Frames of Significance: Technological Agenda-forming for Strategic Advantage

MARTYN PITT & KEN CLARKE

ABSTRACT *Technological innovation is a source of competitive advantage and potential corporate rejuvenation. The problematic issues that managers frame, then devote attention and resources to solving, constitute the strategic technological agenda of the firm. We propose and elaborate a perceptual frame model by which the agenda may be understood. We use the model to interpret three innovation episodes in divisions of large, multi-divisional corporations. The patterns of framing over time and the issues addressed are particular to each firm. We acknowledge the existence of partial perspectives associated with the vantage points of the various decision-makers and observers, and we suggest that greater awareness of this partiality could lead to a better appreciation of the complexity and implications of ambiguous issues. We suggest that agendas evolve in a broadly 'logical-incremental' way although we question whether sufficient priority is being accorded to extending the new capabilities to emerge from innovation to other areas of the parent corporations.*

Introduction

The continuing advance of technology is widely recognized as a major vehicle for firms to create and sustain strategic competitive advantage. But technological innovation presents strategic decision-makers with problematic uncertainties,[1] especially in large, diversified and decentralized firms.[2] In particular the 'unknowability of the future'[3] creates doubt over the manner in which technological pathways will evolve; decision-makers have to consider whether to innovate, in what direction, when and how quickly if advantage is to accrue to the innovating firm. None the less, firms do cope with the demands of integrating technology and strategy, sometimes spectacularly well.

At any particular time, we hypothesize that the firm's strategists are aware of a variety of salient, but unresolved, concerns linked to uncertainty over markets and technologies. We would expect an evolving pattern of attention and resources to be accorded to tackling these issues. This pattern constitutes the innovating firm's implicit or explicit agenda for achieving and sustaining advantage.

In this paper, we explore ways in which firms' strategic agendas for technological innovation may be constructed. Drawing on the literature, we posit four perceptual frames that we would expect decision-makers to evoke, tacitly or otherwise, as they try to make sense of issues associated with technological innovations. We add an encompassing

Martyn Pitt is at the School of Management, University of Bath, Claverton Down, Bath BA2 7AY, UK; Ken Clarke is at the Portsmouth Business School, University of Portsmouth, Locksway Road, Milton, Southsea, Hants PO4 8JF, UK. E-mail: mnsmrp@bath.ac.uk and clarkek@pbs.port.ac.uk.

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perspective, or 'meta-frame', informing judgements about the suitability of an innovation not only in the light of market and technological considerations, but also in relation to perceptions of organizational ethos and aims. We then elaborate these frames by applying them to three relatively successful innovation episodes. In the subsequent discussion and conclusion, we argue that the approach has descriptive and predictive potential for the firm and its strategic agenda for innovation.

Strategic Agendas for Technological Innovation

Although technological innovation is recognized by writers on strategy as a major source of competitive advantage, conceptual models of the related strategic decision process remain underdeveloped. Following Wernerfelt's seminal article,[4] the strategic management literature has addressed technological innovation mainly in terms of distinctive competencies that create strategic advantage. The leveraging of competencies occurs in the context of the opportunities and threats posed by market demand, industry competition[5] and the firm's positioning options.[6] To achieve adequate economic returns and long-term security, the technological capabilities of the firm must be enhanced and matched to evolving market and stakeholder expectations.[7] The innovation management literature recognizes the need to go beyond dualistic strategic models such as offensive versus defensive, or market opportunism (demand-pull) versus curiosity-driven (technology-push),[8] but only recently has it acknowledged firms' complex motives and stakeholder expectations.[9]

Although a firm exhibits an evolving pattern of concerns and issues, the definition or consideration of an issue within the firm can be controversial.[10] When dilemmas are perceived, their resolution requires, *inter alia*, decision-makers to reconcile perceptions of risk and regret.[11] That is, they have to balance the expected costs of unsuccessful actions with the costs of failing to act. Thus, the wider implications of an innovation can remain highly ambiguous.

The strategic technological agenda is linked to the firm's technical, managerial and organizational knowledge and assumptions. This is largely experiential, cumulative and often tacit.[12] Especially in multi-divisional firms, much of this tacit knowledge is held in decentralized units and structures, often undisseminated and immune to external challenge.

The agenda is subject to multiple stakeholder expectations and influences. Various conceptual and empirical studies have addressed the 'political', bargaining aspects of decision processes whereby objectives are agreed and innovations sanctioned.[13] Others have examined the contingent nature of appropriating returns to strategic innovation under risk and uncertainty.[14] Others still have recognized the subtle influences on agendas that encompass perceptions of mission and ethos.[15]

Some expectations derive directly from managers and technologists. While these stakeholders, typically recognize technological innovation as the engine of sustained growth, they may also regard it as an emblematic, defining feature of the firm's *raison d'être*, expressed notionally in terms of market and technological 'prospecting'.[16] Firms like DuPont, 3M, Glaxo, Sony and Intel, engaged in the development of advanced materials, devices and processes, are examples. In this respect, expectations of internal and external stakeholders may be at one. Yet, although in firms such as Sony, perceptions of technological possibilities seem to channel strategy in a realistic way, in other firms technological innovation may become an end in itself, divorced from pragmatic interpretations of strategic reality.[17]

We propose that technological innovation in the firm may be examined via a model

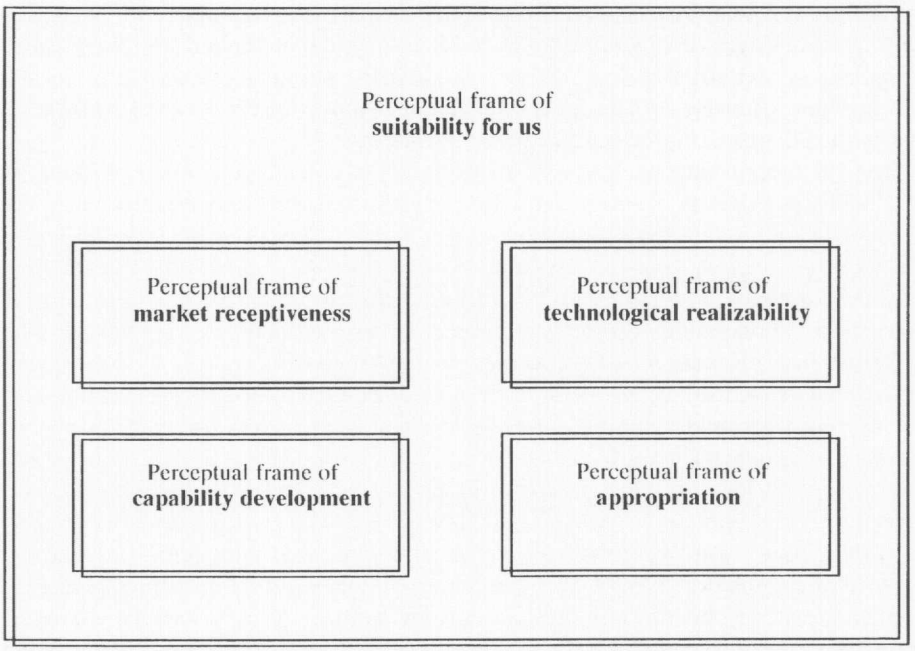

Figure 1. Strategic frames for interpreting technological innovation.

comprising four perceptual frames and a fifth 'meta-frame' (Figure 1). These sense-making frames[18] are a way to understand how decision-makers may filter, construct, question and interpret strategic issues. Awareness of these frames, albeit at the tacit, intuitive level, may enable decision-makers to cope with technological uncertainty and its associated dilemmas by according shape and significance to issues, thereby directing attention and channelling resources to them. By appreciating how issues may be framed in the firm, external observers can attempt to interpret the actions of the firms they observe. We begin by elaborating on the model itself, and then use it as the perspective from which we present our case illustrations. Then we broaden the discussion to explore the implications and questions that flow from the model and our initial use of it.

The Perceptual Frame of Anticipated Market Receptiveness

Application and exploitation are what distinguish innovation from invention. Successful application requires a market need, a tangible product for meeting that need and a process for its realization. Many sources emphasize that a firm's propensity to innovate is stimulated by perceptions of latent, demand-led applications to which prospective technologies can in theory be matched.[19] Thus the innovator can ask: Will the outputs of an envisioned new technology be widely valued in the market-place?

A pertinent question for the innovator is whether a highly valued initial application may emerge to which the new technology can be applied, both demonstrating its efficacy and generating economic returns via early adopters. Then, in the longer term, will the market-place come to legitimize and respect a new technology—in the sense that it becomes widely regarded as the most practical, preferred means to satisfy an acknowledged need? Or will alternative solutions emerge? For example, despite the historical dominance of analogue compact cassette tape players for in-car use, the shift to digital

encoding has resulted in compact disc (CD) technology becoming perceived as the legitimate approach to high-quality audio reproduction, marginalizing Sony's digital audio tape system in the process. As we write, market acceptance accorded to the more recent digital compact cassette from Philips and Sony's MiniDisc remain equivocal, so that both still appear high-risk innovations.

Market receptiveness to a novel technology often remains imponderable for a long time. Dilemmas about whether (and how far) to proceed with applications-specific technology are rarely resolved solely by market research. For the innovating firm, errors of both type 1 (failing to pursue an innovation to which the market subsequently proves receptive) and type 2 (pursuing an innovation to which the market subsequently proves unreceptive) are common. So we would expect anticipated market receptiveness to be a significant issue for innovating firms as they try to relate technology options to competitive strategy. Moreover, we would predict that while uncertainty persists over market receptiveness, the latter will remain on the strategic agenda.

The Perceptual Frame of Technological Realizability

Individual firms have to realize technological innovations as specific processes and products. We propose realizability as this concept of technological feasibility for the firm. Perceptions of realizability include both objective and subjective elements. Firms may introduce concerns over realizability to their strategic agendas for three reasons. First, a new technology is innovative because it contains features not attempted before and possibly because it requires a technological discontinuity to be bridged.[20] Indeed, some envisionable technologies stay unrealized over long periods because of a technical difficulty beyond the capability of any firm. The high energy density battery for electric vehicles is an obvious example. Accordingly, decision-makers perceive a barrier to progress which may not be surmountable.

Second, perceptions of technical feasibility may be influenced by the widely held belief that a technology traces an evolutionary path towards a dominant design configuration, ultimately with well codified standards and processes.[21] Each firm therefore anticipates technological realizability in the context of its own position on this path, and so in ways that are partial and, to a degree, idiosyncratic. The firm's decision-makers see both firm and sector trajectories in ways that are conditioned by their commitments to the firm's current (and potentially obsolescent) technology set, rooted in the firm's cumulative and idiosyncratic knowledge base and its investments in resources, structure and culture.[22] Assessment of realizability is often subject to additional uncertainty arising from the perceived need to develop successive generations of a technology if the firm is to stay competitive. Because competing firms develop idiosyncratically, their capabilities remain asymmetric and hard to emulate.[23]

Third, an innovation may constitute or require an unproven reconfiguration of existing technological competencies.[24] Yet firms typically demonstrate quite limited abilities to reconfigure their technological competencies. For example, a firm with bottling plants for soft drinks and beer exploits two particular configurations of food packaging technology located in time and place. Each configuration is a specific array of subtechnologies in biochemistry, metallurgy, mechanical and electrical engineering and so on. Although its technologies are potentially reconfigurable (e.g. by setting up a plant for bottling sauces), decision-makers may see reconfiguration as highly problematic because they believe the firm may be unable to gain access to all the necessary technological expertise.

If, for whatever reason, decision-makers lack confidence in their ability to realize an

envisioned innovation, for practical purposes it remains infeasible for them. We can therefore equate realizability with the notion of perceived 'feasibility-for-us'. Given firms' unique developmental histories, decision-makers' assessments of anticipated realizability may often differ as to the potential of their own firm and that of others. Those who claim that a novel technology is 'feasible-for-us' presumably believe that their firm already has the relevant capabilities, or that they can be readily acquired.

Innovators have the opportunity and, we would predict, the motivation to assess embryonic technologies through the perceptual frame of anticipated realizability. Their conclusions will depend not just on objective, external data, but on necessarily imperfect managerial judgements[25], about how current capabilities may evolve, given the competing demands on the firm's scarce resources. Decision-makers' judgements may of course prove inaccurate. A firm enhances its prospects of achieving convergent perceptions of realizability when its staff participate in interpersonal networks[26] or when it participates in coherent supply chains or collaborative inter-firm relationships.[27] Thus, it may achieve a more balanced and realistic view of feasibility-for-us in relation to its decision-makers' perceptions of feasibility-for-others.

The Perceptual Frame of Appropriation

Another way of framing issues for the agenda of strategic innovation is to anticipate the prospects of capturing good financial returns through sustainable competitive advantage. A strong appropriability regime for the innovator inhibits competitive emulation, offering the prospect of quasi-monopoly profits with minimal interference.[28] Often framed simplistically as the choice between first mover and early follower strategies, a strong regime has many facets. These include the time anticipated for appropriating returns as rivalry intensifies, the opportunity costs of not pursuing other uncertain projects, the potential cannibalization of the firm's current technologies and the scope to protect the firm's position by erecting emulation barriers, such as patents, copyrights on technical standards (yielding potential returns through licensing agreements) and 'golden handcuffs' employment contracts for skilled staff.[29]

The returns anticipated may differ markedly depending on whether a short or long-term perspective is adopted. For example, nimble, but resource-constrained, first movers may anticipate and indeed extract good short-term returns. Although research shows that firms often enhance their long-term prospects by entering a new market before a dominant design emerges,[30] early innovators may fail to anticipate problems over long-term appropriability. Failure to anticipate major changes in the trajectory of the prevailing sectoral knowledge base can disrupt or even destroy the value of the firm's existing capabilities and limit its ability to appropriate future returns. Highly innovative, dematuring transformations prompt fundamental shifts in the competitive standing of the protagonists, as when Xerox introduced dry powder copier technology.[31] From the appropriability standpoint, the most problematic instances are those which prove disruptive to the innovator, but not to its customers—'revolutionary' in Clark's terminology[32]—and those which disrupt well established product architectures, as opposed merely to affecting component design.[33]

As elsewhere, when decision-makers anticipate and evaluate issues of appropriability, they do so in a subjective perceptual frame, since truly objective assessment is not possible. In general, we would expect firms to adopt the appropriability frame as part of their assessment of technological innovation. None the less, under extreme uncertainty, decision-makers may simply ignore potential concerns or defer judgements until, with the passage of time, issues are clarified beyond reasonable doubt.

The Perceptual Frame of Anticipated Capability Development

Concerns about market receptiveness, realizability and appropriability bear so directly on the prospective success of any innovation that most neutral observers, we think, would be surprised if a firm did not try to anticipate its implications in these terms. The frame of capability development is perhaps less obvious. We proceed from the well rehearsed argument that successful firms can and should build corporate strategy out of core competencies.[34] We prefer the word 'capability', since it connotes a sense of evolving as well as current competence.

Elsewhere,[35] we distinguished a particular technology from the intangible and often tacit scientific and other knowledge-based capabilities that underpin it.[36] In this view, a new technology is a manifest, realized configuration of capabilities, some resident in the firm, some perhaps imported. Capabilities and technologies may be only loosely coupled in the firm, with well developed but under-exploited skills in one domain accompanied by dependency on external skills in others.[37] Therefore, joint and complementary tracks of technology and capability developments both enable and constrain the direction of the firm's innovation path.[38] The firm's stream of technological innovations constitutes a learning process that enables it to establish capabilities with the potential for future distinctiveness and competitive advantage.[39] In Mintzberg's terms,[40] distinctive capabilities are realized *ex post* as opposed to being intended *ex ante*.

We would expect alert decision-makers to be sensitive to the need for (and value of) assessing novel technological possibilities as vehicles to enhance and extend the firm's capabilities in pursuit of future advantage. In such instances, and especially in the divisionalized corporation, decision-makers may justify engaging with an embryonic technology because it provides impetus for upgrading capabilities. These, they may argue, can subsequently be diffused into applications supported elsewhere in the firm. The process of perceiving capability development and diffusion in these terms is akin to the perception of strategic 'common threads'.[41] By framing issues of technological innovation in terms of anticipated capabilities, decision-makers significantly shape the strategic agenda of the firm.

The Encompassing Perceptual Frame of 'Suitability for Us': The Effect of Managerial Styles and Stakeholder Expectations

Strategic decisions under uncertainty are subject to an evolving, relatively unstructured and politicized process, involving stakeholder groups and influenced by organizational norms of procedure, culture, ethos and identity.[42] Decision-makers tend to be partially aware of these influences. When they recognize and interpret strategic issues, the managerial and organizational approaches that they regard as normal and legitimate in the firm will predispose their outlooks. Implicitly, these assumptions will affect the relative salience of the perceptual frames they adopt, the kind of issues that reach the strategic agenda and how each is then perceived.

Strategic agendas are firm specific, with characteristically different patterns of focus and attention in the 'structural repertoire' of the firm wherein framing occurs.[43] The implication is that although decision-makers may anticipate the attractiveness of a prospective innovation in 'global' terms, they will frame their practical assessments by emphasizing 'local', even idiosyncratic, concerns. They are likely to anticipate an innovation in terms of its perceived appropriateness for the firm. From their vantage point, this frame can be characterized as perceived 'suitability-for-us'. Graham's account of strategic research and development (R&D) decisions in RCA offers an excellent illustration of this process.[44]

The suitability-for-us frame is conceptually distinct from the others. It encompasses them, but adds further scrutiny from other perspectives, as it takes account of more subtle considerations arising from the influence of corporate ethos and stakeholder expectations and their systematic difference as between firms. Differences in organizational styles, exemplified in the distinction between prospectors and defenders,[45] offer support for the 'suitability' frame. Prospectors—proactive 'technology-push' innovators like 3M and Sony—have characteristically optimistic, outward-looking corporate mindsets that accord considerable priority to developing and exploiting technological expertise. Decision-makers articulate bold, intuitive visions of the future, often supported by simple decision heuristics, and they champion competitively aggressive, first-mover technological strategies.[46] They are more sensitive to anticipated regret at lost opportunities than to potential failure. Individuals who implement innovations successfully are (and expect to be) well rewarded.[47] Over time such firms create portfolios of diverse technologies and capability bundles.

By contrast, a defender firm like Rolls Royce Aero Engines tends to adopt a circumspect attitude to innovation, geared primarily to sustaining a dominant industry position by deepening its capability base through coherent and complementary extensions. Its strategic judgements are likely to draw on careful analysis and experience in the industry setting—the recipe.[48] Issues not perceived as salient in this context may be ignored completely.[49] A hybrid analyzer firm like Matsushita generally allows others to demonstrate solid demand in new arenas before it responds. It then adopts an early follower strategy to secure a dominant position that owes more to its commercial strength than its innovativeness.[50]

Other, subtle aspects of decision-making styles may bear on the suitability frame. We would anticipate that among engineers and technologists, the myth of 'technical rationality' will be potent.[51] A team of such individuals will aim to consider strategy systematically and comprehensively. Its innovation agenda will contain a multiplicity of problematic issues, even though their complex interdependency may in practice result in selective and sequential treatment.[52] Although the team may believe it controls the unfolding agenda, it is not immune from the twin phenomena of 'groupthink' and escalating commitment to premature first-mover initiatives.[53]

A Trio of Innovators

We now explore the utility of our model by applying it to episodes of technological innovations implemented by three firms. All are divisions of decentralized international corporations. The accounts of these episodes are based on a combination of semi-structured narratives of the technology developments given to us individually by a handful of experienced senior managers in each firm, corroborating personal conversations and observations, and secondary data. The initial narratives asked the managers to identify the significant events shaping the innovation episodes, and particularly to focus on the development of the firms' marketing, operations and technology capabilities and relationships. We then developed the frame model both in the light of, and to explore, the episodes. The analysis here of these episodes offers illustrative and confirmatory evidence for the model. We do not offer definitive research findings about the final outcomes of particular innovations. Where as external observers we make inferences, we make this clear. In each case, we start with a brief review of the firm and how the meta-frame appears to condition perceptions of the innovation. We then consider possible influences on technology development. Where relevant, we draw attention to divergence of managers' interpretations and seemingly counter-intuitive perceptions.

PropCo

PropCo's parent company began in the late 1920s as a component supplier to the aircraft industry. It has grown organically and by acquisition, and has established several divisions supplying aircraft and aerospace subsystems. It derives most of its turnover from this sector. PropCo is a leading manufacturer of forged alloy propeller blades. The innovation considered here is a moulded carbon composite blade. This technology has enabled it to create a very effective blade with a complex profile and a non-uniform internal structure. From the outset, a composite blade was perceived to combine the prospects of enhancing air speed, lower noise, greater fuel economy, and greater durability and repairability.

PropCo's ethos is conservative and its organizational structures are hierarchical. There is considerable respect for engineering excellence. Incremental, in-house development of new products has been the preferred basis for innovation. We would characterize PropCo as a defender.

Viewed through the meta-frame of 'suitability for us', some senior corporate managers took the view that composites constituted a technological discontinuity in PropCo's developmental trajectory of excellence in metal working, and were thus an unnecessary risk. Since PropCo was a comparatively minor part of the corporate portfolio, it was also possible to regard such a development as peripheral. Within PropCo, however, decision-makers saw composites as a logical and appropriate engineering extension of the trajectory. For a time, development work was sponsored by a handful of 'technology champions'. Only as the technical risks became better understood and controlled did senior executives find it possible to reconcile the corporate outlook with continued development.

Propeller use has been confined largely to light aircraft and 30–110 seat regional, inter-city commuter planes. In PropCo, the commuter niche was seen as the opportunity that justified initial development. Some were also optimistic that, if realized, high-performance composite propellers would motivate aircraft makers to explore new applications. Most lacked confidence that the market would be sufficiently receptive to ensure substantial short-term demand. In any event, no one would adopt new propeller technology unless, and until, it had been proved totally safe as well as better performing. As prototypes were developed, market receptiveness remained a significant concern. Although composite propellers have new found specific applications, long-term demand is still largely uncertain.

Composites technology was sufficiently developed in other companies for its advocates to have few doubts in principle over the technical feasibility of moulding propellers. Indeed, after development began in earnest, anticipated feasibility was not fundamentally in question. However, doubts persisted over the ideal blade profile and durability, given the high stresses in use. Prototype development was protracted.

Despite its initial success in niche applications, PropCo's appropriability regime may be considered, objectively, as rather weak. Designs are proprietary but moulding technology is widespread. First moving has created an initial advantage, but the need to customize each application gives early followers opportunities to catch up. PropCo has limited bargaining power over the crucial engine and airframe makers. The prospects for moving beyond niche applications remain uncertain. Even if jet-prop airplanes become commonplace again, emulators of composites propeller technology will probably emerge. While these concerns were partially anticipated, appropriability seemed largely irrelevant or ignored until the composite propeller was a technical reality. Had the appropriability frame been evoked at the corporate level, it is probable that this issue could have resulted in the project being cancelled, from which we infer that PropCo's decision-makers took

care to avoid or ignore emerging appropriability concerns. Later, when the product had demonstrated some commercial potential, future appropriability became perceived as a significant issue on PropCo's own strategic agenda.

To bring composite blades to market PropCo required access to relevant design and manufacturing capabilities. It is part of the PropCo technical heritage to regard having such capabilities in-house as the basis of manufacturing advantage. Implicitly evoking the 'suitability-for-us' frame, the advocates of composite propellers argued successfully to internalize these skills rather than rely on outside contractors. They recognized the need to extend PropCo's skills in other areas too, including computer-aided design, manufacturing and testing. These new capabilities have now been internalized in new facilities. In principle, they can be extended to other areas of the parent company, such as fuselage components. However, although capability development for the envisioned niche applications was central to the PropCo agenda, the diffusion of these new capabilities elsewhere in the parent company was apparently not seen as a high priority.

MotorCo

Founded in the 1920s, MotorCo's divisionalized parent company engaged in a variety of automotive, aerospace and other manufacturing engineering sectors. MotorCo is a world leader in fuel injection engine equipment. In the 1950s, it introduced and developed what was to become the dominant industry design. MotorCo's latest innovation alters both component technologies and system architecture. Fuel distribution to the injectors is now at relatively low pressure, while each injector incorporates an electromechanical pump under electronic control operating with great precision at very high pressures. The benefits are a combination of higher engine power, lower fuel consumption and less exhaust gas pollutants.

As with PropCo, MotorCo has a well entrenched ethos of engineering excellence and hierarchical structures. Issues are thoroughly analyzed and quantified and the approach to innovation is pragmatic, patient and subject to long time horizons. Development of the new innovation has taken more than a decade. As its technical capabilities grew, it has relied increasingly on in-house R&D skills. We would characterize MotorCo as a defender, although this could change as major stakeholders recognize the opportunity for MotorCo to spearhead corporate growth.

Some aspects of the innovation were sufficiently novel for conservative elements to argue that it would be an unwelcome discontinuity in MotorCo's developmental trajectory. Conversely, advocates of the innovation argued that it was highly suitable since it defended and reinforced the strong position of the firm in its sector. Indeed, once the innovation had been envisioned, they argued that failure to proceed would expose MotorCo to the risk of competitive technological leapfrogging. Because MotorCo was a major element in the corporate portfolio, assessments of suitability-for-us made at corporate and business unit levels largely converged. Moreover, the application of electronics to hitherto mechanical systems was gaining ground in many other engineering sectors, weakening reactionary objections.

Because MotorCo's decision-makers see the fuel injection market as their domain, they have been very sensitive to environmental pressures that would affect market receptiveness to innovations. Rising fuel prices in the 1970s alerted them to the need to reduce fuel consumption. Subsequently, they acknowledged ecological pressures to reduce exhaust gas pollution. Anticipated future demand for more efficient, clean-burning engines legitimized discussion of new design concepts, although there was no consensus in MotorCo that original equipment makers of engines and vehicles would seek radical

innovation, indeed might be quite unreceptive to it. Legislation on future vehicle emissions levels merely added to uncertainty over whether vehicle manufacturers would regard catalytic converters (in which MotorCo has no expertise) as both a necessary and a sufficient (hence legitimate) way to control emissions.

Development of the new technology progressed in collaboration with a few large truck engine builders. In these applications the higher cost of the new technology was seen to be comparatively insignificant in relation to the benefits. Until the project was well advanced, comparatively little thought was given to using the new technology in cars, possibly because they doubted whether car makers would accept a premium price. Thus, issues of market receptiveness were firmly on the strategic agenda from the start, albeit varying in salience over time.

Whether MotorCo could realize the envisioned new technology in practice was imponderable for a long time. Development was slow because of intractable technical difficulties and limited resources. Mindful of the risk of being beaten by a major competitor, the engineers doggedly persisted. Like PropCo, in-house development was preferred in order to maintain secrecy. Early prototypes failed because of metallurgical problems. An unresolved problem in a key subsystem late in the development cycle forced engineers to replace a radical component technology with a well proven one, causing further delays. Thus, significant concerns about technological realizability remained on the internal agenda until MotorCo ultimately produced saleable devices. New technical questions about the feasibility of miniaturizing and reducing component costs, deemed necessary for car applications, were then addressed. We speculate that, given its preference for internal development, decision-makers in MotorCo would have perceived it as in the firm's interest to keep concerns about realizability off the corporate level agenda.

Appropriability has been a major concern in MotorCo and at the corporate level. MotorCo re-engineers the technology for each new application in spite of the costs and time, because when equipment has been accepted in a specific application, competitive substitution is rare. In fact, the appropriability regime for the new technology appears quite strong. MotorCo has patents pending on various aspects of component design and system architecture. Decision-makers believe that only a handful of competing corporations world-wide have the fundamental know-how, expertise and financial resources to develop an equivalent product. Licensing proprietary design standards to would-be competitors may be MotorCo's most viable route to full exploitation of the innovation, given the strong bargaining power of the vehicle makers who typically desire low prices and dual sources of supply. However, we think that MotorCo's strategists anticipate being able to manage the progressive substitution of current technology in high-volume car applications to its benefit.

Historically, MotorCo's core skill was its ability to engineer a design for the marketplace and produce it efficiently in high volumes. The innovation was seen as consistent with MotorCo's developmental trajectory. But the firm lacked skills in marrying electronics to mechanical systems, designing miniature electromechanical servos, computer programming and ultra high pressure fluid dynamics. Capability development therefore emerged as an issue and remained an on-going concern over a long time-scale. The view prevailed that they were operating continually at the limits of the firm's capabilities. To our knowledge, decision-makers never seriously entertained the prospect of external collaboration. As shortcomings were acknowledged, qualified staff were hired. When the project neared production MotorCo set up a new factory on an isolated green field site where it introduced major changes in work organization. Yet, as in PropCo, the diffusion of emerging capabilities elsewhere in the corporation does not seem to have been a high priority at any time.

LectroniCo

LectroniCo's parent company was founded in the 1940s and is a major producer of branded computer equipment and software. Technologically innovative, with a reputation for technical overkill, the firm has grown rapidly by serving demanding, typically specialist, niche markets. LectroniCo's role is to spearhead corporate diversification into value-added peripherals for incorporation into corporate products and increasingly as a supplier to other equipment assemblers. The innovation we focus on is a data storage devise using a new form of tape-based digital encoding technology. It offers cost-effective, multi-gigabyte capacity and high rates of data transfer.

LectroniCo's ethos is youthful, competitive, self-confident and optimistic: decision-makers fear the cost of lost opportunities more than making mistakes. The culture is promulgated in part through epic 'war stories'. The 'can-do' approach to innovation is based on a sense of urgency and teamwork, with in-house development preferred. It appears well characterized as a prospector. Stakeholders understand and accept its style of operating, although as the firm has matured, financial expectations have assumed greater importance and there is less scope to be cavalier. Still, LectroniCo's decision-makers can apply current skills in new directions, confident of corporate support. Once initial debate about objectives had established the 'suitability-for-us' of this innovation, widely seen as very consistent with the firm's development trajectory, the strategic agenda focused on implementation issues.

Decision-makers anticipated that the new storage technology would find a receptive market for a compact, low-cost device, although the variety of potential approaches created uncertainty over the optimum direction for development. They construed market receptiveness largely in terms of device performance, data standards, cross-platform compatibility and so on. They did not find it hard to make convincing estimates of market potential. Indeed, given the prevailing optimism, they tended to regard their forecasts as conservative. Only later, when it was apparent that the firm faced serious competition from unexpected sources, did they reconsider these estimates.

Attention quickly turned to how the innovative device could be realized in practice. Like PropCo but in contrast to MotorCo, LectroniCo's engineers had little doubt over its realizability, since the hardware already existed. However, they had no experience of manufacturing tape drives, and major uncertainties remained over the software specifications required. The evident constraints on project feasibility as a solo venture pointed to a collaboration with a tape drive manufacturer. Having set up such a collaboration, decision-makers no longer saw realizability as a serious concern.

Initially they saw appropriability as an issue of first moving. Unforeseen delays associated with the collaboration allowed competing alternatives to enter the market as retrofit and original equipment. This showed that emulation barriers could be overcome and LectroniCo responded by licensing copyrighted software protocols cheaply to promote an industry standard. Despite delays in launching the new technology, it has become widely regarded as the superior, most legitimate solution. Although the firm may initially have accorded insufficient importance to the issue of managing appropriability, it appears since to have corrected the position most effectively. It has created a strong appropriability regime for the innovation by exploiting the parent company's global presence and strong brand name to reinforce the new technology standard and also by proceeding rapidly to second and third generation devices. Unsurprisingly, the firm remains very sensitive to appropriability issues.

Despite having many capable electronics engineers, there were obvious perceived gaps in LectroniCo's initial expertise to execute this project. The joint venture seemed to

address the design and manufacture of low-cost, high-volume electromechanical assemblies. Thus, it seemed a low-risk approach to filling the capability gaps, enabling a pre-emptive first-mover strategy. Gaining new know-how was evidently on LectroniCo's internal strategic agenda, and although the original partnership was less rewarding than expected, the project has both extended and deepened LectroniCo's capabilities. For this reason, corporate headquarters would appear right to encourage such entrepreneurial initiatives. However, structural barriers to the diffusion of know-how across the parent firm persist, as in the other two firms.

Discussion

We have used the model to explore how decision-makers in three firms appear to have framed and interpreted strategic technological issues in relation to the innovations we have described. We contend that processes make better sense if we acknowledge the influence of multiple perceptual frames as posited in our model and accept that decision-makers use these frames implicitly. So their attention is directed to a variety of issues perceived through and made salient by the sensitizing effect of one or more frames. Moreover, as the model suggests, judgements about the perceived suitability of an innovation for the firm are expressible not only in terms of market receptiveness, technological feasibility, etc., but also in relation to taken-for-granted assumptions about stakeholder priorities, organizational ethos and identity—the frame we have called 'suitability-for-us'.

There are some further general implications and questions which follow from the model and its application to these accounts. Attention to issues and frame selection inevitably shifts over an innovation episode. But what can be argued and discerned about these fluctuations and the patterns by which frames are evoked? Do some frames dominate an episode or are frames evoked in a common pattern, to be given sequential or parallel attention? Differing vantage points within the firm may evoke different frames. What are the consequences if these actors fail to see eye to eye? Is attention to the frame of capability development sufficient to stimulate effective corporate capability development and diffusion? It is these questions to which we now turn.

Fluctuating Issue Salience and Competing Meanings

The three cases suggest that although the construction and interpretation of an issue may be multi-faceted, dominant perceptions emerged and then shifted over time. While external events and attitudes also affected issue salience and interpretation during each innovation episode, decision-makers constructed a variety of specific issues of local concern. Issues of differing perceived significance jockeyed for attention as their relative salience changed over time. Thus the prevailing patterns of issues that constituted the strategic agendas were fluid, yet particular, both to the firms and to the innovation episodes.

Once identified, issues generally remained on the agenda while unresolved ambiguities persisted. For example, decision-makers in MotorCo could not anticipate whether potential users would see the primary benefit of the innovation as lower fuel consumption or less noxious exhaust emissions. Uncertainty persisted until, as time passes, fuel costs stabilized and then declined in real terms. Prevailing opinions hardened in favour of the emissions reduction priority. It then became possible to focus technological choices accordingly.

Occasionally an issue may have been sidelined because decision-makers saw it as too

imponderable or irrelevant to devote energy to resolving. Quasi-resolution may have been sought via an early, perhaps arbitrary, decision. This could have been particularly dangerous if, in consequence, new information was ignored. An extreme example is provided by RCA when it developed SelectaVision as a video disc player because top managers decided that consumers were indifferent to the concept of video recording.[54] So they largely ignored tape-based video cassette recorder (VCR) developments in Japan, in the US and even in RCA itself, until Sony and JVC made the VCR a commercial reality.

Less extreme instances arose in PropCo, where, although market receptiveness and appropriability were recognized as concerns, they appeared to receive comparatively little attention initially, presumably since to focus on these issues was thought likely to divert attention away from the technological task and perhaps even to challenge the viability of the project. In LectroniCo, concerns over technical feasibility were diminished for a time by the decision to collaborate. As the project evolved, these issues resurfaced and attracted greater attention in the light of new information. Quite commonly, problematic issues seem to have been considered resolved, only to re-emerge later, as happened in MotorCo over technical realizability, and in LectroniCo over the problem of appropriation.

Decision-makers can perceive complex linkages among issues and ways of framing them. This complicates the assessment and resolution of an issue and further contributes to uncertainty. For example, if the first mover anticipated that the aviation market would not receive a composite propeller enthusiastically, decision-makers could perceive the appropriation of limited consequential returns as the main concern. Conversely, if they concluded that the innovation would also be unattractive to potential competitors, this would reduce their concern over appropriability. This dilemma faced PropCo's decision-makers and their judgements about it appear to have changed over time.

Dominant Frames: Parallel and/or Sequential Attention to Issues?

We might expect 'technically rational' decision-makers to interpret issues by evoking multiple frames in parallel. This approach is consistent with a systematic, integrative evaluation of all possible concerns, so as to minimize the risk of ignoring anything significant. However, with a 'logical incremental' approach,[55] we might predict issues to be interpreted in a sequence of dominant frames, overlapping and changing over time. The first dominant frame might be 'suitability-for-us', supplanted by other frames in a sequence determined by the characteristics of the innovation and the organizational and environmental circumstances. In the multi-business corporation the innovation might conclude with a concern to extend new capabilities across divisions. Sequential framing is consistent with fluctuating issue salience and attention. Alternatively, a different process might prompt a reactive or quasi-random approach to framing, and the predicted pattern would be idiosyncratic and non-generalizable. The logical incremental model comes closest as a description and explanation of the process in our three cases. Issue attention and resolution appear to have been both frame and time dependent. Although multiple frames may have been influential in each firm at any given time, it seems that one frame was typically quite dominant, often for long periods.

Attending sequentially to issues is a somewhat reactive, although not necessarily flawed process, since it may reflect informed technical and other judgements about fast changing circumstances. What is less clear is whether the issues that received attention when they did were the result of political power plays among influential decision-makers having differing vantage points, or the anticipation of (or reaction to) an unexpected difficulty or perceived crisis,[56] or the result of cognitive constraints acting on key

individuals or groups.[37] We cannot answer this question here. Under conditions of chronic technological and market ambiguity, progress is understandable partly in terms of cognitive simplification: decision-makers adopt a single, interpretive frame that for the time being seems appropriate to resolve the issue. For example, after decision-makers in PropCo thought that they had resolved the immediate concerns over capability development, they seemed to recognize market receptiveness as key to the success of the innovation. So the firm attempted to create awareness and acceptance among key decision-makers in the engine and airframe community that the composite propeller was a legitimate technology.

Decision-makers in MotorCo initially recognized technological realizability as a crucial way of looking at the innovation, which they linked to internal capability development. For a long time, market receptiveness was imponderable and framing the innovation in this way had little influence. Until issues framed in terms of realizability and capability development had been addressed to their satisfaction, decision-makers accorded comparatively low significance to issues framed in terms of appropriability, other than to maintain secrecy via in-house development. When development reached the application stage, MotorCo tried to enhance market receptiveness by working with preferred engine builders and began to address appropriability concerns by making patent applications.

In LectroniCo the dominant frame appears to have been capability development, to exploit a taken-for-granted market opportunity. The perceived capability gap was thought to justify external collaboration. Later, appropriability became the dominant frame, explaining the drive for a dominant market position by early moving and standard setting.

In all three firms, we propose that some perceptual frames appear to have influenced thinking much more than others. These highlighted some kinds of issues in preference to others, and ensured that attention was focused on some aspects of issues rather than others. This may also have applied at the corporate level and among the technology champions. Evidently, the dominant frames would not necessarily have been the same at these different vantage points.

Looked at through differing frames, the 'same' issue can take on different significance. The same is true of acknowledged frame changes. An issue over which there was convergence suddenly stimulates divergent interpretations. LectroniCo's collaboration with another firm was initially viewed as enhancing technical realizability. When some individuals revisited the issue through the frame of appropriability they anticipated that the established partner would become a significant competitor. For a time, this was a minority view, although it gained ground as the project progressed.

Multiple Frames Enrich Multiple Vantage Points

An actor's vantage point may influence which frame(s) are implicitly adopted and therefore how an issue is framed. We can surmise several such vantage points: the corporate decision-maker; the business unit decision-maker; the technology champion; the competitor; the industry observer. Interpretations that appear to make sense from one perspective may seem counter-intuitive from another. For example, PropCo's decision-makers framed concerns over composites technology in terms of its prospective market reception, no doubt influenced by the conservatism of existing customers. In contrast, corporate decision-makers framed the innovation initially and sceptically as unsuitable for an engineering group. Specifically, they seem to have perceived it as technically inappropriate for a company with a tradition in precision mechanical

engineering, and also commercially inappropriate given the limited perceived importance to the parent company of the propeller market. Presumably for the technology champions, these concerns were seen as tactical commercial matters. The dispassionate external observer could have argued that the composite propeller was not worth pursuing, given the risks arising from market uncertainties, the firm's current knowledge base and corporate priorities. Even though one might have anticipated benefits to corporate capabilities by developing composites, one might have proposed working towards this aim where the payoff appeared more attractive, e.g. fuselage components.

Decision-makers in MotorCo saw their innovation as pushing back the technological frontiers. So the realizability frame influenced them throughout the episode At corporate level, concerns would have focused more on appropriability, because failure to exploit the innovation would have had major adverse consequences not only for MotorCo, but also for the parent company. Conversely, both corporate and business unit managers supported the innovation, in terms of its perceived suitability for the firm.

In LectroniCo the appropriability frame seems to have become increasingly dominant as decision-makers' experience sensitized them to the fast-moving industry competition. In contrast, the optimistic 'can-do' culture conditioned them to regard technical difficulties merely as puzzles to be solved, a task requiring ingenuity and attention from appropriately skilled people, not fundamental issues of feasibility. At corporate level we suspect that appropriability was initially not seen as a key issue, given the anticipated combination of early moving, a strong brand and collaboration with a strong partner. As in MotorCo, corporate and business unit levels appear to have agreed over the suitability of the innovation.

However, when decision-makers share the same vantage point, they may still evoke different frames, according issues different meanings and priorities in consequence. For example, some in PropCo interpreted concerns about the optimum profile of a composite propeller blade as an issue of technical realizability, while others framed it in terms of market receptiveness (would potential users reject an esoteric shape?). Looking at an issue through different frames makes it harder for individuals to agree on the significance of an issue, let alone how best to address its implications. Such 'interpretive flexibility'[58] may well be a central part of the process shaping the consequent evolutionary path of the innovation within the firm.

Attitudes to Capability Development

The three cases confirm the complementary evolution of technologies and capabilities. An application-specific technology generates returns that support the continuing development and extension of supporting capabilities. Evolving capabilities germinate the seeds of technological renewal, a process that underpins the long-term strategic position of the firm.

The three firms each perceived the need for new capabilities to sustain competitive advantage in their respective sectors. They have been relatively successful in developing them. Whether individuals perceived a subsequent opportunity to extend these capabilities in new directions is open to question. MotorCo has begun to extend its new capabilities from truck applications on which it was originally focused. LectroniCo has begun marketing its storage devices worldwide and has accelerated the development of more advanced generations of the device. The firms do not seem to have been particularly motivated to inject new capabilities into other divisions of the parent company. For example, in LectroniCo the outward looking prospector ethos is part of a competitive inter-divisional culture that inhibits widespread diffusion of new capabilities.

Decision-makers in MotorCo and PropCo perceived forthcoming changes as being highly significant in their implications for manufacturing capabilities. They developed green field sites on which to implement the new technologies and integrate the supporting capabilities. However, the long lead time associated with implementing each innovation means that neither firm can disband facilities based on obsolescent technologies for many years to come. So new and old capabilities must necessarily coexist in each firm, giving rise to a variety of potential organizational difficulties.

Conclusions

Strategic innovation in each firm has been a complex and at times uncertain process. The firms participate in complex networks of suppliers, customers and competitors. Their innovations constitute bundles of advanced technologies that converge on particular, systematic applications, not isolated and singular adaptations. The agendas of innovation have melded a variety of issues dynamically and—to the external observer—unpredictably over time.

From our vantage point as external observers, we have applied an interpretive model to try to make sense of these innovation episodes. All the posited perceptual frames in the model, including the meta-frame that we have called 'suitability-for-us', have played a useful part in our exposition. None the less, they need confirmation and development. To the extent that each has tacitly influenced the thinking of decision-makers in the firms, it has the potential to shape the strategic agenda of innovation.

The currency and utility of each perceptual frame has differed, from one firm to another and in the same firm over time. The examples suggest evolving firm-specific patterns of issue framing and issue salience over time. Frames in use result from the configuration of power, status and approach of senior technical and other stakeholders within and around the firm. Although an external observer (including a competitor) has comparatively little knowledge of the internal workings of the firm, the model can be a useful aid to interpret information about the firm from a multitude of potential sources.

Working through a strategic technological agenda involves elements of choice and chance. Because innovators perceive that much lies beyond their control, we suggest that they will generally be influenced by some perceptual frames more than others. Guided implicitly by these frames, they will attend to areas they perceive as significant and problematic, during the lifetime of innovation. Other issues may be sidelined through ignorance or cognitive blind spots. Our cases suggest a 'logical-incremental' rather than comprehensive 'technical-rational' attention to strategic technological issues, with more than one frame informing decisions at any time.

Multiple vantage points lead decision-makers to frame issues differently. Individuals and groups have the capacity to frame the 'same' issue differently over time. If these various interpretations were more widely shared, it is possible that innovation processes would benefit. Awareness of the model would give decision-makers a more comprehensive account of the subjective constructions of issues. They might then confront decisions and priorities that appear counter-intuitive from their own vantage point but make good sense from others.

Ideally, decision-makers will benefit from interpreting emerging issues through a variety of frames. The meta-frame of 'suitability-for-us' highlights and integrates many crucial aspects of technological innovation. Frame selection, however, is generally intuitive, influenced by decision-makers' experience, the way they understand the circumstances of the innovation and how they anticipate events unfolding. Still, we propose that 'vigilant

problem—solving'[59] involving periodic challenges to major assumptions,[60] provides a blend of formal analysis appropriate to an innovation episode.

In hindsight, any external commentator can criticize the strategic innovation agendas others have pursued, but that was not our purpose. The innovations of PropCo and MotorCo strengthen their respective positions in application areas where these defender firms already have good records. The innovations enhance their respective capabilities in depth. By contrast, in the prospector-oriented LectroniCo, the innovation extends its scope into complementary applications and broadens as well as deepens its capability base.

Arguably, none of the three firms has accorded sufficient attention to the available opportunities to deploy their new capabilities more widely. The diffusion of capabilities among the business units of large corporations remains problematic, given a tendency for differing and seemingly parochial divisional cultures and managerial styles to create relatively opaque organizational boundaries.

This points to a fundamental shortcoming in the strategic management of technological innovation. Although capabilities may diffuse informally, much still has to be learned about facilitating the process.[61] Evolving and exploiting capabilities systematically across the multi-divisional firm is too important a task to be left to idiosyncratic framing or chance.

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