impossible—by the time they have imitated, the leader has already introduced the next-generation product! Table 5 lists items for assessing sustainability.

An interesting aspect of the statements in Table 5 is that the team working on a new business often gives little thought to how it will protect against imitation, beyond the obvious use of patents and trademarks. When it does consider the matter, it might dramatically revise its entry strategies. For example, instead of introducing a product as a stand-alone, the team might decide to bundle it. AT&T, for instance, has found that it can get price premiums and differentiation by bundling several services for individual customers and by introducing new technologies in packages with older services. You might also choose to enter gradually, or target non-mainstream niches first.

A final, and powerful, influence on sustainability has to do with standards and what are often called "dominant" designs. To the extent that a new business is able to leverage off its ownership of standards, it is much more likely to enjoy sustainability than if it must wrestle in a world in which no standard has been established, or worse yet, find itself on the wrong side of the standards battle (*9*). Table 6 addresses standards.

You can leverage control of standards by selling upgrades, by deploying alliances, or by creating a network of influential customers and users (*10*). This is also a good point at which to anticipate different scenarios for industry evolution and to encourage people to think creatively about them.

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We have so far considered drivers of revenue. Before we can think about option value from a big upside, however, we need to address costs.

Assessing Commercialization Costs

The genetic code logic says that a cost profile that is large and has the potential for growing out of control is far less attractive than one in which outlays are modest and can be contained. Obvious cost factors include the investment required to create and distribute the product or service; creation of production assets, including manufacturing and distribution facilities; acquisition of inputs; training and organization of staff; positioning with respect to channel; and advertising or promotion expenses. The more ambitious and complex the concept, the more likely it is to incur substantial commercialization costs. Table 7 presents the relevant statements.

Insufficient attention is often paid to the cost of creating a supporting infrastructure for launch and post-sales service. Infrastructure costs can include creation of physical infrastructure, such as communication and transportation systems, adoption of commonly accepted business practices, and creation of human capital infrastructure. You can gain advantage if you possess resources that allow you to avoid or defray such costs. Table 8 presents the measures you might use to see whether you can minimize investments in infrastructure.

A second way to gain cost advantage is to leverage other resources of the firm. If tangible and intangible assets already in place make commercialization easier, faster or less expensive, a project has higher potential for profit. Table 9 lists items that suggest ways in which this can occur. As you think about your team's responses to these items, consider whether every possible advantage has been taken of the resources already in place, relative to future competitors who may not enjoy these advantages.

Existing customers are more likely to prefer to continue purchasing from you than from new vendors (providing, of course, that the relationship has been mutually satisfactory). Changing supplier relationships is a hassle. To the extent that you see ways to capitalize on this, the value of the project can be enhanced. Similarly, you are

Table 7.—Commercialization Costs. (The more you agree with these items the greater the likelihood that commercialization costs will be large and uncontrollable. Score 1 if you strongly disagree, 7 if you strongly agree.)

- The proposed new business will require a long time to complete.
- The proposed business model is complex.
- To develop the product, we will have a significant need for skills in short supply.
- We will have a significant need for expensive equipment and/or systems.
- The equipment and/or systems needed for the project must still be developed.
- There will be a need for several new technologies to develop in parallel with this business.
- The parallel technologies needed are still undeveloped.
- Commercialization will require large, fixed investments.
- Investments to commercialize will be highly specialized.
- Significant investments will be needed to create infrastructure.
- This is a very-large-scale project.

Table 8.—Commercialization Cost Advantages. (The more you agree with the items in Part A, the greater the likelihood that you will capture a cost advantage in the commercialization process; agreement with Part B raises a red flag. (Score 1 if you strongly disagree, 7 if you strongly agree.)

A: Positive indicators of commercialization cost advantage.

- We anticipate being able to leverage our existing supply system during commercialization.
- We anticipate being able to leverage our existing distribution system during commercialization.
- We have a history of successfully commercializing technologies we develop.
- We have control (or significant influence) over parallel technologies needed for commercialization.
- We have the right skills in place for commercialization.

B: A negative indicator.

- We have had trouble in the past making the transition from development to commercialization.

Table 9.—Leveraging Resources for Commercialization. (The more you agree with these items, the more opportunities you have to leverage existing resources for faster, easier and more cost-effective commercialization. Score 1 if you strongly disagree, 7 if you strongly agree.)

- Anticipated demand is similar to markets already served by our firm.
- This technology is likely to meet future needs of our existing customers.
- We already have close relationships with prospective customers.
- This technology is likely to require marketing and selling processes similar to our current technologies.
- We are skillful at understanding user needs.
- We are good at defining target markets.
- It will be possible to license the technology to competitors.
- We may be able to license technology to parties other than competitors.
- We can identify firms that would be prepared to engage in joint commercialization efforts.
- We have a history of successfully licensing or jointly commercializing technology.
- We can learn to commercialize the technology by first entering smaller, less challenging markets than our long-run markets.

Table 10.—Industry Novelty. (The more you agree with these items, the more novel your industry setting and the more you should be prepared to take an experimental approach to market entry. Score 1 if you strongly disagree, 7 if you strongly agree.)

- It is not yet clear which combinations of features will sell best.
- Many competitors are experimenting with different design variations.
- There is not yet a clear understanding of what price customers will pay for different features.
- Customers are hesitating to purchase because of the variety of products and features competitors are offering.
- Few suppliers of complementary products and services (e.g., VCR movies for VCR players) are willing to invest because standards are not yet in place.
- We are pursuing several technologies at the same time because we don't yet know what the standard will be.
- Informal standards-setting groups, such as industry trade associations, have not yet taken a position.
- We are waiting for critical decisions to be made by formal standards-setting bodies, such as government regulators.

likely to have greater insight into the future needs of your customers than someone who has never done business with them, suggesting that more applications may be envisaged for the firm with pre-existing relationships. Likewise, adoption is apt to be faster if customers already know and trust you.

However, these principles do not necessarily apply in the

case of a radically new area, in which the features and functionality that customers want is not yet clear. Recall the history of the personal digital assistant. The concept of such a device had been around for a long time—indeed, Superman used something very like it. Yet, many companies, from Apple, to HP to 3Com tried any number of design variations before finally closing in on a set of features that large numbers of people would pay for.

In such new-to-the-world products and services, nobody knows which configuration of attributes will eventually win. Learning what is important always requires some kind of prototyping, beta testing or experimentation with real customers, because customers are notoriously ill-equipped to provide you with information about products they have never used (*11*). In such circumstances, the right approach is to experiment.

Under high levels of uncertainty, launching immediately is an almost certain route to disappointment (unless you are incredibly lucky). Try, then, to reserve funds for multiple, trial-and-error attempts to bring something to the market for the primary purpose of identifying customers' true needs. These experiments should be managed to learn, rather than to demonstrate the correctness of prior expectation. We call these investments in learning in the field "scouting options" to distinguish them from other kinds of investments and to clearly articulate that their key benefit is in the information they reveal, not whether they succeed as businesses.

We use the items in Table 10 to assess the extent to which newness of the industry is likely to be an issue. Commercialization costs are almost always higher in a new industry setting, because investments are needed to figure out what customers want, to settle regulatory and legal issues, and to establish legitimacy (*12*). For instance, in the formative stage, value chain partners you are depending on to make complementary investments will tend to hold back until they can clearly see which combination of features will become accepted. In such confusing conditions, your strategic objective is to try to find out fast what users will pay for and to get your version into as many hands as possible.

By this point, your group should have a clear sense of whether the upside gain from investment in commercializing the project exceeds the likely costs. In an attractive project, the genetic code for revenue potential is large or unlimited, and the genetic code for commercialization cost is small and containable. An unattractive project is one in which revenues are constrained or likely to be so long in coming that costs could balloon out of proportion. One final consideration enters the logic at this point; namely, what is the effective price on the option to take a project to the commercialization stage? Usually, this reflects the costs needed to develop the technology, product or concept.

What we are trying to establish next is whether it is worth the development cost to capture the value of the option (anticipated positive cumulative cash flows less negative cumulative cash flows).

Assessing Development Costs

Development costs must be incurred before you even know whether or not you have something that can be commercialized. Costs can be considered in light of the basic investments in facilities and skills required; design, prototyping, testing, and model development expenses; and investments to produce with appropriate quality and reliability.

Three factors relevant to development costs are worth considering early in a project. The first has to do with your firm's own resources and track record with respect to developing projects like this one. The second concerns the extent to which investing in the new project offers the potential to create benefits in your ongoing businesses, or positive spillover effects. The third has to do with the level of catastrophic risk the development effort might represent for your firm.

There is considerable evidence that when it comes to successfully tackling highly uncertain new projects, experience counts and can help to lower development costs (*13*). The key issue here is knowing, first, what strengths your company possesses, and, second, making sure they are leveraged. Part A of Table 11 suggests possible points of leverage for your project, while Part B highlights areas in which key weaknesses may cause development costs to mushroom.

Leveraging your existing resources has additional competitive benefits. To the extent that your team can draw on firm-specific skills or know-how, you have the opportunity to establish an advantage in development cost over competitors who must start from scratch. Others are going to find it harder to imitate or match what you are doing to the extent that development requires skills, know-how and knowledge built up over time. This gives you the proprietary claim on the results that is so fundamental to options thinking (*14*).

Development investment often creates a valuable byproduct: internal knowledge spillovers. If new insights and new capabilities developed in the pursuit of a new project can be used to enhance the attractiveness or lower the cost of existing products, the cost of development may be reduced quite a bit, which has the effect of improving profitability for the firm as a whole. Japanese companies are justifiably famous for using development investments in new technologies to simultaneously improve the performance of older

Table 11.—Development Cost Considerations. (The more you agree with the items in Part A, the greater the likelihood that you can leverage your company's resources to cut development costs; Agreement with items in Part B signals weaknesses. Score 1 if you strongly disagree, 7 if you strongly agree.)

A: Positive indicators of development advantage.

- We understand why the dead ends that were pursued in the past failed.
- We understand what could cause this project to fail.
- Pursuit of this technology fits very well with the firm's past strategy.
- We understand which development skills are needed to succeed.
- We know who we need on the development team in order for the project to succeed.
- We have assembled a complete team.
- Each development team member has an outstanding contribution record.
- We have assembled a team that has worked well together.
- We have assembled a team with superior technological skills, relative to competitors.
- Our development team is very good at receiving an extensive flow of knowledge from external sources.
- Our people are part of a leading-edge network of expertise in this technology.
- We have in place all of the crucial skills needed to pursue the technology.
- We have demonstrated our ability to develop technologies like this one before.
- Our processes allow us to achieve rapid cycle time in development.
- Our team will have strong support from top management.
- Our firm has enough resources to develop the technology; or else is very creative in finding alternative funding.
- We have a history of success in jointly developing technology.
- There are firms prepared to develop the technology jointly with us.

B: Negative indicators.

- We must overcome many technological obstacles to succeed.
- The obstacles we must overcome are very large.
- We do not yet understand the breakthroughs that need to be made in order for the technology to succeed.

Table 12.—Spillovers. (The more you agree with the items in Part A, the more opportunities you have to leverage knowledge spillovers from the new business by creating opportunities elsewhere in the company; if you agree with the item in Part B, beware of internal resistance to the success of this project. Score 1 if you strongly disagree, 7 if you strongly agree.)

A: Positive indicators of spillover benefits.

- We may be able to use the evolving technology to reduce the cost of existing products.
- We may be able to use the evolving technology to increase the value of existing offerings.
- Pursuing this product will make it easier to exit other efforts that are showing poor results.
- This development effort will increase our knowledge in a crucial new area.
- This project affords us the opportunity to learn about several new technologies at once.
- This project will create know-how and build skills that will be useful even after the project is over.
- This project will enhance our overall reputation.
- This project will enhance our ability to react quickly should circumstances change.
- *B: A potentially negative spillover.*
- There is a significant danger that the product will cannibalize existing products.

Table 13.—Potential Damage. (The greater the potential for a damaging impact on the firm in the following areas, the more it should try to contain costs, sequence investments and plan according to milestones. Score 1 if damage is unlikely, 7 if damage is highly likely).

- Scientific capacity.
- Development capacity.
- Engineering capacity.
- Marketing capacity.
- Operations capacity.
- Service capacity.
- IT development capacity.
- Workforce relationships.
- Capital structure.
- Physical infrastructure.
- Distributor relationships.
- Supplier relationships.
- Sales capacity.
- Information processing capacity.

technologies—investments such as miniaturization in tape recording and video products, for instance (*15*).

A second form of spillover effect occurs when a firm can utilize the new project to enter modest markets with the intention of using them as a springboard to other markets after the technology is sufficiently well-developed. Such strategies may either allow you to capture many small markets (akin to building a string-of-pearls strategy) or to reduce uncertainty in such a way that opportunities to capture entirely new and significant market spaces are revealed. This can also reduce development costs. Table 12 presents the items that we use to measure potentially valuable spillover effects inherent in a development effort.

A final concern has to do with the potential for devastation that making investments in an uncertain project can create. If a project is of such a significant scope or scale, or if your people foresee that developing it will require so many of your very best people that the rest of your business is likely to suffer, this suggests the need for great care. Table 13 offers items that measure some ways in which development of a project may create real problems for you and your company by creating considerable downside risk.

Situations in which the firm faces high resource debilitation require "bet the company" decision-making. Although they are potentially dangerous, they might represent an opportunity to gain advantage in an entirely new class of product/market environments. Canon's decision to leave its core photographic business behind, Monsanto's to venture into biotechnology and DuPont's current thrust in life sciences are examples of decisions with this quality.

In such situations, investments can be made as a series of deliberately staged and sequenced options. Managing such investments calls for the kind of discipline traditionally used by venture capitalists, in which funding decisions are only made as key milestones are reached and a great many assumptions have been tested (*7,16*). As each milestone is achieved, you have the opportunity to stop further development or to sell, trade, license, or otherwise attempt to gain some return for investments in R&D to that point. The idea is to keep each successive round of investment to an absolute minimum and to frequently re-assess the project. We call these stepping-stone options, and distinguish them from scouting options in that they represent credible, if not large, market applications.

Such stepping-stone R&D options focus on the creation of a new technology platform by utilizing the developing technology for entry into specialized sub-fields or modest new markets. This is done deliberately to return cash flows to, and develop experience with, the technology, sometimes with no intention of remaining in those markets after the technology is sufficiently well developed. Thus, you can make deliberately parsimonious resource allocations designed to pursue carefully selected and increasingly challenging opportunities, with the objective of evolving a new technology along an increasingly sophisticated trajectory.

Investments can be made as a series of deliberately staged and sequenced options.

Japan's Kyocera Company used this approach to pursue the industrial ceramics business. Instead of investing to crack high-level applications, the company initially invested in low-end applications for known markets: for instance, ceramic scissor blades for the textile industry. Through this initial effort, Kyocera resolved considerable technical uncertainty, such as how to source and process clays and how to reliably make precise edges with consistent quality. This created an initial technological competence and, as it evolved, took the firm along a trajectory of increasing technical sophistication. Kyocera is now a major global supplier of substrates for computer chips, an industry that was in its infancy when the company began development.

Revenue streams generated from stepping-stone options make a technology program more valuable, and position the firm to move forward aggressively as new opportunities emerge.

The analysis to this point should have accomplished two things: 1) It should have highlighted situations in which a project proposal can be expected to run into trouble, thereby affording the opportunity to resolve the issues in advance; and 2) it should have provided insight into whether the benefits of proceeding to invest in the project (the claim on the underlying upside potential) are likely to exceed the cost of development (equivalent to the cost of the option). One set of issues remains, having to do with the timing and aggressiveness of investment.

Timing and Investment Strategy

The major influence on timing of investment concerns whether the critical uncertainties you face can be resolved by making an investment, or whether something completely beyond your control has to happen before you will have the answers.

In the first situation, you face internal uncertainty, which is often technical or practical and difficult to get the answers that would resolve it without making an investment. For instance, you may not know whether a process will be effective running at production scale, but you could find out by investing in a pilot plant. You face

a different problem when the key uncertainties are external and no amount of investment on your part will make much difference—these things typically require the passage of time. Assumptions regarding the likely market price of oil, for instance, cannot be converted to fact by your investments.

It is useful to distinguish between these two kinds of uncertainty because they have different implications for entry timing. High internal uncertainty suggests urgency, since the longer you delay, the longer it will take you to find out what you need to know. External uncertainty, on the other hand, suggests that you may benefit by holding off on the investment, since the uncertainty will not be reduced no matter what you do at this point (*17*). Tables 14 and 15 raise questions that can be used to think through the nature of the uncertainties facing the project.

Japan's Kyocera Company used a stepping-stone R&D options approach to pursue the industrial ceramics business.

Putting STAR to Work

Trying to apply complicated methodologies to uncertain situations is usually futile. The greater the uncertainty, the more you need to keep things simple; otherwise, you

Table 14.—External Uncertainty. (The more uncertain your management team is about these items, the wiser a "wait and see" approach could prove to be. Score 1 if the team is very certain, 7 if it is highly uncertain.)

- Total demand for future products.
- Total future revenues from these products.
- Extent to which you will be able to obtain necessary support from third parties (e.g., distributors and suppliers).
- Stability of the revenue stream generated.
- Extent of exposure to long-term liabilities.
- Extent to which sustained premium pricing can be expected.
- Speed with which products will be approved by necessary regulatory bodies.
- Speed with which products will be accepted in the market.
- Degree to which parallel technologies will be needed.
- Whether parallel technologies will be available in time.
- Whether there is licensing potential.
- Probability of being blocked by others.
- Probability of profits being controlled by third parties (governments, distribution channels, labor unions, etc.)
- Probability of being matched by others.
- Probability that competitors will rapidly imitate us.
- Degree to which we will have to constantly change designs.
- Degree to which technical specifications will be standardized in the industry.
- Who competitors are.

Table 15.—Internal Uncertainty. (The more certain your management team is about these items, the more valuable an immediate investment is likely to be. Score 1 if the team is very certain, 7 if it is highly uncertain.)

- Time it will take to complete development.
- Cost of equipment that must be developed.
- Infrastructure that needs to be created.
- Total costs of development.
- Our ability to access needed complementary technologies.
- Cost of systems needed.
- Type of skills needed.
- Availability of necessary skills.
- Cost of staffing.
- Type of equipment needed.
- Availability of equipment needed.
- Cost of equipment needed.
- Raw materials needed.
- Availability of needed raw materials.
- Our ability to overcome technology barriers we will face.
- Required level of product quality.
- Required levels of support and service.
- How much production capacity will be needed.
- Commitment of senior management.
- Whether we will be able to recruit the right people.

run the risk of having everyone blow a conceptual fuse trying to cope with both the uncertainty of the situation and the uncertainty introduced by management's insistence on using complicated methodologies. Consequently, we find that most of the benefit of the STAR© process can be gained by taking a straightforward approach to gathering and analyzing the survey data.

One way to start is to have a team respond to the questions. The ideal group consists of people who have diverse perspectives on the technology and its potential applications; for instance, people from sales, marketing, operations, R&D, and development. An easy way is to do this with pen and pencil. With the responses in hand, we calculate the average response to each item across the team as well as the range of responses (highest minus lowest). You are now ready to review the responses with your group. It is crucial to this process that everyone feel comfortable articulating their point of view and underlying rationale. It always pays to establish ground rules in advance for making sure that the environment is right and that the participants are clear on the expectations for making it an effective interchange (*18*).

Areas of Disagreement

Any item in which the range of responses from your team exceeds 3 or so represents an aspect of the project that people don't agree on. This is quite natural, particularly if the project is highly uncertain and you are inviting people with genuinely different perspectives to comment. Such disagreements represent a terrific opportunity to get discussions started on issues that might be potentially important as the project moves forward. Thus, as you begin to discuss your survey results, focus first on those items which seem to represent major points of disagreement.

Your objective is to solicit alternative scenarios for why people responded as they did. Often, you will find that agreement on the basic facts does not lead people to the same conclusions. This is always interesting, and possibly useful. In particular, focus on areas in which the technical people and the marketing people seem to be at odds. As Bower and Christensen have observed, genuinely new technologies with unforeseen and

Trying to apply complicated methodologies to uncertain situations is usually futile.

unforeseeable qualities often do not meet the needs of existing customers, yet can represent substantial opportunities (*19*). Often, these will be projects that the technical people are excited and optimistic about, but for which the marketing people are unenthusiastic.

Structure of Demand

If you have more than one item with a low score—which we arbitrarily identify as 4 for the initial project review—the objective is to identify the sources that might limit the projects' demand potential and see whether there is anything that might improve your chances. One way to think about making the potential demand materialize is to identify a market (even a small one) that will compensate you handsomely for solving a critical problem.

Assuming that the genetic code of demand is attractive, a major focus should be on the risks that might prevent this from materializing. Can your team identify an early-adopting market segment for which the concerns in Part B of Table 1 are minimal? If so, think about entering there. Another idea is to talk systematically about "most wanted" and "least wanted" initial customers. Your team should be building a shared understanding of what makes a particular customer group desirable. Are you looking for savvy and sophisticated customers, or do you want to appeal to those who need your sophistication to compensate for skills they don't have and don't want to spend time acquiring? The more crisp you can be about the segments, and more importantly, the reason why some are more attractive than others, the more likely it is that the team will be able to act coherently to pursue them.

Adoption Speed

Low scores in this section provide a hint as to which forces might delay customers' adoption. One approach to shortening adoption lags is to identify and target bellwether customers (*16*). These are leaders—people or companies who are influential and whose endorsement of your offering gives it legitimacy. A good reference from these customers is so valuable that many companies virtually give away early versions just to get the nod.

Blocking

Because blocking is such a significant threat, a high score on any of these items can be a "show stopper." The

Assess Your Projects On the Web

We are in the process of developing a web-based questionnaire that will allow respondents to conduct a STAR analysis on-line and receive a customized report. Please e-mail either author for further information.
RDM20@columbia.edu/
macmillan@wharton.upenn.edu

time to think about how blocking can be overcome is now, not later. What you do not want is to make a group of fixed investments in development and then be surprised by an unanticipated block. Tapping the insights of people who understand the regulatory and legal environment can be crucial. Sometimes, a strategic alliance or acquisition can overcome a particular blocking hazard. You may need to be proactive on many dimensions that have little or nothing to do with your project but everything to do with the context in which it will eventually be introduced.

Competitive Response

High scores on competitive response mean your current strategy is likely to receive a nasty reception. Moves that are visible, moves that affect competitors directly, and competitors that are exceedingly capable all exacerbate this risk (*20*). It makes a lot of sense to spend some time considering whether there are ways to tone down the reaction. You might, for instance, introduce your first product in markets that are not strategically central to your competition. Alternatively, you might consider an approach to distribution they have never used, or tackle the market in a way that forces them to reorganize internally in order to compete with you. This may not stop them, but it can slow them down (*21*). An additional advantage is that unless they have top-notch competitive intelligence, you may well be able to get into the market quickly, before rivals see you coming.

It is also useful to avoid "shooting yourself in the foot." Eager to build brand equity, many new product managers actually *provoke* competitive response by advertising heavily. If you are really expecting a strong reaction, this is ill advised.

Time can also be on your side. If you can afford to choose when to enter, you may want to launch when your most significant competition is under a handicap. Many companies pay less attention to external competitive issues, to their ultimate detriment, if they are already pursuing another target market aggressively, if they are in the midst of a major reorganization, if an acquisition has distracted senior management, or if the CEO is in transition (*22*).

Finally, make sure that nobody is assuming that competitors won't respond. They usually will at some point, and often in ways that don't benefit you or them—for instance, by impulsive price cutting. It is important that you plan for this and set aside resources to cope.

Imitation

If scores for the imitation items suggest you are vulnerable, you have two possibilities. The first is to move so quickly that you preempt would-be-imitators with your next-generation product. The second is to see whether there is some way of making imitation more difficult. You may be able to leverage other assets (such as long-term relationships). You may also be able to focus on the needs of a particular niche and get to understand them so well that competitors would have to try hard to come between you—a favorite approach of entrepreneurial startups (*23*).

If none of these is possible, be prepared for rapid imitation. Make certain that your launch is aggressive and rapid and that you take maximum advantage of the time until you are imitated.

Standards

If most of the questions in this section suggest that standards are an important competitive element in your industry, conforming to or setting the standard will be key to competitive success. Standards are vitally important in many industries, but particularly so when customers won't buy unless they are confident that their purchase will work with complementary products and that it will continue to be supported. Ideally, you and your allies will be able to create a standard around which the product category can develop. This is another arena in which investments in technology, *per se,* may well be less important than investments of other kinds—for instance, in the support of standards-setting bodies and membership groups.

Commercialization Costs

High commercialization costs may be indicated if the responses to these statements are high. This may be acceptable if you have a high demand business; however, incurring high fixed costs ahead of demonstrated market acceptance is often an expensive way to find out that you still have a lot to learn.

Looking at the items that threaten to be costly, your team might explore whether the cost burden can be shared. If customers, distributors or suppliers will benefit economically from your success, perhaps they will defray some of your commercialization costs.

You might also be able to leverage existing firm resources. Responses to the statements in Tables 8 and 9 can often provide insight into how you might be able to do this. High scores represent places in which you can use advantages already possessed by your company to reduce commercialization or development costs. Low scores represent places in which you cannot reduce these costs, and at which you are at a potential disadvantage.

Another source of cost advantage can occur if you can capitalize on internal spillover effects. Table 12 suggests places in which spillover potential between the proposed new business and the existing business might lower

development and market access costs for the company overall. High scores represent places in which the evolving business can create substantial near-term benefits for the company. It might make sense for you to devote some time prior to launch to thinking through how you can capture this value, and who in your company would need to support you in achieving this result.

Development Costs

The final set of considerations has to do with the price of the option, which we have argued is analogous to development cost for the new project.

The first set of issues to consider is the kind of environment your project is being launched into. Table 10 can give you clues as to whether competitive dynamics in the industry depend on rapid rates of product innovation and development of new features, or whether competition is based on a set of well understood product and service features. High scores here suggest that the basis for competition in the industry has not yet been sorted out; in other words, customers have not yet settled on which functions and features they want in a product, and it is therefore hard to anticipate which product characteristics or services to offer. In such situations, it is important to experiment to discover what it is that customers want (and will pay for). Make sure you reserve enough budget for repeated tries, and that management makes it clear that multiple forays into the market are acceptable, even if they invalidate earlier assumptions. Lots of inexpensive failures from which you can learn are the key to effectively applying real options reasoning (*24*).

Next, consider Table 11. These items assess the extent to which you have historically pulled off a project like this. They also indicate whether the necessary skills, team issues and technical competencies are in place. Low scores on any of these items suggest areas of weakness or vulnerability. This may imply the need for additional investment in skills, training or personnel. Worse, low-scoring items suggest that your team does not perceive you as having advantages in developing projects like this, and suggests caution with respect to competitors. Make sure that people really understand the nature of the challenge that they are up against, and push them to be realistic with respect to costs, budget and deadlines. Spillovers can offer advantage here, too.

Look now at the questions that assess potential damage to the firm by undertaking the project (Table 13). It is worth thinking through how you are going to put in place protective measures to help cushion the stresses that the project could create. At the same time, you need to be prepared to avoid escalating commitment in the event that the project does not go as planned—try to avoid the enormous temptation to continue pouring in resources without validating the most critical assumptions (*25*).

Lots of inexpensive failures from which you can learn are the key to effectively applying real options reasoning.

Finally, you should consider the items in Table 14 and 15 that relate to the nature of the uncertainty you face. These have implications with respect to the timing and aggressiveness with which you pursue the project. Table 14 identifies major uncertainties that are beyond your control. If you have high scores, the big question is whether you are best advised to postpone significant investments in the technology until you have more information. High scores on Table 15, on the other hand, suggest places in which investment might be warranted. The key idea is to focus on those investments in which you can learn the most at the least possible cost.

Comparing Alternative Projects

Coming to a group consensus on how a particular project rates allows you to compare different projects by comparing the scores. This can help you think through tradeoff decisions among competing investments in a portfolio. For instance, other things being more or less equal, a project with a high blocking hazard or low sustainability is less attractive than a project without these problems. The STAR questions are also useful when applied to those R&D projects that may already be in the pipeline. Although more information is typically available about these projects, the STAR process can offer a systematic way to look at multiple projects using the same discipline.

A Project Management Tool

The STAR statements were developed to try to simplify the considerations shaping the fate of highly uncertain new technology projects. We use real options reasoning, rather than more conventional approaches to project assessment, because it represents a robust and coherent way of thinking about highly uncertain situations. Using the statements as the basis of a group discussion also has the advantage of being fast, inexpensive and a great way to get involvement and communication from many critical people. The insights that come from your own people, given a chance to focus on the right questions, can be a revelation.

Companies differ in how aggressively they have used STAR and at what level in the firm. In Japan, one major electronics firm is using the method to assess the most

promising technologies across its entire corporate portfolio, while others use the questions routinely in reviews of new projects. (STAR was chosen one of the 50 most significant management innovations in Japan in 1998 by *Nikkei Shimbun,* a leading business publication.) In Finland, a venture capital fund is using STAR to assess whether the entrepreneurs it has funded are thinking broadly enough about their technology strategy.

STAR has been found useful by several dozen high-technology manufacturing firms in the United States as a speedier alternative to the often unintentionally cumbersome process through which projects are evaluated. Groups such as the Commercial Development Association are using STAR as a framework for helping members think about the issues that are likely to arise during the commercialization process. Even a major (*Fortune* 50) chemical company has been using it to sort out the opportunities available to it as it moves into higher-margin industrial arenas. STAR has also been used as part of a portfolio of management techniques that are appropriate to an uncertain environment, such as discovery-driven planning.

The philosophy behind STAR fits with a world in which we simply do not have the time to do a lot of complicated analyses, or the money to invest in projects whose competitive window of opportunity is short. Winners in this world will act like entrepreneurs—taking out experimental options, ruthlessly postponing or dropping those that don't promise a substantial upside, and swiftly and boldly capturing opportunities in a rapidly shifting competitive landscape (*26*). ◆

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Real options reasoning represents a robust and coherent way of thinking about highly uncertain situations.

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