Less is More: How shipping fewer, simpler products and doing less work can drive growth and profitability

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Executive Summary

Recently, observations of seeming market anomalies, evidence from research and work with companies on managerial challenges in R&D motivated us to re-examine the supposed link between spending a lot of money on R&D and business success. Further impetus came from the search for a solid explanation for Apple's success despite very low spending on R&D, a sparse product portfolio and products with few features. The research focused on high-tech domains such as personal computers, personal media players, automobiles and mobile phones, where several companies offer portfolios of several products differentiated by performance and features, each of which must be periodically renewed.

We adopted a three-pronged approach, combining a review of the relevant research and literature, empirical data from case studies and a program of discussions with managers in businesses concerned with these issues. In doing so, we were inspired by the words of Ernest Rutherford, the Kiwi Physicist: *"We didn't have any money, so we had to think"*.

We concluded that conventional wisdom is wrong; more spending on R&D does not equate to success. Instead, 'less is more'. Because customers are not rational, most businesses should be offering fewer products in their product portfolio, typically providing customers with just four to six choices, albeit well-aligned along a few key attributes; each of these products should have fewer features, and less information should be provided about them. Spending on in-house R&D activities should typically be greatly reduced and focused only on three areas: architecture; absorptive capacity; and 'bottleneck' activities, those that have greatest impact on what really matters to customers. Moreover, because R&D and innovation is inherently uncertain, there should be fewer projects in the product pipeline, with R&D operating at lower utilization.

Apple's high R&D productivity is not an anomaly; whether intended or unintentional its approach incorporates all of these practices. Its success provides strong confirmation for this new theory of how to get the most out of spending on R&D: shipping fewer, simpler products and doing less work can drive growth and profitability.

1 Introduction

Over the last couple of years, a combination of observations of some anomalous outcomes in the marketplace and mounting evidence from academic research, together with work with a couple of large global companies on some specific managerial challenges motivated us to subject the conventional wisdom of a strong causal link between high levels of spending on R&D and commercial success to critical examination.

Further impetus was provided by the search for a robust theory[2] that explained Apple's success despite relatively low levels of spending on R&D and a product portfolio that offers fewer choices and comprises products with fewer features than its competition:

- Apple spends only ~3% of its revenues on R&D, a much lower proportion than any of its competitors
- its product portfolio has many fewer products, whether in personal computers, portable media players or mobile phones, and its products typically have many fewer features than its competitors
- it has nevertheless a strong position in personal computers, has grown to domination of the personal media player market with the iPod and to a leadership position in mobile phones with the iPhone
- its stock price has appreciated approximately ten-fold over the last decade, and it appears to be sustaining its market position and profitability

The three specific managerial challenges all related to how to maximize the return on investment in R&D:

- how do we maximize the value of our product portfolio and pipeline?
- what should we be investing R&D spending in?
- how do we get good R&D project performance, in particular time-to-market?

We took as part of our inspiration the words of Ernest Rutherford, the Nobel Prize-winning Physicist from New Zealand: *"We didn't have any money, so we had to think"*. Or, to paraphrase in this case: 'if we didn't have any money, how would we think?

If we are thinking of R&D as a system, these questions can be re-characterized along the following lines:

- what should be the *outputs* of the system?

[2] Christensen on theory

- what should be the *resources* of the system?
- what should be the *utilization* of resources to outputs, people allocated to projects?

The research and analysis focused on domains that meet specific criteria:

- each company offers a portfolio[3] of several differentiated products targeted at each significant market segment at any one time
- each product can be differentiated along a few attributes, and its functionality is determined by its product features
- customers can choose amongst these and competing products
- these products have a finite lifetime in the marketplace and need to be renewed periodically, as innovation renders them obsolete, so that there is a pipeline of new products being developed

The domain that meet these criteria include many high-tech products:

- personal media players
- mobile phones
- automobiles
- personal computers
- consumer electronics

Although these were the primary focus, we believe that the insights may have broader applicability. For example, as part of this work, the discussions with managers have frequently turned to the services associated with some of these devices, such as mobile services and broadband services. The characteristics here are a little different as services typically persist in the marketplace and continue to be available and subscribed to by customers unless explicitly time-bounded and temporary, or explicitly withdrawn by the service provider. Nevertheless, many of the same considerations about customer choice, the scope of activities and the linkage between resources and projects that are explored below apply to services as well.

This is a difficult problem to develop a robust and well-founded theory for, because of the inherent complexity of the differences amongst businesses and the high degree of path dependence involved in many of the outcomes. In many cases it is difficult or impossible to

[3] We use the term *portfolio* to refer to the offers currently made available in the marketplace, and the term *pipeline* to refer to the stream of projects underway at any one time that will result in the evolving product portfolio over time

construct experiments or control well for other factors that may influence the outcome, so we found ourselves forced to take an eclectic and expansive approach.

Following discussions with a number of people focused on these issues, across both academia and industry, a synthetic approach emerged that combined three complementary thrusts:

- first, a systematic and thorough review of the relevant research literature, starting from the well-cited and insightful papers in the field, but also involving a broader search in many cases motivated and guided by colleagues in these related fields[4]
- second, consideration of primary and secondary empirical data from public case studies such as Apple, and in particular private case studies from work with the businesses that provided the original motivation and support
- third, a program of interviews and discussions that combined open inquiry with explicit testing of the working hypotheses developed from the research and case studies, conducted with several senior managers worldwide with relevant responsibilities for these R&D activities, extending in some cases to day-long workshops on specific issues

All of these thrusts are continuing, and in particular we are keen to continue the dialogue with managers involved in these issues.

Although we recognize that there is the potential for a great deal more work, and in particular for more rigorous quantitative analysis, we thought that the initial conclusions were interesting enough to warrant sharing more widely. We hope that this will stimulate vigorous discussion and perhaps even motivate further research.

2 Conventional wisdom

Conventional wisdom has long suggested that success in high-tech products and services depends on and is driven by spending on R&D, that there is a virtuous circle:

- devote a significant percentage of your revenues to R&D
- invest in broad and deep resources in-house, within the business
- try to maximize the utilization of these abundant resources
- use these resources to offer your customers a choice of many diverse products, so that they're likely to find products that best meet their individual needs

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[4] We are indebted in particular to Rebecca Henderson and Duncan Simester of MIT's Sloan School of Management for their support and guidance in this regard

- endow these products with many rich features, so that they are attractive and command are likely to command both market share and price
- as a result, happy customers will choose your products, pay a lot of money for them, and you can re-invest the resulting profits in R&D.

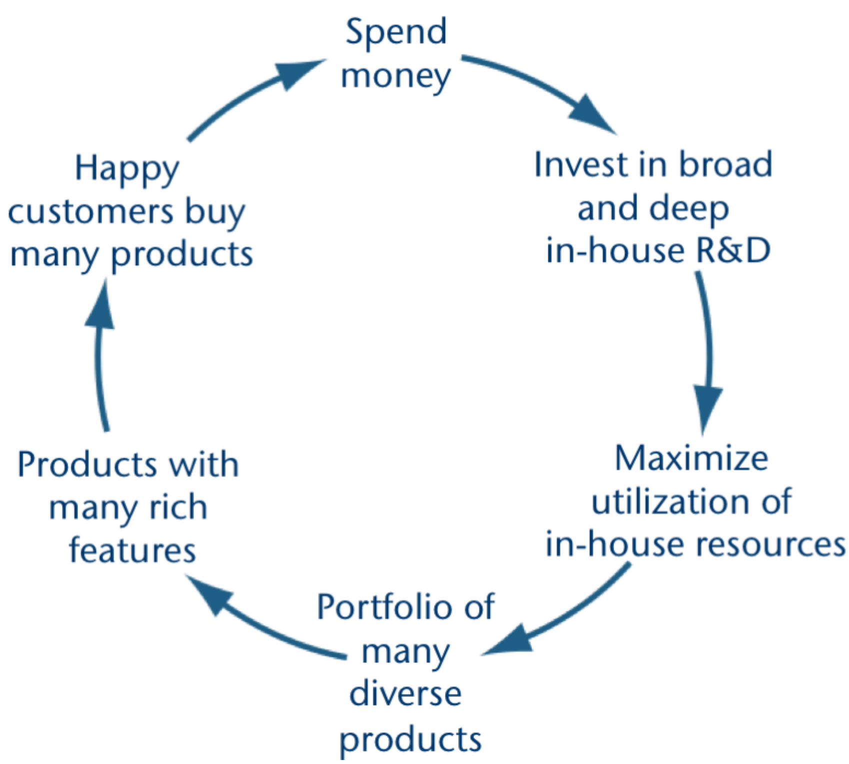

Figure 1: Conventional wisdom of causal linkage and virtuous circle between high spending on R&D and business success

Over the last few years, we had, however, made several interesting empirical observations that to provided counter-factual evidence that challenged this view of the world, motivating this exploration:

- large, rich companies spending a lot of money on R&D without much to show for it, while at the same time small, weak companies being successful, despite much lower levels of spending on R&D
- small, resource-strapped companies and organizations being highly productive, while much larger, richer competitors don't get the same bang for their (very many) bucks

- businesses achieving commercial success with very sparse product portfolios, just a few products each of which have fewer features, in sharp contrast to competitors struggling to maintain market share and profitability despite rich, broad and diverse portfolios of complex, feature-rich products
- although it has long been argued that more choice is a good thing, in many cases customers and users of high-tech products in particular seemingly overwhelmed by product choice and overcome by product complexity
- some organizations that have a more laid-back approach to projects, seemingly self-indulgent, outperforming competitor companies in which people are working much harder, which are operating at higher levels of utilization

3 The link between R&D spending and success

There is already both statistical evidence and anecdotal evidence that the link between R&D spending and commercial success is weak at best:

- in 2005 Booz Allen Hamilton conducted a study of 1000 companies, and found that there was no identifiable causal link between spending a lot of money on R&D and any measure of success[5]:
  - *"Money doesn't buy results. There is no relationship between R&D spending and the primary measures of economic or corporate success, such as growth, enterprise profitability, and shareholder return."*
  - while there is a connection between high spend on R&D by the top decile and gross margin and gross profit growth, this does not translate into operating profit growth or returns to investors
  - at the other end of the scale, there is an important caveat: *"...spending too little will hurt...Companies in the bottom 10 percent [by R&D to Sales Ratio]...underperform...on gross margins, gross profit and shareholder returns."*

[5] Barry Jarulzelski, Kevin Dehoof and Rakesh Bordia, "Booz Allen Hamilton Global Innovation 1000", May 2005

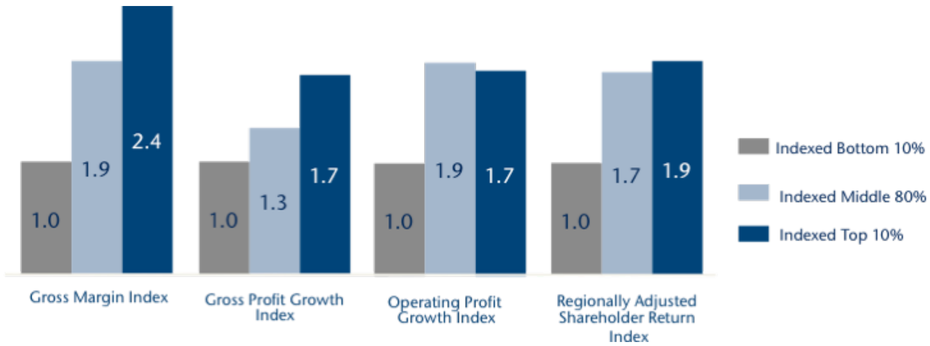

Figure 2: Measures of success for the top and bottom deciles and middle 80% of the Global Innovation 1000, May 2005

- while Microsoft is perceived by many as a leading innovator[6], there was a growing chorus of criticism that despite spending billions on R&D[7], it was not yielding results:
  - *"[Microsoft]...generates $9 billion in cash flow and $8 billion in profits from $37 billion in sales... But when it comes to online search, arguably the hottest technology of the past five years, Microsoft has missed the boat.*
  - *Heck, it hasn't even been near the dock. Say the same for the Web browser (created by Netscape), the streaming media player (by RealNetworks), the game box (Sony), interactive television (TiVo), so-called smart phones (Nokia, Ericsson, and Motorola[8]), and digital-music distribution (Napster and now Apple).*
  - *... Microsoft has watched from the sidelines as comparatively smaller, poorer companies brought to market virtually every important technical innovation of the past decade."[9]*
  - *"Microsoft would be better off cutting its R&D in half, saving shareholders' money and concentrating on how to have the technology it has mustered up for us to date fit into the world a whole lot better...*
  - *Microsoft's successes in innovation—Xbox 360?—do not move the needle on Microsoft's revenues or earnings more than an iota, but their numerous failures move the needle downward a ton. The company spent over $6 billion on R&D in the last twelve months, but does anyone know what they got for all that dough? I don't.*

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[6] In BusinessWeek's ranking of the 50 most innovative companies, while Apple is Number 1, Microsoft is still Number 4 (http://bwnt.businessweek.com/interactive_reports/innovative_50_2009/)
[7] Microsoft spending on R&D is now more than US$8 billion, and although it has not recently increased as fast as sales have grown, it is still ~13% of sales
[8] And now Apple, who have staked out a leadership position with the iPhone in just a couple of years
[9] What Money Can't Buy, *Fast Company*, December 2004

  - *...Xerox PARC had a mere 60 technologists creating a slew of the biggest breakthroughs we have seen."*[10]

- in sharp contrast, Apple's commercial success was being accomplished with a much lower percentage of its revenues being spent on R&D, which made this spending in absolute terms a small fraction of Microsoft's
  - *Apple is widely viewed as one of, if not the, most innovative company in the world. But innovation at Apple comes cheap compared to other tech companies: Of the industry's 50 most prolific investors in research and development, Apple spends the least as a percentage of revenue.*
  - *Apple spent $844 million on R&D in the calendar year 2007, just 3.2%*[11] *of its revenue over that time. In contrast, Microsoft, which spent the most on R&D of any tech company, spent $7.4 billion, or 12.8% of its revenue...*
  - *In all, the top 50 R&D spenders plowed more than $50 billion into new products and services in 2007, spending an average of 9.7% of revenue on R&D"*[12]

- Apple's product portfolio also comprised many fewer products than its competitors, versus Sony for example, selected as its closest analog amongst other major vendors of personal computers:
  - in May 2008 Apple's complete product portfolio comprised only twelve device product families, and it had just three laptop families with a total of five products, and three desktop families, with five products

[10] The Innovation Mirage At Microsoft and Sony, Pip Coburn, 25 October 2005 (http://www.alwayson-network.com/comments.php?id=12554_0_1_0_c)
[11] This was down from 5.9% in 2004, and the falling ratio was enough in 2006 to prompt analyst concern, exemplified by Troy Wolverton's article entitled "Apple: Frugal to a Fault?" (http://www.thestreet.com/tech/gamesandgadgets/10273658.html)
[12] Innovation Comes Cheap at Apple. 23 April 2008 (http://blogs.wsj.com/digits/2008/04/23/innovation-comes-cheap-at-apple/)

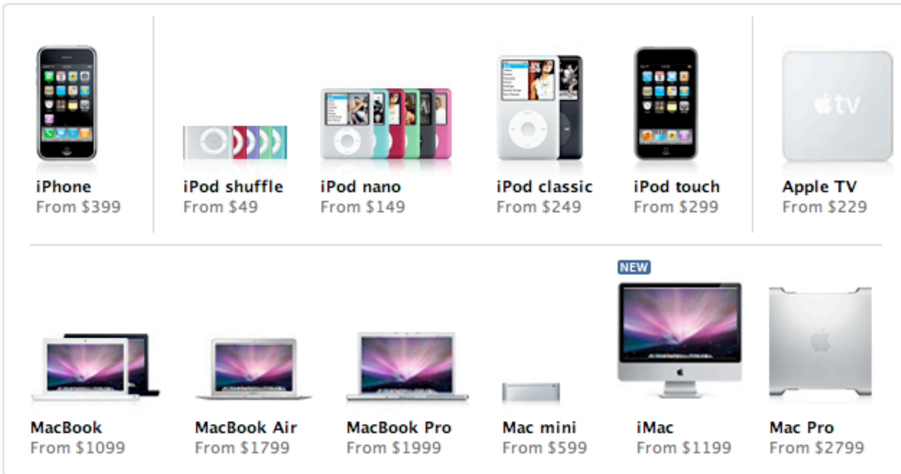

Figure 3: Apple's full product portfolio, May 2008[13]

– it nevertheless had ~14% overall share of the personal computer market, and ~66% of the market for personal computers costing more than US$1,000

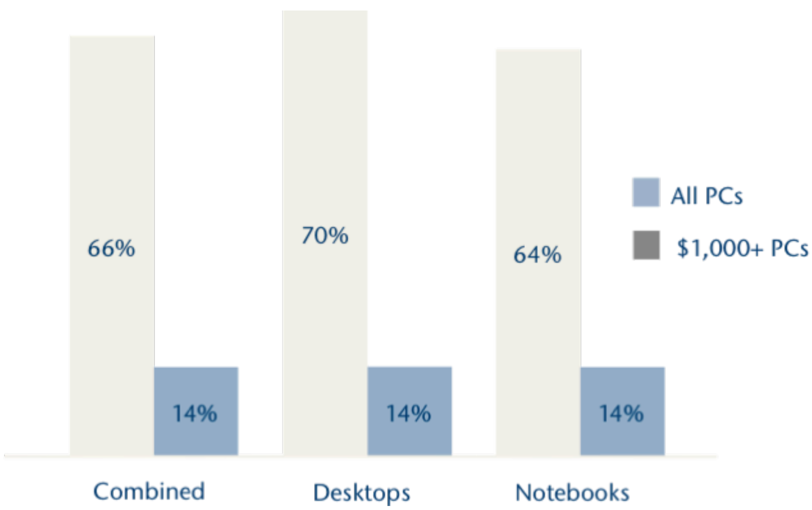

Figure 4: Apple's share of the personal computer market, 2008

– at the same time Sony offered customers a choice of twice as many laptop families, six in all, with at least twenty-six possible choices, seven (7) principal attributes for comparison amongst them and nine (9) possible groups of attributes for comparison

[13] http://www.apple.com accessed on 25 May 2008

Figure 5: Sony's personal computer portfolio[14]

- in automobiles, there was a particularly sharp contrast between the logical and well-organized portfolios of leading German automobile manufacturers such as Mercedes-Benz, and the confusion of competitors such as General Motors
  - Mercedes Benz's entire automobile profile can be arrayed on a single page, comprising six (6) families with up to four (4) vehicle types within each family and a total of 43 possible models
  - the same web page enabled customers to narrow the selection along just four key attributes: price; power; passengers; and fuel efficiency

[14] http://www.sonystyle.com accessed on 25 May 2008

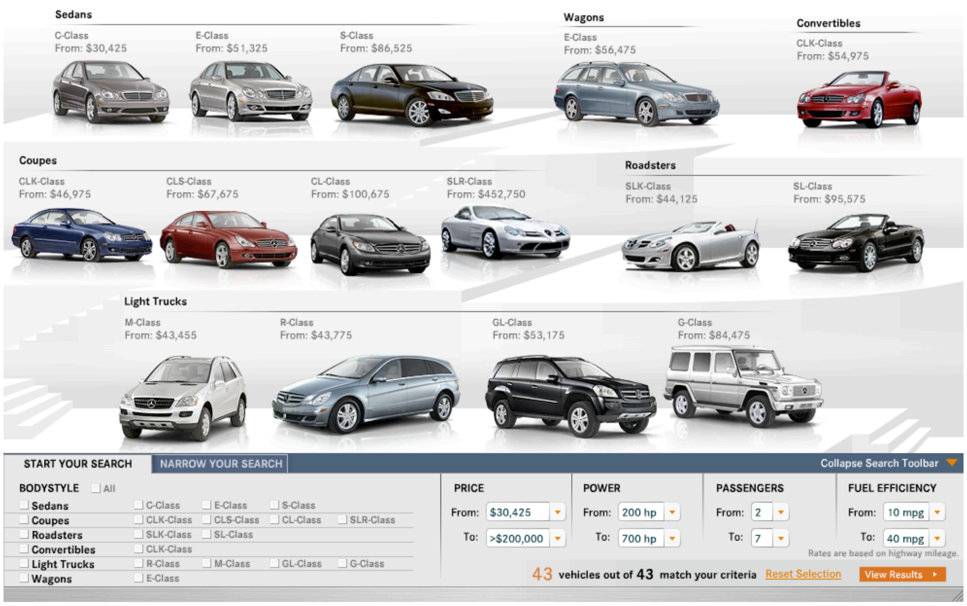

Figure 6: Mercedes-Benz passenger vehicle portfolio, May 2008[15]

   - in contrast, at the time General Motors portfolio comprised seven (7) major families, some of them with more than twenty (20) possible choices and many different brands, for a total of nearly 100 different vehicles

- Apple's success was also being achieved with products such as the iPod that were, in some important cases, lacking in features relative to their competition:
   - as Apple's Jonathan Ive, Vice President of Industrial Design put it: *"It was about being very focused and not trying to do too much with the device -- which would have been its complication and, therefore, its demise. The enabling features aren't obvious and evident, because* ***the key was getting rid of stuff****."*[16] (our emphasis added)
   - *"Bruce Claxton, who [was then] the current president of the Industrial Designers Society of America and a senior designer at Motorola, calls the [iPod] emblematic of a shift toward products that are 'an antidote to the hyper lifestyle', which might be symbolized by hand-held devices that bristle with buttons and controls that seem to promise a million functions if you only had time to figure them all out."*[17]

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[15] http://www.mbusa.com, accessed on 25 May 2008
[16] Straight Dope on the iPod's Birth, *Wired*, 17 October 2006
[17] Rob Walker, "The Guts of a New Machine", *New York Times*, 30 November 2003

– despite only five products, a couple of variants and at the time six (6) different colors for the low end device, the iPod dominated the market for personal media palyers

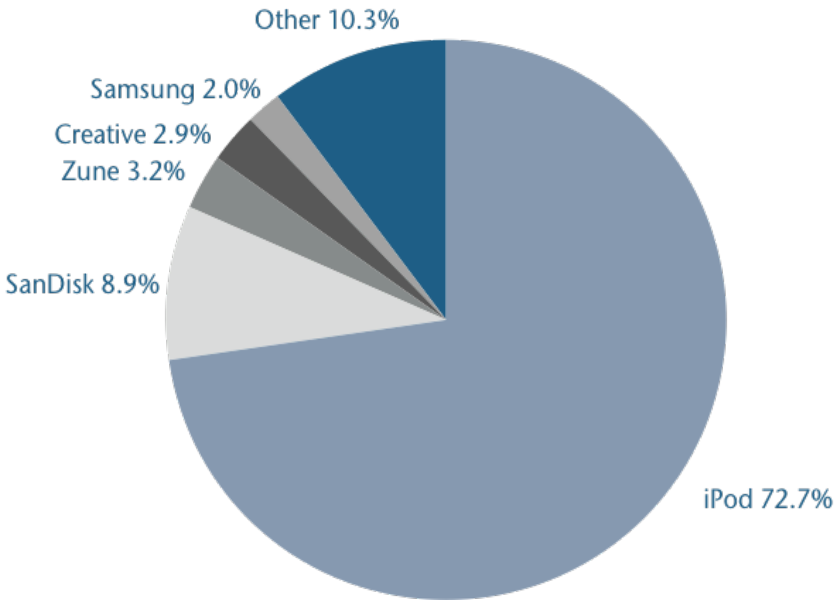

Figure 7: Apple's share of the market for personal media players, 2007

4 Portfolio management

We began by focusing on portfolio management, or how managers think about the choices amongst products for their potential customers.

From a review of the literature relating to portfolio management, it became clear that the primary focus was on the allocation of available resources to individual projects:

- "How should the business most effectively invest its research and development (R&D) and new product resources? That's what portfolio management is all about: ***resource allocation*** to achieve the business's new product and technology objectives.":
  - *a dynamic decision process whereby a business's list of active new product (and R&D) projects is constantly updated and revised*
  - *new projects are evaluated, selected and prioritized*
  - *existing projects may be accelerated, killed or deprioritized*

– *resources are allocated and reallocated to active projects*[18, 19] (our emphasis added)

While the literature on product portfolio management and the most cited publications do recognize the need to consider the shape of the resulting product portfolio, it is seen as secondary; it is characterized as portfolio management: *“**includes**: making go/kill decisions on **individual** projects on an ongoing basis, periodic reviews of the total portfolio of all **projects**, and developing a new product strategy for the business”* (our emphasis added).

Although managers have a toolbox comprising several different approaches, the most widely used are financial metrics. These assess the economic payoff of individual projects, and, perhaps with some strategic weighting, allocate resources to the projects that offer the highest returns, using a metric such as risk-adjusted net present value relative to resources(rNPV). Next come so-called business strategy methods, used by about two-thirds of businesses and the dominant approach to portfolio management in about one quarter of all businesses[20]. These approaches typically consider the fit between a project and the overall long-term strategy of the business, trying to match the allocation of R&D resources to the stated strategic goals.

[18] Robert Cooper, Scott Edgett and Elko Kleinschmidt, Portfolio Management in New Product Development - Lessons from the Leaders I, II - *Research & Technology Management, Volume 40, Issue 5 pages 16-28,* September/October 1999 and *Volume 40, Issue 6 pages 43-60* November/December 1997 – hereafter PMiNPD - LftL

[19] Most of the discussion that follows here draws from the two works cited, they in turn provide a set of related references reflecting a consistent perspective

[20] PMiNPD - LftL

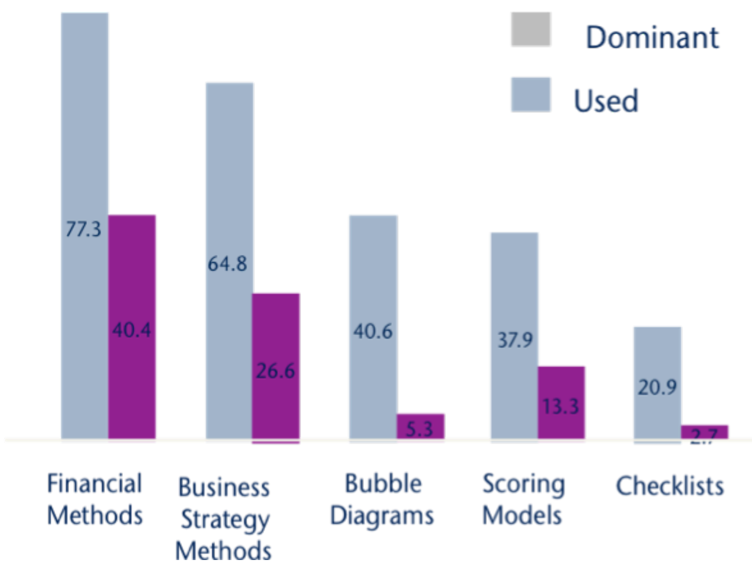

Figure 8: Methods used for product portfolio management

Most managers are, however, not happy with the effectiveness of their portfolio management. Although most would more or less agree that the portfolio contains some high value projects, and is aligned with business objectives, unsurprising given the dominant methods used, there is clearly room for significant improvement[21]:

- even amongst the 'best' businesses, those who self-report as happiest with their portfolio management, there is only lukewarm agreement that projects are done on time, that the portfolio is well-balanced or that it has the right number of projects
- amongst all businesses, managers are between neutral and in disagreement that projects are timely, the portfolio is balanced and in particular that is has the right number of projects

[21] PMiNPD - LftL

Figure 9: Managers' perspectives on the effectiveness of product portfolio management

There are two beliefs implicit in this way of thinking about portfolio management, which may be influencing managerial behavior and thus linked to these poor outcomes:

- the primary goal is to optimize the allocation of available resources, rather than to optimize choices for potential customers
- individual projects in the portfolio can be evaluated in isolation, as independent rather than interdependent, reflected for example in dominance of financial measures

This working hypothesis was tested in discussions with a number of managers in industry responsible for portfolio management; their responses provided anecdotal but widely consistent support for this belief.

Given, however, these managerial concerns, and as noted above the doubts cast on the causal link between the level of R&D resources or spending and commercial success, we refocused our thinking about portfolio management on how customers make choices:

- how large and diverse should the product portfolio be, and how should it be balanced amongst these products?
- alternatively, how *few* products should we offer and what should the relationship be amongst them, or how *few* choices do customers really need?

Clearly, the answer to the question how few choices do customers need lies in understanding how customers make choices amongst competing offers.

Conventional wisdom assumes that customers are rational and value-maximizing. They will invest the time, effort and emotion needed to determine their best option, the one that offers them the highest value, taking into account the performance of the product and the costs involved, both in initial purchase and subsequent use.

If this conventional wisdom is well-founded, then the managerial implications are clear:

- a larger number of products, more possible choices is better, so that customers are more likely to find a close match for their needs
- a wider range of products, more diversity is better, again so that individual preferences can be satisfied
- providing more information is better, because this enables customers to make better-informed decisions, increasing their likelihood of happiness
- a product with more features is better, because this delivers more value to customers, which will make them happier.

Unfortunately, it appears that in many cases, customers behave in ways that do not fit this model of rationality. Yes, customers want some choice; it is well-established that giving customers no choices makes them unhappy[22]. It appears, however, from the program of interviews with managers, that many already had strong albeit unsystematic evidence that too many products offered to customers can make them unhappy; too many choices can be too much of a good thing.

From a review of the research literature, we identified three principal reasons why customers may prefer to have fewer choices:

- cognitive overload – the level of effort involved in choosing
- selection provides information – fewer choices may result in a better decision, a higher quality outcome
- loss aversion – having fewer choices may reduce the downside involved

First, customers may prefer fewer choices because of the effort involved in trying to make the right choice amongst a large number of alternatives[23]. Research has shown that as customers are confronted with a wider range of choices, they develop coping strategies.

[22] See for example S Taylor and J Brown, "Illusion and well-being: a social psychological perspective on mental health", *Psychological Bulletin, Volume 103, pages 193-210* and E Langer, "The Illusion of Control", *Journal of Personality and Social Psychology, Volume 32, pages 311 -328*
[23] Dmitri Kuksov and J Miguel Villas-Boas, "When More Alternatives Lead to Less Choice", *Working Paper*, September 2007

They adopt simple decision-making heuristics, such as quickly and even arbitrarily eliminating some possibilities to reduce the number of choices they have to consider[24]. For example, in research conducted by D Timmermans, the proportion of potential customers that were eliminating some options rose from 21% with three (3) choices to 31% for six (6) choices, and then to 77%, an overwhelming majority of customers, when confronted with nine (9) possible choices.

Note in particular, that this behavior is not linear; there appears to be some sort of threshold effect: doubling the number of choices from 3 to 6 increases the use of elimination strategies by ~50%, but moving from 6 to 9 raises this from fewer than one in three to more than three in four. At nine choices, fewer than one in four customers are still considering all of the available options. Potential customers may also choose to process less information, narrowing their focus to just a few key attributes, so that have less work to do to consider each option[25].

Second, customers may regard having a more limited range of options offered to them as useful, as the selection itself provides information about what is likely to be a good choice; they may believe that weak or inferior products have already been eliminated[26].

For example, in experiments conducted by Maria Salgado at Northwestern University, about one third (32%) of participants chose to consider a random subset of five options from a larger set of twenty-five (25) possible options, but when the size of the total possible choices was expanded to fifty (50), the proportion of participants selecting the randomly chosen subset rose by about half to almost half (48%) of all participants. When informed that the subset was chosen by individuals with relevant skills, implying that the selection itself contained information, there was a significant increase in the proportion of the participants choosing the subset of five choices: about two in three or three in four (70-77%), depending on the number of total possible choices.

Third, and perhaps most importantly, more possible choices means more regret because of the opportunity cost of options foregone, choices not made. People respond much more strongly to losses than to gains, a phenomenon known as 'loss aversion'[27].

[24] D Timmermans, "The impact of task complexity on information use in multi-attribute decision-making", *Journal of Behavioral Decision-Making, Volume 6, pages 95-11*
[2525] J R Hauser and B Wernerfelt, "An evaluation cost model of consideration sets", *Journal of Consumer Research, Volume 16, pages 393-408*
[26] Maria Salgado, "Choosing to Have Less Choice", *Working Paper*, February 2006
[2727] Daniel Kahneman and Amos Tversky, "Choices, Values and Frames", *American Psychologist, Volume 39, pages 341-350*, April 1984

Figure 10: Loss aversion[28]

As a result, as the number of possible choices increase, at some point the increasing unhappiness from the opportunity cost of choices foregone outweighs the benefits of having more choice, a phenomenon that has been explored in particular by Barry Schwartz of Swarthmore College.[29]

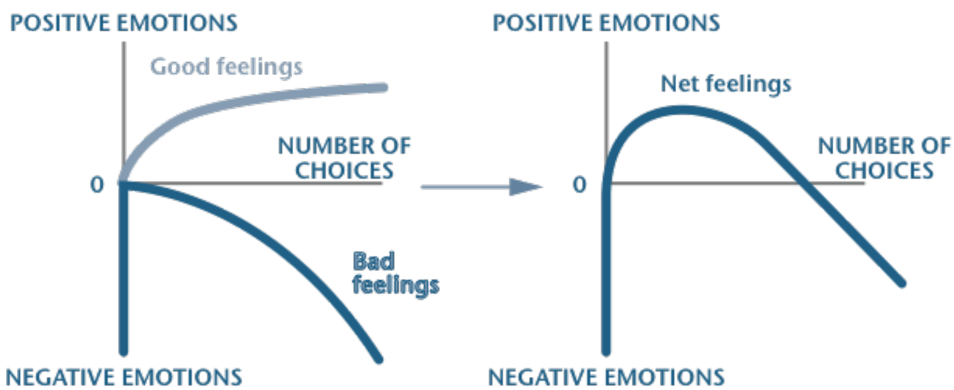

Figure 11: The impact of the number of choices on positive emotions, negative emotions and net feelings[30]

[28] Adapted from Barry Schwartz, “The Tyranny of Choice”, *Scientific American, pages 70-75*, April 2004
[29] Barry Schwartz, “The Tyranny of Choice”, *Scientific American, pages 70-75*, April 2004, and see also Barry Schwartz, “More Isn’t Always Better”, *Harvard Business Review*, June 2006
[30] Adapted from Barry Schwartz, “The Tyranny of Choice”, *Scientific American, pages 70-75*, April 2004

Recent research and experiments has, in fact, shown that customers can be more likely to purchase if they have fewer rather than more choices[31,32]:

- "...although having more choices might appear desirable, it may sometimes have detrimental consequences for human motivation..."
- "...the provision of extensive choices, though initially appealing to choice-makers, may nonetheless undermine choosers' subsequent satisfaction and motivation."

For example, in research conducted by Sheena Iyengar and Mark Lepper, more customers were attracted to a display with 24 options than to one with 6, but customers were much more likely to purchase if they had only encountered 6 options. In another experiment conducted by Peter Boatwright and Joseph Nunes, although people said that they enjoyed choosing from a larger number of options more, they were nevertheless more dissatisfied and regretful afterwards.

Tragically, for some customers at least, this effect is particularly powerful. While many customers, in contrast to conventional wisdom regarding value maximization, are content to purchase once they've found something 'good enough', they satisfice, a significant proportion of customers do seek to maximize[33]. For these so-called 'maximisers', perversely, too much choice turns out to be particularly painful: although the extra effort invested achieves outcomes that are objectively better than for 'satisficers', they are subjectively less happy with their choices.

It's not just the number of products in the portfolio that is important, however. It seems that how products relate to one another is also important. Increasing the size of the assortment can actually be harmful; even if that means you have a larger proportion of the products on offer, if the design of your product line causes more regret.

If you offer potential customers an increasingly diverse array of products, each of which has some unique 'special feature', which the other products in your lineup do <u>not</u> have, the likelihood that customers will choose your product decreases, rather than increases. There is a

[31] Sheena S Iyengar and Mark R Lepper, "When Choice is Demotivating: Can One Desire Too Much of Good Thing?", *Journal of Personality and SocialPschology, Volume 79, Number 6, pages 995-1006,* 2000
[32] Peter Boatwright and Joseph C Nunes, "Reducing Assortment: An Attribute-Based Approach", Journal of Marketing, Volume 65, pages 50-63
[33] Barry Schwartz, Andrew Ward, Sonja Lyubomirsky, John Monterosso, Katherine White and Darrin R Lehman, "Maximizing Versus Satisficing: Happiness is a Matter of Choice", *Journal of Personality and Social Pschology, Volume 83, Number 5, pages 1178-1197,* 2002

double or triple whammy: more products, hence more costs; more unique features, hence more costs; lower sales, hence lower revenues[34].

On the other hand, if your product line is well-aligned, so that products vary along a single attribute, such as size, speed or capacity, then increasing the number of products offered can increase the likelihood of purchase, up to a point[35].

In research carried out by John Gourville and Dilip Soman, the effects seem in some cases at least to be very strong: from about 50% likelihood of purchase for a single product versus a single competing product, purchase likelihood declines to ~40% if each of four or five different products have a unique 'special feature', but increases to ~80% if the product line is well-designed, so that the choices amongst competing alternatives are clear.

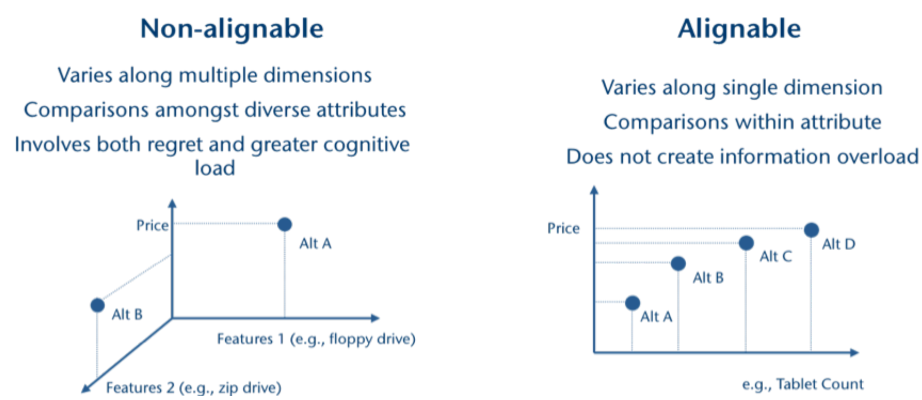

Figure 12: Alignable and non-alignable assortments[36]

[34] Itamar Simonson, Ziv Carmon and Suzanne O'Curry, "Experimental Evidence on the Negative Effect of product Features and Sales Promotions on Brand Choice", *Marketing Science, Volume 13, Number 1, pages 23-39*, Winter 1994

[35] John T Gourville and Dilip Soman, "Overchoice and Assortment Type: When and Why Variety Backfires", *Marketing Science, Volume 24, Number 3, pages 283-395*, Summer 2005

[36] Adapted from John T Gourville and Dilip Soman, "Overchoice and Assortment Type: When and Why Variety Backfires", *Marketing Science, Volume 24, Number 3, pages 283-395*, Summer 2005

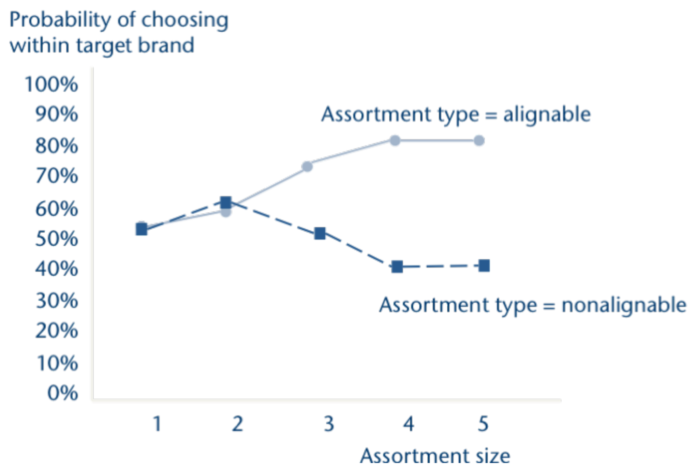

Figure 13: The effect of assortment type and assortment size on choice[37]

Some of this effect may be related to prior observations about how customers interpret 'special features', and to extreme choices. 'Special features' may actually decrease sales, rather than increasing them, if the group of customers who perceive it as providing little or no value is large, compared to the customers who find this special feature attractive[38]. In this case, more expense, but lower sales.

Customers' lower likelihood of buying extremes, which can translate into greatly increased purchase of other products in the lineup, may also arise from 'loss aversion'. An intermediate option involves giving up less relative to either extreme of a product line, than does each end of the product line. At the both extremes of the product line, the gain in one positive attribute is outweighed by the much larger loss in the attribute for which there was a negative trade-off, while choices in the middle are axiomatically less far from either extreme[39].

We have already noted that too many products can overwhelm customers; in response they adopt coping strategies that can include looking at fewer attributes. Perhaps unsurprisingly then, recent research demonstrates that even with a small number of products, too much information can overwhelm them.

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[37] Adapted from John T Gourville and Dilip Soman, "Overchoice and Assortment Type: When and Why Variety Backfires", *Marketing Science, Volume 24, Number 3, pages 283-395*, Summer 2005

[3838] Itamar Simonson, Ziv Carmon and Suzanne O'Curry, "Experimental Evidence on the Negative Effect of Product Features and Sales Promotions on Brand Choice", *Marketing Science, Volume 13, Number 1, pages 23-40*, Winter 1994

[39] Itamar Simonson and Amos Tversky, "Choice in Context; Tradeoff Contrast and Extremeness Aversion", *Journal of Marketing Research, Volume 29, pages 281-295*, August 1992

Another part of the research carried out by John Gourville and Dilip Soman demonstrated that where one company offers two products and its competitor has only a single product, providing a 'full profile' that covers all of the attributes, rather than a 'simple profile', that focuses only on the key differences amongst the products reduces purchase likelihood from three in four, 75%, to less than one third, 33%[40].

Figure 14: The impact of full and simplified profiles on consumers' choices[41]

These findings have powerful implications for portfolio management, encompassing the number of products being offered, the relationship amongst these products and the information provided about them:

- first and foremost, the products in a portfolio are not independent of each other, but can be highly interdependent, so that portfolio management should not consider resource allocations decisions or evaluate projects in isolation from each other
- managers may in many cases be able to increase the likelihood of purchase, and customers' subsequent levels of satisfaction by offering fewer products
- although there is not yet rigorous research to support this, a review of the evidence across the studies cited, and supported by discussions with managers involved in these issues, suggests that as a simple heuristic or 'rule of thumb' four to six is about the right number of choices to offer a customer

[40] John T Gourville and Dilip Soman, "Overchoice and Assortment Type: When and Why Variety Backfires", *Marketing Science, Volume 24, Number 3, pages 283-395*, Summer 2005
[41] Adapted from John T Gourville and Dilip Soman, "Overchoice and Assortment Type: When and Why Variety Backfires", *Marketing Science, Volume 24, Number 3, pages 283-395*, Summer 2005

- this would be consistent with a hypothesis that customers will avoid the extremes of the range, but then want to still have a meaningful choice once the extremes have been eliminated:
  - three initial choices confronts them with only a single meaningful choice, that is no choice, once the two extremes have been eliminated
  - four initial choices is the minimum number that preserves a meaningful choice when the extremes have been eliminated, and five or six initial choices leaves three or our meaningful choices without extremes
- these choices should be well-aligned along clearly defined attributes so that the trade-offs involved in choices minimize the regret involved, or customers are instead more likely to buy from competitors with a single simple and straightforward offer
- differentiation amongst products should be focused on a very few key attributes that matter most to customers, and this should be reflected in how the products are positioned within the portfolio and how this is communicated to customers
- unique 'special features' can do more harm than good

As noted above, these working hypotheses were tested in a program of discussions with managers involved in these issues. Each of the discussions began with open inquiry, seeking unprompted responses to these issues, before progressing to testing explicitly with them each of these hypotheses.

While different managers emphasized different aspects, there was almost universal agreement that the conclusions fit with their experience and intuition. Somewhat counter-intuitively, there was also widespread agreement that this was not reflected in current management practice; for a variety of issues most of the businesses involved found themselves with proliferating product portfolios:

- as one senior manager put it: *"…they're like kudzu, you just have to keep hacking them back…"*[42]
- or another one, reflecting on the impact of incentives: *"Engineers believe that they have to be [project] managers to be successful, to get respected. So their motivation becomes: 'how do I have a project myself'. You get a lot of smart, ambitious hard-working people trying to stuff their project into the pipeline."*[43]

[42] Personal communication with the head of marketing for a multi-billion dollar division
[43] Personal communication with senior human resources manager for a global engineering business

Another factor highlighted in these discussions, and identified in discussions with colleagues was that interdependence amongst products does not arise just in the marketplace; it also arises in the product pipeline from the use of platforms[44]. In this context a platform is a set of components or sub-systems that are common to a family of related products, enabling economies of scope and scale[45].

Thus, the evidence suggests that the first significant step towards getting the most value out of spending on R&D is to ship many fewer products, but to ensure that the choices amongst them are crystal clear to customers, and that they are empowered with just enough information to make well-informed choices amongst these few competing options.

5 Product features

From the discussion above, it is already apparent that getting the most value from spending on R&D also involves consideration of the features of individual products.

There appears to be a strong impetus for businesses to invest in R&D to offer products that include many rich features[46]:

- perception (and often reality) that the incremental cost of each additional feature is low or negligible – the cost of adding features is low
- the economic assumption, reflected in market research techniques such as conjoint analysis, that each positively valued attribute increases the utility for the customer, and hence either or both likely market share or the price that they will pay[47] – the value from adding features is high
- it may seem cheaper to offer a few feature-rich products to address the diverse needs of heterogeneous customers than to produce targeted products with fewer features – the incremental cost of more features is lower than the incremental cost of more products
- the features may be heavily influenced by early adopters, so-called 'lead users', who subsequently are found to rather than being representative of the needs of subsequent mainstream customers, are in fact more demanding

[44] Personal discussions with Jan Bosch of Intuit, and with James Utterback of MIT's Sloan School of Management

[45] See for example David Robertson and Karl Ulrich, "Planning for Product Platforms", *Sloan Management Review, Volume 39, Number 4, pages 19-31*, Summer 1998

[46] Debora Viana Thompson, Rebecca W Hamilton and Roland T Rust, "Feature Fatigue: When Product Capabilities Become Too Much of a Good Thing", *Journal of Marketing Research, Volume 42, pages 431-442*, November 2005

[47] V Srinavasan. William S Lovejoy and David Beach, "Integrated Product Design for Marketability and Manufacturing", *Journal of Marketing Research, Volume 34, pages 154-163*, February 1997

On the other hand, there are two bodies of powerful conflicting evidence:

- as noted above, the commercial success of very simple and straightforward products with few features, exemplified by Apple's iPod
- customers neither needing nor using many of the features in products

Mercedes Benz, for example, found that its customers did not use many of the electronic features of its automobiles, and that the resulting complexity made the systems more costly and less reliable; it subsequently eliminated many functions[48]:

- "Mercedes-Benz had to replace many of its early Comand integrated control systems because of failures, and has since worked to simplify the controls. Stephan Wolfsried, vice president for electronic systems in Germany, [said] that the company had eliminated 600 electronic functions in its cars... to improve quality and make the remaining functions easier to use. [He said] these were features that 'no one really needed and no one knew how to use.'"

Mercedes-Benz is not the only automobile company facing this challenge; early versions of BMW's iDrive were notorious:

- "I spend the next hour trying to tune in other frequencies, using the car's iDrive controller to scroll through menus on a screen. Eventually, I figure it out:
- ? Pull the iDrive knob back to select the "entertainment" menu.
- ? Scroll to the bottom of the screen and click "memory."
- ? Scroll to the top of the next menu and highlight "M FM."
- ? Scroll to the right and click "manual."
- ? Twist the knob to tune in a station.
- In a lesser car, you might simply twist a knob. In the 745i, tuning the radio is an interactive experience at 75 m.p.h. After a bit of this, you may wonder what's the fuss over handheld cellphones."[49]

Clearly, in some cases customers are overwhelmed by the sheer complexity of modern technology[50].

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[48] Tim Moran, "What's bugging the high-tech car?", *New York Times*, 5 Februrary 2005
[49] James G Cobb, "Menus Behaving Badly", *New York Times*, 12 May 2002
[50] David Glen Mick and Susan Fournier, "Paradoxes of Technology: Consumer Cognizance, Emotions and Coping Strategies", *Journal of Consumer Research, Volume 25,pages 123-143*, September 1998

It is also clear from the research cited above that getting the most value from R&D requires careful consideration of not just the number and balance of products in the portfolio, but also the features of individual products:

- one of the coping strategies that customers employ when overwhelmed with choice is to focus on fewer attributes, so that additional features may not even be being considered when customers make choices[51]
- as simplified profiles with less information can increase the likelihood of customers' choosing a product[52], features that are not reflected in this profile may be extraneous
- special features can have an adverse rather than positive impact, where they are highly valued by only a small proportion of the potential customers[53]

It appears that when it comes to product features, what customers actually do does not correspond to models of rational behavior. In particular, there is a disconnect between what they choose, and what makes them happy.

In the discussion of the size and shape of the product portfolio above, we have already established that the amount of the information provided about products, the profile or specification, can influence the choices that customers make. Some of the most recent research shows that the choices that customers make can also be influenced by the way in which this information is communicated as well, the nature of the specification[54]:

- customers' choices can be influenced by specifications, even where they have more relevant direct experience
- how specifications are framed can have an effect on customers' choices, even when the products are directly equivalent and there is no objective difference.

In recently-published research led by Christopher K Hsee of the University of Chicago with digital cameras and mobile phones, for example, customers have been shown to both be prepared to pay a premium even where there is no perceptual difference, and to weight more

[51] D Timmermans, "The impact of task complexity on information use in multi-attribute decision-making", *Journal of Behavioral Decision-Making, Volume 6, pages 95-11*
[52] John T Gourville and Dilip Soman, "Overchoice and Assortment Type: When and Why Variety Backfires", *Marketing Science, Volume 24, Number 3, pages 283-395*, Summer 2005
[53] Itamar Simonson, Ziv Carmon and Suzanne O'Curry, "Experimental Evidence on the Negative Effect of product Features and Sales Promotions on Brand Choice", *Marketing Science, Volume 13, Number 1, pages 23-39*, Winter 1994 and John T Gourville and Dilip Soman, "Overchoice and Assortment Type: When and Why Variety Backfires", *Marketing Science, Volume 24, Number 3, pages 283-395*, Summer 2005
[54] Christopher K Hsee, Yang Yang, Yangjie Gu and Jie Chen, "Specification Seeking: How Product Specifications Influence Consumer Preference", *Journal of Consumer Research, Volume 35, pages ?*, April 2009

heavily a comparison that produces higher numeric ratios (such as number of dots) versus lower numeric ratios (such as diagonal screen size).

For example, in this research the percentage of participants choosing a particular model doubled from about one in four (26%) absent a numeric specification to about one in two with a diagonal-dot specification, and tripled to three in four (75%) for a total-dot specification (whose ratio is the square of the ratio of the diagonal dot).

Ironically, while the specification may influence the choices that customers make, it does not necessarily have the same impact on their liking for the product, as they experience it in use. Ina related experiment with mobile phones, while the impact of a specification could increase choice preference significantly; it had a minimal or even negative effect on liking. As a result, *'…while choice chases specifications, liking stays put…'*[55]; what customers choose may be different from what they like. Customers may be their own worst enemies, choosing to make themselves unhappy.

This disconnect between choice and liking for specifications is also apparent when it comes to the features of products. It appears that when making purchase decisions, customers give more weight to capability, what a product is capable of doing, and less weight to usability before they have actually used the product.[56] They may persist in doing this, even if they understand that products with more features will be more difficult to use once they have made this choice.

This issue has been explored in research by Debora Viana Thompson, Rebecca W Hamilton and Roland T Rust using a variety of consumer electronics, such as digital audio players and personal digital assistants. For a digital audio player, a clear majority (~62%) of customers who had three possible models to choose from selected the one with the highest number of features, even though they recognized that this complexity was going to compromise usability. They did this whether they were novices, or experts who might have been expected to know better.

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[55] Christopher K Hsee, Yang Yang, Yangjie Gu and Jie Chen, "Specification Seeking: How Product Specifications Influence Consumer Preference", *Journal of Consumer Research, Volume 35, pages ?*, April 2009

[56] Debora Viana Thompson, Rebecca W Hamilton and Roland T Rust, "Feature Fatigue: When Product Capabilities Become Too Much of a Good Thing", *Journal of Marketing Research, Volume 42, pages 431-442*, November 2005

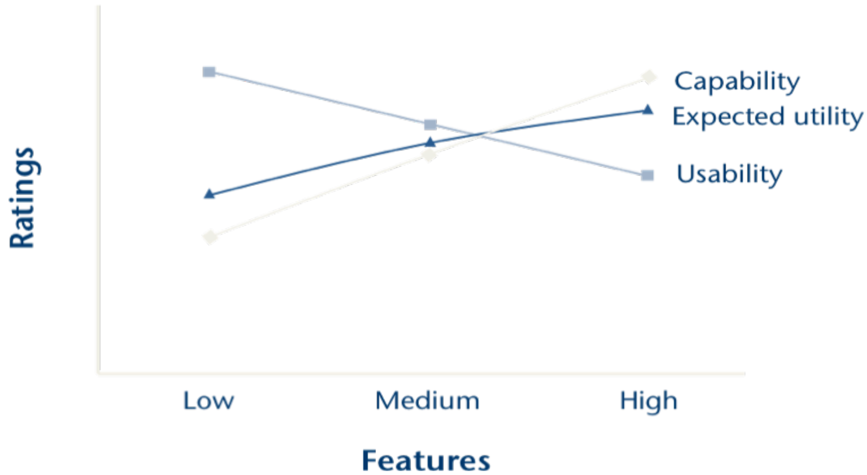

Figure 15: Relationship amongst capability, usability and expected utility for products with low, medium and high numbers of features[57]

This happens not just with a choice amongst three possible models; given the opportunity to customize a product with the precise features that they wanted from the total of 25 possible features, the average number of features chosen was still nearly 20, or 80% of all possible features. And again, this happened regardless of whether the customers were novices or experts, although there was some difference in the specific features chosen.

These choices did not, however, make them happy. After experiencing the products in use, customers no longer rated the feature-rich products highest; when it came to a subsequent purchase decision there was a substantial decrease in the share of the high feature model, from 66% to 44%.

Experience with the complex product, the one with most features, drove down the likelihood of buying it again by a third, relative to initial consideration. Product use re-shapes customers' preferences and their buying behavior.

Related research on the impact of experience in use suggests that initial ease-of-use is extremely important in the subsequent choices that customers make[58]. Yes, familiarity breeds comfort; as customers experience a product in use, such as a web site or other user interface,

[57] Adapted from Debora Viana Thompson, Rebecca W Hamilton and Roland T Rust, "Feature Fatigue: When Product Capabilities Become Too Much of a Good Thing", *Journal of Marketing Research, Volume 42, pages 431-442*, November 2005

[58] Kyle B Murray and Gerald Haubl. "Explaining Cognitive Lock-In: The Role of Skill-Based Habits of Use in Consumer Choice", *Journal of Consumer Research, Volume 34, pages 77-88*, June 2007

and become more familiar with it, they become more likely to choose to use it, all other things being equal[59].

Research conducted by Kyle Murray and Gerald Häubl on how the choices that consumers make are influenced by habits of use showed that usability challenges, which may arise from complexity or poor design, resulting in usage errors have a long-lasting adverse effect:

- *"...the negative effect of having made errors on preference for that product is persistent and essentially irrecoverable, even with a significant amount of additional experience..."*[60]

This presents some tough challenges for businesses trying to maximize the value they get from their spending on R&D and considering their product portfolio and product features:

- specifications can influence customers' choices, so that 'what they choose, is not what they like', making them unhappy and less likely to re-purchase
- while adding features increases the likelihood of purchase, it reduces usability, and once customers have used the product they chose, they are much less likely to re-purchase the same (or a similar) product
- at the same time, initial usage experience is critical, as early errors shape long-term perceptions of ease-of-use so that despite familiarity and expertise in the use of a product, it does not command loyalty

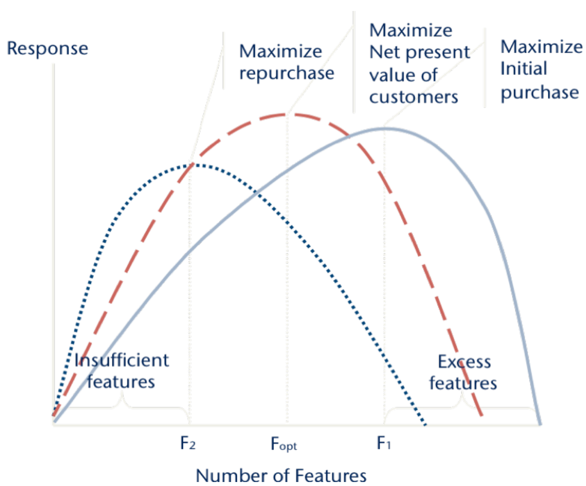

Figure 16: The trade-offs amongst initial purchase, re-purchase and customer lifetime value[61]

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[59] Eric J Johnson, Steven Bellman and Gerald L Lohse, "Cognitive Lock-In and the Power Law of Practice", *Journal of Marketing, Volume 67, Number 2, pages 62-75,* 1984

[60] Kyle B Murray and Gerald Häubl, "Explaining Cognitive Lock-In: The Role of Skill-Based Habits of Use in Consumer Choice", *Journal of Consumer Research, Volume 34, pages 77-88*, June 2007

For many products, subsequent purchase decisions are a particularly important consideration in maximizing the value from R&D spending:

- many high-tech products have finite lifetimes, as they are rendered inferior or obsolete by continued technological innovation – customer lifetime value is heavily influenced by the propensity for repeat purchase, that is loyalty effects
- for novel products, adoption depends on the diffusion of information about the product, or so-called 'word of mouth' effects[62]

Re-purchase and word-of-mouth are particularly important if there are network effects involved[63], wherein the likelihood of subsequent customers choosing depends on the size of the installed base, such as in a standards battle[64] or contests amongst platform players[65]. These contests are prevalent in high-tech products, and are currently being played out in browsers, in smart phone software platforms and in many other arenas. In these cases long-term customer value, their experience in using the product and resulting loyalty become critical.

Again, this working hypothesis was tested in discussions with managers responsible for the decision-making about the features and attributes of products. It is important to note that despite the linkage identified above between the product portfolio and the features of individual products, these were in many cases different individuals within the organization.

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[61] Adapted from Debora Viana Thompson, Rebecca W Hamilton and Roland T Rust, "Feature Fatigue: When Product Capabilities Become Too Much of a Good Thing", *Journal of Marketing Research, Volume 42, pages 431-442*, November 2005

[62] See for example, for a broad overview, Paul Geroski, "Models of Technology Diffusion", *Research Policy, Volume 29, pages 603-625*, 2000

[63] See for example M Katz and Carl Shapiro, "Product introduction with network externalities", *Journal of Political Economy, Volume 94, pages 822-841*, 1986

[64] See for example Carl Shapiro and Hal R Varian, "The Art of Standards Wars", *California Management Review, Volume 41, Number 2, pages 8-32*, Winter 1999

[65] See for example Thomas Eisenmann, "Managing Proprietary and Shared Platforms", California Management Review, Volume 50, Number 4, pages? Summer 2008, and note that the use of the term 'platform' here refers to the infrastructure that supports 'two-sided markets', rather than common components or sub-systems for a family of products, as described in David Robertson and Karl Ulrich, "Planning for Product Platforms", *Sloan Management Review, Volume 39, Number 4, pages 19-31*, Summer 1998

The feedback and responses were similar in some interesting ways to those on the overall product portfolio; these insights were validated, but again the consistent view was that they were not necessarily well reflected in managerial practice. Again questions of inertia and incentives came to the fore:

- one manager described a situation in which despite the specification explicitly excluding the feature, an FM radio was added to a high end mobile phone targeted at business customers because, as one of the engineers involved put it: *"We did it on another product I worked on, it doesn't cost much, and someone might want it."*[66]
- a particular emphasis was put on the importance of risk aversion on the part of product managers; as one senior manager expressed it: *"It takes courage as a product manager to exclude a feature, when it might reduce sales. On the other hand, it's all too easy to add features, and the costs are not readily apparent. If your product managers are at all risk-averse you get galloping feature bloat."*[67]

As a result, businesses seeking to maximize the value of their investment in R&D have to carefully balance competing considerations:

- the highest number of features maximizes initial sales, as customers value capability more highly than usability
- usage errors, however, have long-lasting negative effects on the propensity to re-purchase the product
- although customers' purchase choices can be influenced by how specifications are framed, even where customers have direct experience, this does not affect their subsequent liking of the product given experience of the product in use
- customer lifetime value is maximized by getting the right balance between more features to drive initial sales, and fewer features to reduce usage errors, drive long-term customer satisfaction and propensity to re-purchase
- in situations such as standards battles or platform wars where there are network effects, customer satisfaction reflected in both propensity to re-purchase and in word-of-mouth may be particularly important

[66] Personal cimmication with the produchead of marketing for a multi-billion dollar division of a personal computer and mobile phone company
[67] Personal communications with the senior strategy executive responsible for product portfolio and product management in a global mobile phone company

6 Portfolio inversion

The learning from portfolio management and product features imply that maximizing the value from R&D spending requires management practices very different from those suggested by conventional wisdom, involving what we have been calling 'portfolio inversion':

- move from a broad and diverse array of feature-rich products that are considered independent of one another to a few well-aligned products, differentiated along only the key attributes that matter most to customers
- for these few products, endow each of them with fewer features and invest in making them much easier to use, to balance the likelihood of initial purchase with experience in use, subsequent re-purchase and customer lifetime value
- as part of that, eschew unique 'special features' that appeal to only a minority of potential customers
- in support of that, focus communication about products in the portfolio only on the key differences amongst them to increase the likelihood of purchase, and frame the specifications in ways that are closely aligned with what will matter to customers in using the product, so that what they choose is what they like
- invest in ease-of-use to minimize or eliminate early errors because of their persistent adverse impact on perception, and hence on long-term loyalty

We coined the term 'portfolio inversion' to describe this because it inverts the shape of the overall typical product portfolio:

- from one with a rich variety of products at its core with many diverse features and a few simpler products at the periphery
- to one with a small sparse core of well-aligned products focused on their essential features and on ease of use, complemented by diverse and creative experiments that extend the design space and explore emerging and evolving consumer preferences

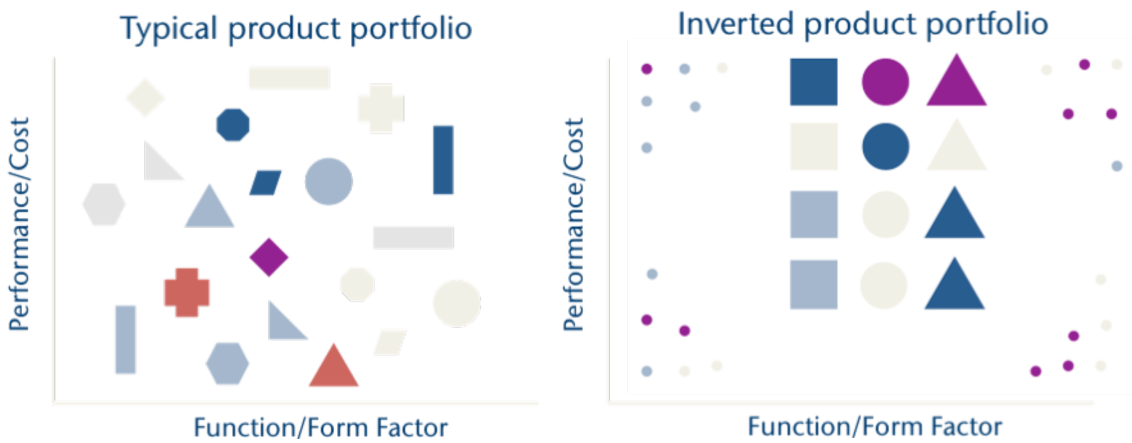

Figure 17: Portfolio inversion

This is different to current management practice and in some important ways more difficult:

- fewer products makes each product more valuable, and makes each decision relatively more important
- aligning products within the portfolio requires assessing the product portfolio and the product pipeline as a whole, rather than looking at products and projects independently of one another
- similarly, fewer product features makes each feature more critical, with tougher trade-offs involved
- ease of use, which is notoriously ambiguous and difficult to achieve, becomes much more important

The degree of difficulty depends on how well understood are customers' needs and the jobs that they want done[68].

For what might be termed the core of the product portfolio, well-established products where there is a clear dominant design[69] and customers' needs are stable and well-defined, this is doable albeit demanding. It requires a higher level of investment in understanding customers' needs and in achieving usability, a shift in resources towards the so-called front end of the

[68] Clayton Christensen, Scott Anthony, Gerald Berstell and Denise Nitterhouse, "Finding the Right Job for Your Product", *Sloan Management Review, Volume 48, Number 3, pages 38-47*, 2007 or Clayton Christensen and David Sundahl, "Getting the Innovation Job Done: Matching the Right New Product With the Right Market", *Harvard Business School Working Paper 02-025*, 2001

[69] See for example Fernando F Suarez, "Battles for technological dominance: an integrative framework", *Research Policy, Volume 33, pages 271-286,* 2004

innovation process. It involves developing a real empathy for what customers want, even where they don't (yet) know it themselves, what has been called 'empathic design'[70].

Beyond the core of the product portfolio, where innovation is more rapid, there is not yet necessarily any dominant design and customers' needs are not yet well-defined or well-understood, or they are endogenous, being shaped by new offers, this may, however, be very difficult and hence costly.

This is where experimentation has a vital role to play, using a carefully designed combination of low-cost experiments to explore the design space[71]. These experiments can, and in most cases probably should, be both virtual and physical. They should be thought of as a portfolio themselves, in which the mix of experiments is designed so that their outcomes are negatively correlated, to maximize the information generated for the investment made.

Our experience where this has been pursued is that successful implementation requires careful consideration of the broader systemic effects. For example, in one case where the number of products in the portfolio was drastically reduced, the business found itself having to re-train and up-skill its sales force; when they had a plethora of products they were in essence abdicating the sales process to letting their major distribution channels choose from the selection offered, subsequently with many fewer products in the portfolio they found themselves having to explain to customers their benefits and the trade-offs amongst them, skills that they had either never had or which had atrophied over time[72].

7 Scope and structure of activities

The shift in the product portfolio and product features described above can make a significant contribution towards increasing the return on investment from R&D. It provides some valuable insights and possible answers to the first managerial challenge: how do we maximize the value of our product portfolio and pipeline?

It was predicated upon a perspective that refocused on the outcomes that the business was seeking to achieve, the outputs from R&D, rather than the allocation of available resources.

[70] See for example, Dorothy Leonard and Jeffrey Rayport, "Spark Innovation through Empathic Design", *Harvard Business Review, Volume 75, Issue 6, pages 102-113*, November-December 1997

[71] This is an area where Stefan Thomke of Harvard Business School has pioneered work, including for example "Managing Experimentation in the Design of New Products", *Management Science, Volume 44, Number 6, pages 743-762, June 1998* or with Takahiro Fujimoto, "The effect of front-loading problem-solving on product development performance", *Journal of Product Innovation Management, Volume 17, pages 128-142*, 2000

[72] Personal communication with the then head of product launches for a global mobile phone business

This same perspective, as well as the need to shift resources to the front-end of the innovation process implied by 'portfolio inversion', motivated us to re-examine the question of what is the appropriate level of in-house resources. This was the second managerial challenge: what activities or resources should we be investing R&D spending in?

Research on the relationship between technology development and its commercialization in products has already motivated a move towards what is called 'open innovation'[73], looking beyond the boundaries of the business:

- *"Open Innovation is the use of purposive inflows and outflows of knowledge to accelerate innovation. With knowledge now widely distributed, companies cannot rely entirely on their own research, but should acquire inventions or intellectual property from other companies when it advances the business model"*[74].

This approach implicitly frames the question about what the right level of resources should be as being a question about what should be done externally, rather than by default in-house:

- *"...companies cannot rely **entirely** on their own research..."* (our emphasis added)

Building on this perspective, we re-framed the question from being about to what extent should companies rely on external resources to what, if any, should be the investment in in-house resources. We adopted a 'zero-based' approach or 'nihilist' philosophy that takes as its null hypothesis that businesses should make no R&D investment in in-house resources. It is axiomatic that the reducing the level of investment in R&D should, all things being equal that is delivering the same outputs, increase the return on investment in R&D.

Interestingly, this outlook is reflected in the minimalist perspective that entrepreneurs and start-up companies have to adopt. They have very limited resources, in terms of time, money people and management attention, as well as a very tight focus on a few key product outcomes, and as one highly regarded and insightful entrepreneur and investor put it[75]:

- *"You need three things to create a successful startup: to start with good people, to make something customers actually want, and to **spend as little money as possible**."* (our emphasis added)

[73] Henry Chesbrough, "Graceful exits and foregone opportunities: Xerox's management of its technology spin-off organizations", *Business History Review, Volume 76, pages 803-838*, Winter 2002
[74] Center for Open Innovation (http://openinnovation.haas.berkeley.edu/)
[75] How to Start a Startup, Paul Graham, March 2005 (http://www.paulgraham.com/start.html)

It has also become the focus of several streams of management research:

- how firms may be able to exploit architectural knowledge and leverage architectural innovation to increase their return on capital invested[76]
- whether to become or remain vertically integrated has become a question of increasing strategic importance[77]
- the importance of absorptive capacity in leveraging external resources[78]
- when novel forms of organization that rely on co-ordinating external resources, so-called 'virtual organizations' are appropriate[79]

We began by focusing on architecture, because of the way in which architectural decisions shape the structure, scale and scope of activities both within and outwith the business. Architecture in this context means the mapping of the functions of a system to components or sub-systems, and the definition of the interactions amongst or interfaces between them, providing what MIT's Engineering Systems Division characterizes as:

- "…an abstract definition of the entities of a system and how they are related…"[80]

Architectural innovations change the ways in which the components of a product or system are linked together, while preserving the knowledge about the components of the system[81].

[76] Carliss Baldwin and Kim Clark, "Architectural Innovation and Dynamic Competition: The Smaller 'Footprint' Strategy", *Harvard Business School Working Paper 07-014*, August 2006
[77] Clayton Christensen, Matt Verlinden and George Westerman, "Disruption, disintegration and the dissipation of differentiability", *Industrial and Corporate Change, Volume 11, Number 5, pages 955-993*, 1992
[78] Wesley M Cohen and Daniel A Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation", *Administrative Science Quarterly, Volume 35, pages 128-152*, 1990
[79] Henry W Chesbrough and David J Teece, "Organizing for Innovation: When is Virtual Virtuous?", *Harvard Business Review, Volume 80, Issue 8, pages 127-135*, August 2002
[80] Engineering Systems Department Architecture Committee, "The Influence of Architecture in Engineering Systems," *Engineering Systems Monograph, MIT, Cambridge, MA*, March 2004 (http://esd.mit.edu/symposium/monograph/)
[81] Rebecca Henderson and Kim Clark, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms", *Administrative Science Quarterly, Volume 35, Number 1 pages 9-30, March 1990*

There are two principal ways in which architectural knowledge can be exploited to increase the performance of a system:

- it can be used to determine the linkage between the performance of individual components of the system, and the overall performance of the system, and in particular to identify those components that constrain the overall performance of the system in ways that are meaningful to customers, specific attributes or features of the resulting product or system
- it can be used to assess how the relationship and interactions amongst the components of the system, the interfaces and structure of the system, affects the overall performance of the system, and in particular to identify ways in which the interfaces and structure of the system can be changed to improve the overall performance of the system, how components can be *"…arranged in a new pattern [to] deliver higher levels of performance"*[82].

In particular, this combination of knowledge about components, and about the relationships amongst them, provides a foundation for increasing the modularity of the system, for hiding information about specific components and decoupling their interactions to make them modules of the system[83].

Although in some cases the performance of the system is constrained by the performance of a single component or sub-system or interface[84], for most of the relatively complex systems with which we are concerned the overall performance of the system, defined in ways that matter to customers, depends on the combination of and interaction amongst more than one component or sub-system. The contribution is not, however, uniform; some components or sub-systems and some relationships amongst components or sub-systems will have a much greater impact on overall system performance than others. This can be thought of as a continuum for each component or relationship amongst components, in which its contribution to or constraint upon the critical parameters or key features of system performance ranges from all or a lot, the 'bottlenecks', through some to little or nothing.

This understanding can be used to increase the return on investment in R&D in two complementary ways:

- first, to focus investment in R&D on those components or relationships amongst components that have the greatest overall impact on overall system performance

[82] Carliss Baldwin and Kim Clark, "Architectural Innovation and Dynamic Competition: The Smaller 'Footprint' Strategy", *Harvard Business School Working Paper 07-014*, August 2006
[83] See for example, Carliss Baldwin and Kim Clark, "Managing in an Age of Modularity", *Harvard Business Review, Volume 75, Issue 5, pages 84 to 93*, September 1997

- second, to minimize or even eliminate investment in R&D on those components or relationships amongst components that have small or negligible impact on overall system performance

Critically, it is these former activities that are vital to value capture:

- *"Attractive profitability seems to flow ... to the point at which unsatisfied demand for functionality, and therefore technological interdependency exists."*[85]

Returning to our null hypothesis, that there should be no investment in in-house R&D, it seems that there is a case to be made, the hypothesis is disproved, for at least two specific areas of investment:

- architectural knowledge
- components or interfaces that have a large impact on overall system performance

Moreover, architectural knowledge can be exploited to reduce the level of interdependence involved in and thereby decouple those components or sub-systems that have a small impact on overall system performance; to 'modularize' them. Making the interface modular allows for well-structured technical dialogue and for a market to be established, so that the relevant activities or resources can then be procured externally, can be out-sourced.

This appears to be supported by and consistent with the results of the deductively derived model built by Clayton Christensen, Matt Verlinden and George Westerman to help managers decide whether to invest in in-house resources (to 'integrate') or to eschew these investments (to 'outsource') [86]. This suggested that a broader scope of activities is appropriate where the performance or functionality of products falls short of what customers are looking for, where there remain significant 'bottlenecks', while a much narrower scope of activities is optimal where the performance or functionality exceeds what customers are looking for.

This is also consistent with a view espoused by David Teece that 'virtual organizations' are appropriate where and when the architecture is modular and innovation is autonomous, which tends to be associated with situations in which the requirements for performance and

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[84] What Carliss Baldwin and Kim Clark characterize as an 'absolute bottleneck'

[85] Clayton Christensen, Matt Verlinden and George Westerman, "Disruption, disintegration and the dissipation of differentiability", *Industrial and Corporate Change, Volume 11, Number 5, pages 955-993*, 1992

[86] Clayton Christensen, Matt Verlinden and George Westerman, "Disruption, disintegration and the dissipation of differentiability", *Industrial and Corporate Change, Volume 11, Number 5, pages 955-993*, 1992

functionality are less demanding[87]. The corollary to this is that for performance closer to the limits of the performance envelope where there are higher levels of interdependence, integral architectures and systemic innovation, then it is appropriate for these activities to be internal to the organization, investing in in-house R&D.

Looking beyond the boundaries of the business, architectural knowledge can extend beyond just an understanding of the product or system that a business offers and its components and sub-systems, to encompass the broader technical system and related business ecosystem of which it is a part[88].

This wider architectural knowledge or insight can also be exploited to increase the value captured by influencing or shaping the overall architecture of this extended technical system and how it is mirrored in the business ecosystem.

The architecture can shaped in a couple of key ways:

- through making and successfully promulgating decisions about the ways in which the various products or systems interoperate, that is how interfaces are defined, often instantiated as compatibility standards enable technical modularization and economic specialization
- by making investments in technology platforms[89], the shared elements of systems that impact the economics of the businesses within the ecosystem

If the key bottlenecks that determine performance from a customers' perspective lie outside the business, then the objective of shaping this overall system architecture, with which the business must work, is to reduce the importance of or eliminate those external bottlenecks, typically by promoting competition. Conversely, where a business has a strong capability that is not readily imitated, for whatever reason[90], the goal is to shape architecture in a way that makes this more important to customers' satisfaction and minimizes competition.

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[87] Henry W Chesbrough and David J Teece, "Organizing for Innovation: When is Virtual Virtuous?", *Harvard Business Review, Volume 80, Issue 8, pages 127-135*, August 2002

[88] See for example James F Moore, "Predators and Prey: A New Ecology of Competition", *Harvard Business Review, Volume 71, Issue 3, pages 75-86*, May-June 1993, and Marco Iansiti, "Strategy as Ecology", *Harvard Business Review, Volume 82, Issue 3*, pages 68-78, March 2004

[89] The definition of platforms in this context is one that encompasses both shared components or sub-systems and the infrastructure that supports two-sided markets, perhaps best described by Michael Cusumano and Annabelle Gawer in "The Elements of Platform Leadership", *Sloan Management Review, Volume 43, Number 4, pages 51-58*, Spring 2002

[90] See for example, David Collis and Cynthia Montgomery, "Competing on Resources", *Harvard Business Review, Volume 73, Issue 4, pages 118-128*, July/August 1995 and David Teece, "Capturing Value from Knowledge Assets: The New Economy, Markets for Know-How and Intangible Assets", *California Management Review, Volume 40, Number 3, pages 55-79*, April 1998

This capability that is inimitable may even be the architectural know-how required for system integration[91]. For complex systems, the specialized knowledge that determines or constrains overall system performance and functionality may be that related to system integration.

Critically, this provides further strong support that our null hypothesis, that there should be no investment in in-house R&D, is disproved for architectural knowledge.

Understanding architecture and investing in the activities and resources relevant to performance and functionality bottlenecks are necessary, but not sufficient. It is almost always the case that much of the information necessary for effective R&D and innovation lies outside the firm so that: *"The ability to exploit external knowledge is thus a critical component of innovative capabilities"*[92]. Simply put, a business must make some investments in in-house R&D to be able to evaluate and exploit external and novel related knowledge; this 'absorptive capacity' comprises: *"...the knowledge, skills, and organizational routines necessary to identify and utilize externally generated knowledge"*[93].

The importance of this absorptive capacity is heightened when a business is seeking to minimize the footprint of its in-house R&D activities; the corollary to this is that more R&D will be taking place externally, thereby increasing the importance of being able to assess this external R&D and avail itself of it. As a result, it appears that our null hypothesis, that there should be no investment in in-house R&D, is also disproved for absorptive capacity.

The need for this absorptive capacity may explain why businesses with the lowest levels of R&D, those in the bottom decile in Booz Allen's survey, underperform[94];

As result, this suggests that the null hypothesis is disproven, and that businesses should invest in in-house R&D, in three areas only:

- architectural knowledge
  - for its own products and systems, how components and sub-systems and the interdependencies amongst them contribute to overall performance

[91] This focus in particular comes from a series of conversations with executives at leading defense and aerospace companies, contemplating how to respond to intensifying competition in commercial aircraft and the US Department of Defense's Modular Open System Architecture (MOSA) initiative and imperatives

[92] Wesley M Cohen and Daniel A Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation", *Administrative Science Quarterly, Volume 35, pages 128-152*, 1990

[93] Iain M Cockburn and Rebecca M Henderson, "Absorptive Capacity, Co-Authoring Behavior, and the Organization of Research in Drug Discovery", *The Journal of Industrial Economics, Volume 46, Number 2, pages 157-182*, June 1998

[94] Barry Jarulzelski, Kevin Dehoof and Rakesh Bordia, "Booz Allen Hamilton Global Innovation 1000", May 2005

  - for the broader technical system of which its products and systems are part, and hence the broader business ecosystem within which it operates
  - to enable it to modularize and outsource activities, and to shape the evolving architecture of the broader system within which it works
- absorptive capacity – the knowledge, skills and organizational routines
- ‘bottleneck’ activities
  - those that have a significant impact on the performance or functionality that is important to customers
  - where also the business has built up competences and capabilities that cannot readily be replicated by others, that are inimitable

Our experience is that there is a very strong managerial bias towards expanding the scope of R&D activities and increasing the level of resources, so that getting the most bang for its buck demands a ruthless and relentless focus on those few key activities that both enable differentiation of its products in the eyes of customers, where a business can also truly excel, where it can sustain superior results. Moreover, in a high-tech environment a dynamic perspective is critical; it’s not the current situation but anticipation of future scenarios that is critical to success.

Businesses should only minimize the footprint of their activities and investment in in-house R&D resources to those that meet tough criteria:

1. first, will this component, sub-system or technology have a significant impact on customers’ buying and usage behavior, linked to performance attributes or functionality that will be important to their choices?
   - this forward-looking view focuses on the future linkage between technology or R&D activities and what customers want, both of which are changing, not on the current situation, as investments take time to come to fruition
   - this excludes, for example, technologies that matter now but will become less important, or needs’ which are going to change as a result of exogenous improvements
2. second, are both the technology and the relevant resources unavailable externally at reasonable terms?
   - if the technology is available, buy it or license it
   - if the relevant resources are available, contract them

3 third, is there a reasonable likelihood that this business can improve the performance of the technology, component or sub-system significantly, in the right direction, with the right timing?

- investment in these activities is wasted, unless it is likely to produce an improvement in performance
- it's not enough that there is in a general sense room for improvement, the key question is can this specific business do so and reap the rewards
- this excludes even critical bottlenecks, which have reached a physical performance limit

This hypothesis appears to be supported by empirical data from a number of case studies of business in high-tech, such as Sun Microsystems[95] and Apple:

- Sun Microsystems achieved success in the face of its larger and better endowed competitor Apollo Computer by focusing its investment in R&D on a much smaller 'footprint', the bottleneck between memory and the processor, achieving higher returns on its investment in R&D, and otherwise leveraging many off-the-shelf components for less performance-critical components or sub-systems

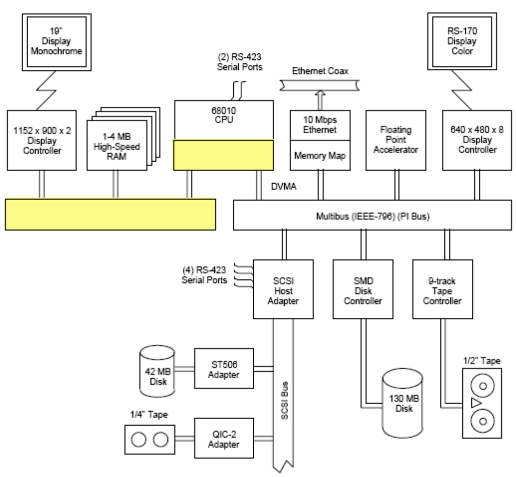

Figure 18: Sun Microsystems focused its initial investment on the performance bottleneck

[95] The discussion here of Sun Microsystems success synthesizes data from two insightful publications, Henry W Chesbrough and David J Teece, "Organizing for Innovation: When is Virtual Virtuous?", *Harvard Business Review, Volume 80, Issue 8, pages 127-135*, August 2002 and Carliss Baldwin and Kim Clark, "Architectural Innovation and Dynamic Competition: The Smaller 'Footprint' Strategy", *Harvard Business School Working Paper 07-014*, August 2006, as well as other secondary sources and discussions with a number of executives who held positions at Sun Microsystems

- on the other hand, it scope was sufficient to enable it to compete effectively with MIPS, a much more virtual competitor, who reduced the scope of its activities too far, so that losing the support of its partners within the business ecosystem MIPS was unable to survive
- Apple's approach to the iPod achieved success by combining off-the-shelf sub-systems, with investment in a few key activities[96]

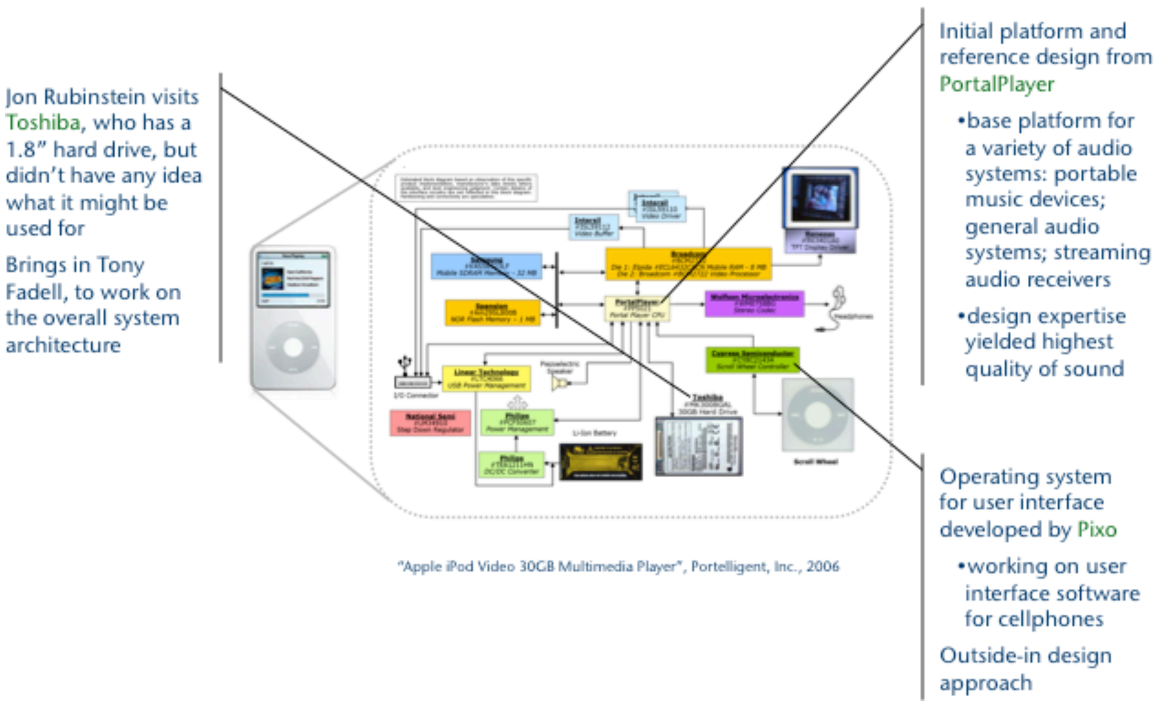

Figure 19: Apple leveraged significant off-the-shelf components and sub-systems in the iPod

[96] Matthew Yi, "Little known startup was behind iPod's easy-to-use interface", *San Francisco Chronicle*, 16 August 2004 and Erik Sherman "Inside the Apple iPod Design Triumph", *Electronics Design Chain, Cover Story*, Summer 2002

- *"[Tony] Fadell was put in charge of a small team of engineers and designers, who put the device together quickly.* ***The team took as many parts as possible off the shelf****: the drive from Toshiba, a battery from Sony, some control chips from Texas Instruments. The basic hardware blueprint was bought from [a] startup PortalPlayer, which was working on "reference designs" for several different digital players, including a full-size unit for the living room and a portable player about the size of a pack of cigarettes.* ***The team also drew heavily on Apple's in-house expertise****. 'We didn't start from scratch,' [Jon] Rubinstein said. 'We've got a hardware engineering group at our disposal. We need a power supply, we've got a power supply group. We need a display, we've got a display group. We used the architecture team. This was a highly leveraged product from the technologies we already had in place.'"* [97] (our emphasis added)

These working hypotheses were tested in discussions with several managers, in this case in particular with those responsible for technology strategy. They were well-supported and in one particular case rapidly adopted as the approach for a major re-evaluation of the scope of R&D activities. In this case, for example, it played a significant role in decisions to divest a large semiconductor operation, change the procurement strategy for a key class of sub-systems and acquire a major software platform.

8 Resources and the product pipeline

These two disciplines together define an R&D organization for which less is more:

- a product portfolio and pipeline with many fewer products, each of which typically has many fewer features
- a much narrower scope of activities and lower investment in in-house resources

The last, but by no means least, piece of the puzzle is then how this much more minimalist organization operates; what is the mapping of the much smaller pool of available resources to the projects that will deliver the product portfolio, the product pipeline.

Conventional wisdom holds that in order to get the most out of the available R&D resources, their utilization should be maximized. This would seem to obtain, even if the output is fewer products with fewer features, and the in-house resources are much more focused. It corresponds to assigning as many of the resources available to the (much smaller) number of projects, to increase the quality of the outcome given the available time.

Again, rather than take this as a given we re-framed the question as how should resources be allocated to maximize the desired output given available resources.

[97] "Straight Dope on the iPod's Birth", *Wired*, 17 October 2006

We noted above that one of the greatest areas of dissatisfaction with portfolio management is when it comes to projects being done on time, what was characterized as *'no gridlock'*[98]:

- for those businesses who self-reported as being most happy with their portfolio management their assessment was that was a little better than 'OK'
- for business surveyed as a whole, this was assessed as below the mid-point between poor and excellent

There is also abundant evidence from both case studies and our discussions with managers that project performance in R&D in general, and timeliness in particular is poor:

- *"the average time to develop a product is 225% of the projected time…with a standard deviation of 85%"*[99]

This phenomenon known as 'firefighting' is both widespread and persistent. It flows directly from the way in which resources are allocated to projects:

- *"…if you look at our resource allocation on traditional projects, we always start late and don't put people on the projects soon enough…then we load as many people on as it takes…the resource allocation peaks when we launch the [product]."*[100]

Our approach to this issue was a little different. Despite its importance, it has not received as much attention in the research field as it deserves, and our insights rely heavily on Nelson Repenning's powerful and path-breaking work, and in particular on the simulations he has developed of these systems. Perhaps understandably, there is not much published in terms of case studies, as these have the potential to expose the management of a business to considerable embarrassment. Instead, we have relied heavily on engagement with managers in businesses struggling with these issues and our experience in working with them to leverage the insights from this research to overcome them. We are particularly indebted to Nelson Repenning who was himself involved in much of this work.

These problems arise because R&D involves innovation, doing new and novel things, being creative rather than just complying with a pre-specified recipe. It involves exploration and

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98 Robert Cooper, Scott Edgett and Elko Kleinschmidt, Portfolio Management in New Product Development - Lessons from the Leaders I, II - *Research & Technology Management, Volume 40, Issue 5 pages 16-28,* September/October 1999 and *Volume 40, Issue 6 pages 43-60* November/December 1997

99 Reported by Nelson Repenning

100 See for example Nelson Repenning, "Understanding firefghting in new product development", *Journal of Product Innovation Management, Volume 18, Number 5, pages 285-300*, 2001, and "Why Firefighting is Never Enough: Preserving High Quality Product Development", *System Dynamics Review, Volume 17, Number 1, pages 173-212*, 2000 and with Paulo Gonçalves and Laura J Black, "Past the Tipping Point: The Persistence of Firefighting in Product Development", *California Management Review, Volume 43, Number 4, pages 44-63*, Summer 2001

experimentation; as such, it is inherently uncertain. Sometimes, things will take longer or involve more effort than was anticipated. It may be because of an external shock, or simple bad luck.

What happens then is critical. Typically, and entirely sensibly, the organization responds by shifting its attention and resources to fix the problem. This is firefighting, shifting resources to unanticipated problems that occur late in the product development process; unfortunately while it can fix a particular project, it significantly degrades overall system performance. Projects do not operate independently of one another; in an overall R&D program that is running at a high level of utilization, as it supposedly should be to get the most out of the available resources, these resources being applied to fix the problem must come from somewhere else.

These resources are typically diverted from up-front work on other projects because of some very strong psychological biases towards this downstream work:

- people overweight salient and tangible features of their environment, and projects near to completion are much more salient and tangible than up-front work on that are at a much earlier stage in the pipeline
- people are averse to risk and ambiguity, and investments in fixing well-defined problems in the late stages of a project have a much more certain outcome than the highly uncertain and difficult to ascertain payoff from up-front work on projects that are at a much earlier stage in the pipeline
- people are biased toward doing things that produce immediate returns and fixing problems provides much more rapid gratification than doing up-front work on projects at an early stage in the pipeline, where the payoff is long delayed

It is well-established that the impact of additional resources or management attention declines rapidly during the course of development of a product or system. Resources applied earlier have a much greater impact on the performance, functionality and level of quality of a product or system[101]. Conversely it takes a much higher level of resources to fix problems found late in the process.

As a result, the unintended consequence of allocating resources to projects to achieve a high-level of utilization, and then diverting them to fix problems in projects near completion

[101] See for example, R G Coper and E J Kleinschmidt, "New Products: What Separates Winners from Losers", *Journal of Product Innovation Management, Volume 4, Number 3, pages 71-85*, 1987 and "An Investigation into the New Product Process Steps" Deficiencies and Impact", *Journal of Product Innovation Management, Volume 3, pages 169-184*, 1986

from projects at an earlier stage in the product pipeline is to tip the system and thereby 'lock-in' poor performance:

- resources are allocated away from up-front work on projects that are at an earlier stage in the product pipeline
- it takes a lot more resources to fix problems late in a project, than it does early on
- as these projects from which resources were diverted near completion, the incidence of problems is higher
- this compounds the need for resources to be diverted to fixing projects nearing completion, further compromising the coming generations in the pipeline

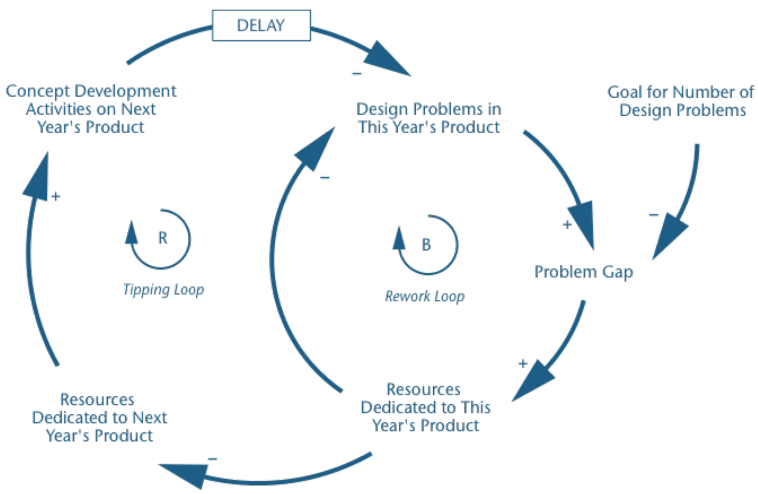

Figure 20: How fixing downstream problems starts a vicious cycle[102]

These problems can be exacerbated by attribution errors, which obscure the causal relationships underlying this phenomenon. People use as cues to causality the order in which things happen, whether or not they change together, and contiguity in time and space. In this case, however, we are concerned with issues and events that are well-separated in time and perhaps in larger R&D organizations, in space and managerial responsibility. As a result, managers focus on the fixes, and develop the misconception that downstream work is more valuable. They then attribute the systemic failure to other causes, such as laziness or incompetence on the part of the people working on the projects, or the management and information systems that they have.

[102] Adapted from Nelson Repenning, "Understanding firefghting in new product development", *Journal of Product Innovation Management, Volume 18, Number 5, pages 285-300*, 2001

As a result, where the allocation of resources to projects seeks to maximize output by maximizing utilization, a transient and local shock, affecting perhaps one or a few projects over a limited time horizon, can cause a permanent deterioration in the overall performance of the system.

Moreover, overcoming this lock-in and systemic failure is tough, because fixing the long-term problem involves a deterioration in short-term performance, as resources are re-allocated away from fixing problems on projects nearing completion to preventing problems from occurring later on projects that are at a much earlier stage in the pipeline.

Our experience is that an effective fix requires three steps:

- first, in the short-run reduce the level of utilization by killing some projects to provide a buffer for the uncertainty involved in R&D
- second, put in place some pragmatic resource planning, which maintains an appropriate lower level of utilization
- third, use learning to overcome the cognitive challenges involved in these systems, tools such as 'management flight simulators' whose accelerated timescale overcomes the issues of saliency and attribution errors

The appropriate level of utilization to maintain timeliness and high quality output depends on the degree uncertainty involved in the projects, the level of variability, and on how fungible the available resources are. The situation can be ameliorated if external resources can be leveraged, although our experience is that this takes time, and always more time than is anticipated.

That notwithstanding, our pragmatic experience over the last few years has led us to a simple heuristic which suggests that the nominal utilization should not be higher than about 75% or 80% of available resources. This provides a buffer of 20% to 25% of the total resources, meaning that the pipeline should be able to cope with a shock that increases the load by between 25% and 33%.

It is interesting to note that the management practice of giving engineers a certain amount of time to pursue their own projects, as Google for example does[103], may also provide an effective buffer:

- *"We offer our engineers '20-percent time' so that they're free to work on what they're really passionate about. Google Suggest, AdSense for Content and Orkut are among the many products of this perk."*

[103] http://www.google.com/support/jobs/bin/static.py?page=about.html&about=eng retrieved June 2009

This buffer response relies upon these engineers responding by setting aside their pet projects when their primary responsibility encounters problems, and returning to it when things are running smoothly.

Although this problem is widespread, one particularly tough case highlighted both the challenges involved and illustrated how to fix them[104]. A large global engineering organization had experienced an external shock as two things happened:

- the underlying technology involved in its products made a generational transition to a more complex compatibility standard
- the software content of its products increased significantly relative to the electronic hardware, mechanical hardware and industrial design

As a result, several projects nearing completion found unexpected problems, and schedule performance deteriorated sharply. Resources were re-allocated from other projects at an earlier stage to fix these problems, compromising the up-front work on these projects.

Indeed, in this particular case, the 'firefighting' mechanism was formalized in a system known as 'tiering':

- top tier projects, at any time typically those involving major products and nearing completion, had priority over lower tier projects for resources, to try and ensure that these projects could achieve their schedule dates
- if a projects' projected schedule performance deteriorated too sharply, however, it became likely to be downgraded to a lower tier, which meant that it not longer had priority over fungible resources
- this created perverse incentives for project managers to be at least optimistic in their projections, as access to resources depended on how well the project was perceived to be performing
- this then created another positive feedback loop, in which being honest early about challenges would lead to a project being starved of resources, further compounding the problems, and in many cases dooming the project to failure

This vicious cycle reached its culmination with the first low-cost, high-volume, worldwide product of this next generation, which was also intended to provide the core platform for a number of derivative products. Started early, attempts to freeze the specification while

[104] Personal conversations with the managers involved, including the top management, the heads of the relevant projects, a detailed two-day long debrief of the leaders of the major low-cost high-volume platform project, as well as work with the team that developed the 'management flight simulator'

uncertainty about key technical issues had not been resolved led to several sequential iterations of the design, and very bad schedule slippage. As the project neared completion, it was assigned to the highest possible tier, and effectively seized a very large proportion of all the available fungible resources. It finally came to market many months late, and with cost overruns that were extraordinary.

Unsurprisingly this had a disastrous effect on the performance of projects coming through the pipeline after it, almost all of which were late and had significantly increased levels of errors.

The fix involved three steps:

- first aggressive triage, in which between a quarter and a third of all the projects in the division were canceled
- second, putting in place a simple set of 'rules of thumb' for how many major and minor projects the organization could take on at once
- last, but by no means least, working in co-operation with a national research organization and a local university to develop a powerful 'management flight simulator' that was used by a significant proportion of the top management in the course of a custom executive education program

Although this is a difficult problem, it can be overcome. We have now been involved in or now know of several other cases in which a combination of triage and simple 'rules of thumb' have served to re-stabilize the system.

In another division within the same company, pioneering entry into a new business area, the triage was even more radical: 54 products were cut back to just 33, a reduction of nearly 40%[105]. In another company addressing the same marketplace, where the motivations were not just reducing overload but also cleaning up the product portfolio to simplify the choices for customers and adapting to a shift in the market, the surgery cut even deeper: ~60% of the projects in the pipeline were canceled to free up resources and refocus on a smaller but much more compelling and product portfolio[106].

Critically, this cutting back projects and reducing the level of utilization is consistent with the changes identified above to the overall product portfolio. Indeed, it may increase rather than decrease overall sales if the products coming out are now clearly aligned and easy to use.

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[105] Personal conversation with the head of marketing for this division

[106] Personal conversation with the head of product planning and portfolio management for this business

9 Summary

The motivation for this critical examination of what drives R&D productivity was a growing intuition that conventional wisdom was wrong.

This synthetic approach, combining case studies with a thorough review of the relevant literature and a program of interviews and discussions with managers involved in this arena, lead us to a very different model for R&D, one in which 'less is more':

- fewer products in the product portfolio
- alignment along a few key attributes
- fewer features for each product in the portfolio
- less information, focused only on differentiating attributes
- fewer in-house R&D activities:
  - architecture
  - absorptive capacity
  - 'bottleneck' activities
- fewer projects in the product pipeline, to have lower utilization

This also explains Apple's superior R&D productivity. Whether through conscious design or happy coincidence, a deliberate or an emergent strategy, its approach incorporates all of these practices. Its resulting success is not an anomaly in any way, but rather provides strong confirmation for this new theory of how to get the most out of spending on R&D: shipping fewer, simpler products and doing less work can drive growth and profitability.

Although what should be done may be clear, how to do it is not necessarily straightforward. It requires significant shifts in beliefs and behaviors, as well as in many cases building new capabilities in areas such as market research and product and portfolio management. Nevertheless, and despite the possibility of 'worse before better', our experience working with businesses facing these challenges, as well as the evidence from case studies, its that the payoff is worth the pain.

We are continuing this program of research, in a number of directions, covering how to implement these changes, extending it to services as well as products and expanding the scope to encompass the related questions such as the organizational structure of R&D, decision-making under uncertainty and the role of dynamic capabilities.

One particular area of interest is what this means for the economics of entrepreneurial activity; does this go some way to explaining the high R&D productivity of highly focused, resource-constrained start-ups and venture-backed businesses?

We hope that it motivates others to pursue these insights or challenge them, thereby making the resulting conclusions more robust.